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Plenary Session

PRECEDENT-FREE FAULT LOCALIZATION FOR HIGH SPEED TRAIN DRIVE SYSTEMS

Asad Ul HAQ [1]
Dragan ĐURĐANOVIĆ [2]

Abstract *– In this paper, a framework for localization of sources of unprecedented faults in the drive train system of high speed trains is presented. The framework utilizes distributed anomaly detection, with anomaly detectors based on the recently introduced Growing Structure Multiple Model Systems (GSMMS) models. Physics-based model of the drive train of a well-known high-speed train was developed using first principles and was calibrated using data from several actual trips on the train. Simulations based on the physics based model as the data source demonstrate the ability of GSMMS based distributed anomaly detection to localize faults within various parts of the drive train system without the need for models of the underlying faults.*

Keywords – Immunity inspired diagnostics, high speed trains, Growing Structure Multiple Model Systems.

1. INTRODUCTION

A growing concern with the environmental impact of air traffic has contributed to the success and growth of high speed rail as a more sustainable transport medium. Consequently, in recent years the European and Japanese markets have seen a significant transition of traffic from airplanes to high speed rail, especially for journeys up to a few hundred miles long [1]. Studies have also been carried out that underline the benefits of high speed rail as a transport system [2].

The growing popularity of high speed rail has inevitably led to investment in the development of the resources required to ensure reliability of the train systems [3], which is critical to the ability of high speed rail to compete with alternative modes of transport. As such, there is a need to develop systems for condition monitoring that would enable detection of faults and localization of their root causes within the system[1]. The increasing complexity of trains running at higher speeds has led to greater challenges in the tasks of detecting faults that cascade through the system, and finding their sources. The first and foremost factor driving the need for such reliable and efficient monitoring systems derives from the safety requirements for high speed trains. In addition to this, there is a two-fold financial significance. First, ensuring reliability is critical as it prevents delays, which becomes a factor in retaining passengers. Second, accurate fault localization contributes to the reduction of wastage of resources on ineffective maintenance.

Unfortunately, monitoring systems based on the classical framework are restricted in their diagnostic abilities, due to their reliance on fault models for these tasks. Namely, the classical diagnostic paradigm requires models of the relevant faults in order to detect their occurrence. Furthermore, these models need to be adequate throughout the operating space which the system experiences. Therefore, a monitoring system under the classical framework is not able to deal with faults that have not been foreseen, or for systems in operating regimes for which diagnostic models were not trained. This is of particular significance for highly complex system operating under highly variable operating regimes, such as the drive train of a high speed train. For such systems, it becomes unfeasible to build models of all possible faults, under all operating conditions. This strongly implies the need for a precedent-free fault detection and isolation approach.

In this paper, the method for precedent-free fault detection and localization introduced in [4],and

[1] *Reliably and efficiently determining which part of the system is at fault*

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further developed in [5], is employed to facilitate monitoring of high speed train drive systems. More specifically, the aforementioned novel diagnostic paradigm was applied to models and data corresponding to the platform of the Trains a Grand Vitesse (TGV), developed by ALSTOM [6] and operated by SNCF in France [7].

The methodology presented in [4] spans the tasks of fault detection, localization and identification in complex systems of interacting dynamic subsystems. Anomalous behavior of the system is detected as a statistically significant departure of its behavior from the normal one. The detection of a fault triggers the distribution of anomaly detectors (ADs) across the subsystems of the faulty system, spreading into increasingly granular levels of subsystems that exhibit deviation from their own models of normal behavior. This process of AD proliferation continues as each AD that detects a fault is replaced by multiple ADs monitoring the constituent subsystems of the faulty system. Thus, the source(s) of the fault(s) is(are) localized, as part(s) of the system surrounded by alarming ADs, in a hierarchical manner once the highest possible level of granularity of subsystems is reached. This distributed anomaly detection based on an a priori known structure of the monitored system[2] has been shown to enable precedent-free fault root cause localization [8]. The entire process is based solely on models of normal behavior, thereby bypassing the need for fault models, which, as previously mentioned, is a major constraining factor in the applicability of traditional diagnostic methods.

After faulty subsystem(s) is (are) located, the natural next step is fault diagnosis, which involves identification of corresponding fault models so that such behavior may be recognized in the future, and possibly remedied via fault-tolerant controller adaptation or maintenance intervention. This obviously amounts to the traditional diagnostic paradigm of recognizing known faults based on their models, or building new fault models when the currently observed behavior of the monitored system does not match any existing fault model. Such fault models can be built based on knowledge about system physics, as well as historical experience and observations of system operation.

The novel diagnostic framework briefly described above has previously been successfully implemented for fault detection, localization and diagnosis in the electronic throttle and crankshaft systems of an automotive internal combustion (IC) engine [4] [9], Exhaust Gas Recirculation System of an automotive diesel engine [5] and most recetly, distributed thermo-fluidic systems [10]. In this paper, this approach is employed for monitoring the drive system of a high speed train. A drive system in a high speed train is a complex system which incorporates linear and non-linear subsystems with continuous as well as discrete inputs and outputs. These factors contribute to a tremendously increased complexity for the monitoring task at hand[3].

The remainder of this paper is organized as follows. Section 2 describes the Growing Structure Multiple Model Systems (GSMMS) modeling approach, which was used as the foundation of the ADs in this work. It also describes the GSMMS-based anomaly detection and isolation procedures. Section 3 describes the physics based and data driven modeling of the system and Section 4 goes on to describe the implementation of the framework to the system in question and the results thereof. Finally, the conclusions and suggested future work are presented in Section 5.

2. DIAGNOSTIC FRAMEWORK

The diagnostic framework described in the previous section does not require fault models for localization of the sources of abnormal behavior of the monitored system. Instead, it only requires models of normal behavior for all the relevant subsystems, which form the basis of the ADs distributed across the system. The recently introduced GSMMS approach for modeling nonlinear dynamic systems [4] is exploited to create the aforementioned models and this section will briefly look into the motivation for the use of this modeling paradigm, as well as summarize methodological traits of the GSMMS model. Further, this section will also discuss how the distributed anomaly detection framework can be used to facilitate precedent-free localization of culprit subsystems causing anomalous behavior of the monitored system.

2.1 Modeling of Dynamic Behavior

Traditional anomaly detection methods, based on global models of system behavior, focus on characterizing probability distributions of behavioral features and detecting anomalies as changes in those distributions. For systems that do not involve interactions between various constituent subsystems, such anomaly detection approaches are appropriate. However, interactions with other subsystems mean that shifts in the dynamic behavior of a constituent subsystem may not occur solely due to changes in the system dynamics (i.e. real faults), but also due to changes in the operating regime (which should not be seen as anomalies). Namely, changes in the upstream

[2] *Knowing what subsystems constitute it and what their respective inputs and outputs are*

[3] *Requiring the use of more distributed ADs and a higher level AD hierarchy than the cases reported in the literature on precedent-free diagnostics so far*

subsystems, whose behavior affects the monitored system, cause shifts in the operating regime of the monitored system, potentially leading to changes in the behavior of the modeling residuals of the relevant anomaly detector and, consequently, false alarms.

Such a situation necessitates the use of modeling and anomaly detection approaches that have the potential to separate abnormalities caused by unusual operating conditions (which are not truly anomalies) and true anomalies due to changes in the internal dynamics of the monitored system. To that end, one can utilize "divide and conquer" approaches, pursued in e.g. [4] [5] [9] [11] [12], where the operating space of the monitored system is indexed using features from other systems affecting it. Divide and conquer models decompose the operating space into regimes of similar dynamic behavior, permitting the diagnostic framework to deal with regime-switching induced behavioral shifts. By postulating relatively tractable models in each operating regime, a set of region-specific anomaly detectors can be utilized. The behavior can then be considered independently in each operating regime and the presence of a fault can be detected as unusual behavior of modeling residuals within any of those operating regimes (i.e. corresponding to any of the local models within the divide and conquer modeling framework).

Within the GSMMS framework, the regionalization of operating regimes of a system is conducted via unsupervised clustering of its inputs and initial conditions using a Kohonen Self-Organizing Map (SOM) [13]. The use of such an unsupervised approach for partitioning the operating space overcomes the drawbacks associated with ad-hoc or variable-by-variable approaches [14] - [16]. In addition, growing mechanisms, such as those reported in [17] - [19], enable the determination of the number of local models required to approximate the underlying nonlinear dynamics, with a desired accuracy.

The Growing Structure Multiple Model System can be seen as a collection of local models, with a local model capturing the dynamic behavior in each operating regime. The simple and tractable linear ARX type models were used for the work presented in this paper,allowing easy parameter estimation and interpretation of local models. Essentially such a GSMMS formulation casts the problem of representing the system dynamics into the framework of interconnected, analytically tractable linear dynamic models. Even more simply stated, it approximates a curved surface (non-linear) with a set of appropriately shaped and sized flat tiles (linear models), where the number, shape, size and location of the tiles is determined via a growing SOM. This structure enables the modeling of complex systems, such as the drive system of a high speed train, while maintaining analytical tractability and an operating regime decomposition that enables regionalized anomaly detection. The GSMMS approach has been used successfully for modeling an electronic throttle system in a gasoline engine [11], automotive crankshaft dynamics [9], diesel engine Exhaust Gas Recirculation (EGR) system and its subsystems [5], electrical portion of an alternating current generator [12] and a distributed thermo-fluidic system [10].

Further details, including the mathematical details and graphical representations, of this modeling approach can be found in [20].

2.2 Method for Detection, Isolation and Diagnosis of an Anomaly

Anomalous behavior can be seen as a statistically significant departure of the current dynamics of the target subsystem away from the normal one. Once a GSMMS model of normal behavior is built for each system to be monitored, anomaly detection can be accomplished through comparison of the statistical characteristics of its residuals displayed during normal behavior with characteristics of the most recent modeling residuals. Since the operating space is decomposed into regions within which a linear model describes the system dynamics, each GSMMS region can be equipped with its own decision making scheme that quantifies how close the current residual pattern is to the normal pattern. Following [11], the performance within each operating region will be described in this paper using the concept of regional confidence values (CVs), defined as the area of overlap of the probability density function (PDF) of the modeling residuals displayed during normal behavior and the PDF of the residuals corresponding to the current behavior, in that region. Based on their universal approximation ability, Gaussian Mixture Models (GMMs) were used to approximate the PDFs [21], which allows efficient recursive updating of the PDFs during operation to obtain the most recent distributions [22], as well as analytical and thus, fast calculation of the distribution overlaps (CVs).

With the above definition, one can see that the CV will be close to 1 when there has not been significant change in the local dynamics of the monitored system, while any notable shift in the local system dynamics will result in lower CVs, with 0 being the lower bound. Following [11] the global CV for the monitored system is then quantified as the geometric mean of the local CVs. This choice of global CV prevents the masking of a fault that is apparent only in certain operating regimes. Namely, a low CV in any given operating regime will force a low global CV for the system, even if the performance is not affected in other operating regimes.

Isolation of the anomaly source can be conducted by proliferating anomaly detectors (ADs) to monitor subsystems of the anomalous system, all of which utilize only models of normal behavior of the system they monitor. Effectively, once an anomaly is detected, the proliferation of the ADs monitoring the pertinent subsystems of that target system is initiated, enabling monitoring and anomaly detection in subsystems of ever finer granularity. Such distributed anomaly detection leads to progressively finer localization of the fault through the hierarchy of the overall monitored system, until the finest feasible granularity is reached.

Once the fault is localized to a subsystem, the next step is to recognize the underlying fault (if the model of that fault exists) or recognize that the underlying fault is unknown. A diagnoser for a specific fault can be constructed following essentially the same approach pursued for the purpose of anomaly detection. Signatures emitted in the presence of the fault that the diagnoser needs to recognize can be utilized to estimate the PDFs of the modeling residuals of that diagnoser in the presence of that fault (residuals of the GSMMS corresponding that fault). Proximity of the most recent system behavior to that fault can then be evaluated via the overlap between the PDF characterizing the most recent residuals of the fault model and that corresponding to the residuals of the fault model observed in the presence of the fault it is supposed to recognize. Whenever this CV-like value for a specific fault model is close to 1, it can be concluded that the corresponding fault is present and a value of this CV-like index close to 0 would imply the absence of that fault. If for none of the existing diagnosers this CV-like overlap happens to be close to 1, the presence of an unknown fault can be inferred and a new fault model must be developed to enable recognition of this fault in the future.

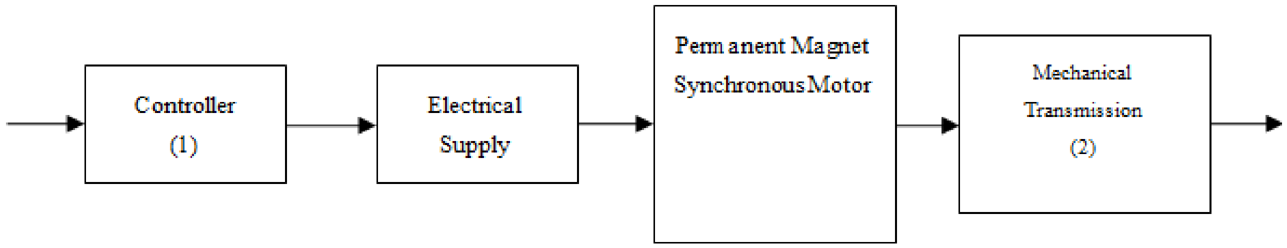

Figure 1: High speed drive train system

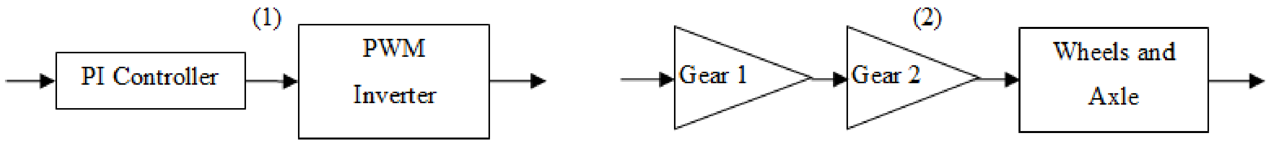

Figure 2: Components of controller and mechanical transmission systems

3. MODELING THE HIGH SPEED TRAIN DRIVE SYSTEM

In order to implement the distributed anomaly detection to the drive system of a high speed train, GSMMS models for the system and its pertinent subsystems must be developed. To this end, a physics based model was first built based on a combination of expert advice and available literature. The model was built in Simulink® and simulated using velocity profiles collected from actual TGV train journeys between Paris and Metz, in France. The simulations generated data for the inputs and outputs of each of the subsystems of interest, which was then used to develop the relevant GSMMS based ADs.

The overall system receives a reference velocity as the input, while the actual velocity generated by the drive system is the output. It is composed of a controller, electrical supply, drive motor and mechanical transmission, as illustrated in Figs. 1 and 2. These figures show the major components of the Simulink® model utilized. In addition, it was assumed that sensors were available to collect the input and output data pertaining to each of these subsystems, as well as their component subsystems.

The drive motor was taken to be a permanent magnet synchronous motor (PMSM), as per expert advice received from ALSTOM engineers and relevant literature [23]. PMSM modeling has been tackled in the literature in various ways, commonly using a transition of the electrical component from the physical 3-phase structure to an equivalent 2-phase right-angled structure, enabled by the Clark Transformation [24]. In this paper, we used model of PMSM dynamics developed in [25]. Following [26], the controller was taken to be a simple proportional-integral (PI) controller, with a pulse width modulating inverter. Finally, the mechanical transmission subsystem consists of two gears and a wheel and axle combination [23], each of which was modeled simply as a proportional gain. The wheel size required for the gain of the wheel and axle was set as per the information available in [27].

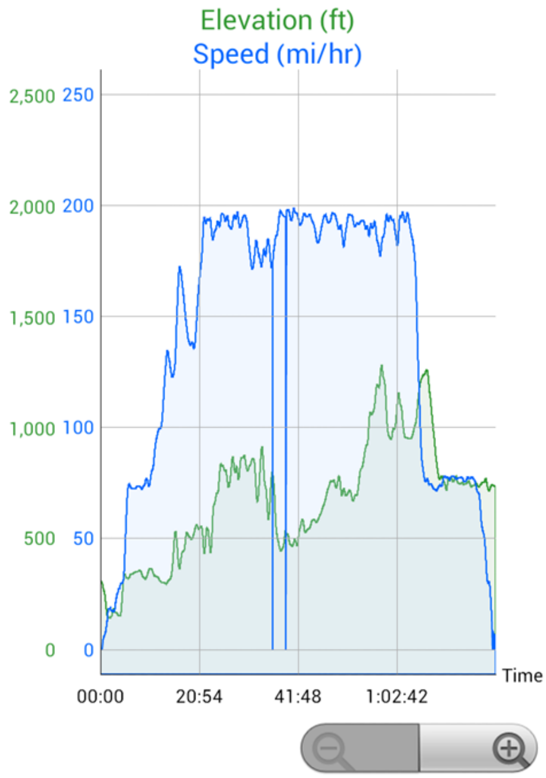

Figure 3: Example reference velocity trajectory

In order to make the data generated as representative of the real world conditions as possible, the reference velocity profiles were collected during actual high speed train journeys between Paris and Metz. Four such profiles were collected, one of which was used for training and the other three for testing of the proposed diagnostic approach. These profiles were gathered using a mobile phone based Android application called 'My Tracks' [28], which tracks position, velocity and height using GPS signals. The measurement of interest here is the velocity profile, an example of which is provided in Fig. 3 as a screenshot from the mobile phone.

Once the physics based model was built, data collected from the simulations was used to build the required GSMMS based ADs for all the relevant subsystems of the drive train. The orders of the local ARX models within the GSMMS, were set ad hoc, although techniques for the automated selection of these parameters can be found in [29].

4. SIMULATION OF DISTRIBUTED ANOMALY DETECTION

With the GSMMS based ADs available to monitor each subsystem, the distributed anomaly detection approach was put to the test. The hierarchy of the AD distribution is shown in Figs. 4 and 5, displaying the AD associated with each monitored system and subsystem. The fault localization process commences at AD1 which monitors the overall drive train system. Once a fault is detected by AD1, AD2 - AD4 are activated and begin to monitor the controller, PMSM and mechanical transmission systems respectively. The fault is then localized to one of these subsystems and, depending on which system is faulty, either AD5 and AD6 or AD7, AD8 and AD9 are activated. AD5 monitors the PI controller within the controller, hence it and AD6 would be activated if the fault had been signalled by AD2. If the fault had been signalled by AD4, AD7 - AD9 would be activated respectively monitoring gear 1, gear 2 and the wheel and axle combination.

The faults considered in this paper were limited to the controller and mechanical transmission systems, and were introduced approximately 8 minutes into the journey.

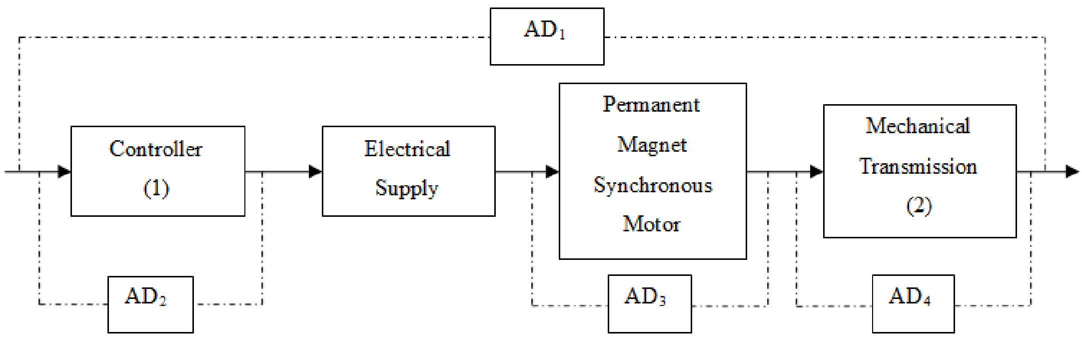

Figure 4: Levels 1 and 2 of the anomaly detector distribution hierarchy

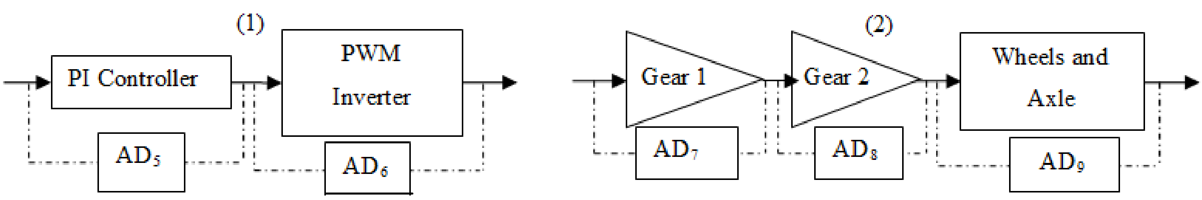

Figure 5: Level 3 of the anomaly detector distribution hierarchy

4.1 Localization of a Fault in the Controller

The fault in the controller was introduced in the form of a delay in its output, with delays of 0.7 seconds and 1.4 seconds being inserted in 2 different simulations. The results are presented in the form of the CVs associated with each AD and shown in Figs. 6, 7 and 8. The fault is detected by AD1 as is highlighted in Fig. 6 by the drop in the associated CV. From Fig. 7 one can see that, of the 3 ADs monitoring the first level of subsystems, only AD2 exhibits a drop in CV. Hence, the fault can at this stage be localized to the controller subsystem. Finally, it is observed in Fig. 8 that the CV associated with AD5 drops significantly, while that associated with AD6 remains high. These results show the fault being tracked through the levels as being local first to the overall system, then the controller subsystem and finally the PI controller. The approach has hence been able to localize the fault without having any signatures or models associated with the fault in question. In addition, it is noted that no fault was signalled at any of the subsystems that were not faulty, including those interacting with the faulty subsystem. With the anomaly detectors having been set up beforehand, the distributed anomaly detection framework is able to detect the fault online.

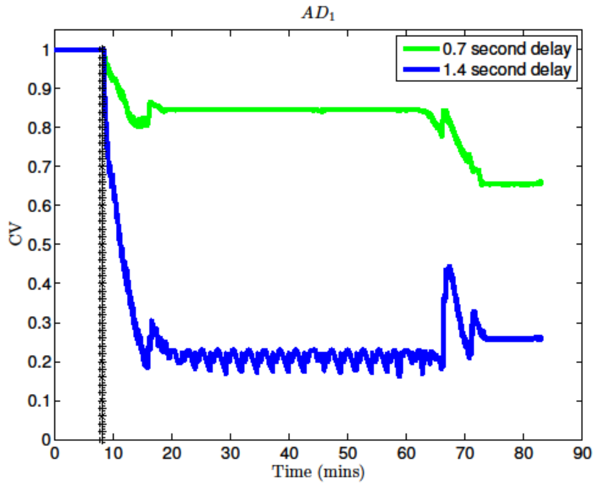

Figure 6: Controller fault detection response of the AD monitoring the overall system

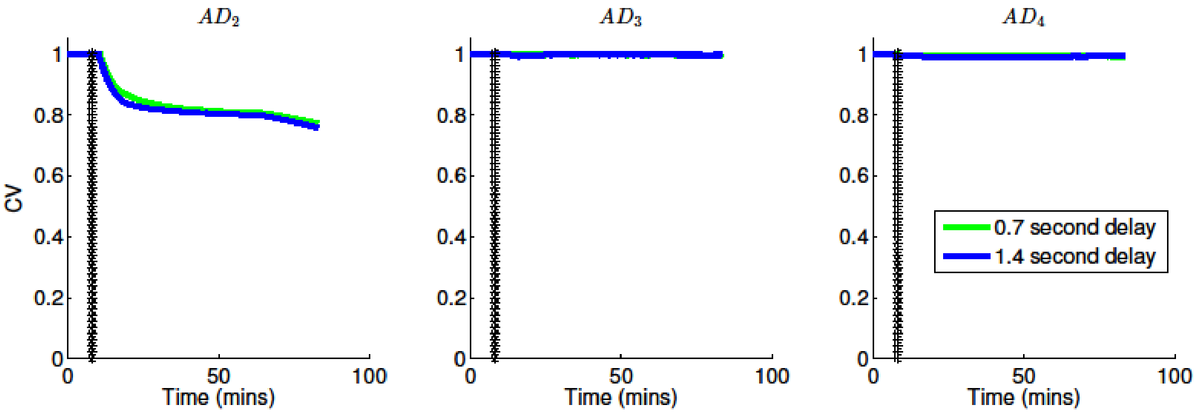

Figure 7: Controller fault localization at first level of subsystems

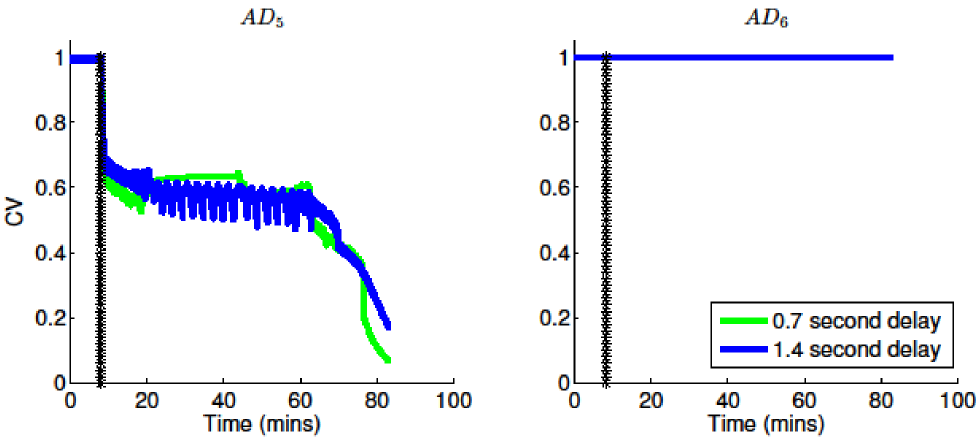

Figure 8: Fault localization within the Controller system

4.2 Localization of a fault in the Mechanical Transmission

A fault in the mechanical transmission was modeled in the form of added noise to the output from gear 2 to simulate a chattering type fault. Once again, the fault was introduced about 8 minutes into the journey and 2 simulations were conducted with added noise at 6% and 10% of the signal, respectively. The resulting CVs for the relevant ADs are shown in Figs. 9 - 11.

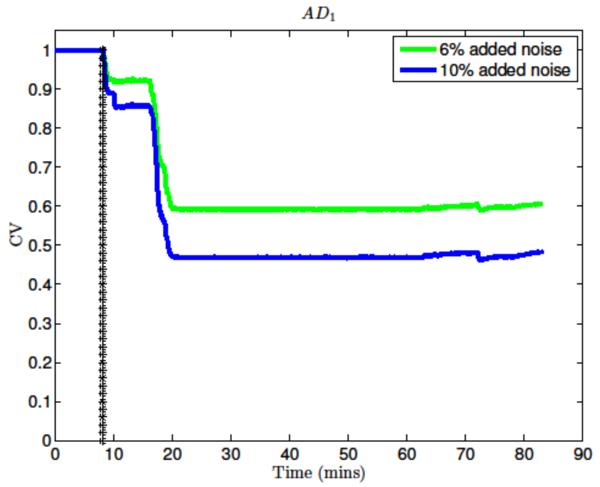

Figure 9: Gear fault detection response of the AD monitoring the overall system

arrives the maintenance team will know exactly which component requires their attention, thereby saving time on inspection and offline fault localization.

5. CONCLUSIONS AND FUTURE WORK

A recently introduced distributed anomaly detection framework is utilized for precedent-free fault localization in the drive system of a high speed train. The framework uses Growing Structure Multiple Model System (GSMMS) models of the monitored system to describe its dynamics and a statistical measure of departure away from normal behavior for fault detection. GSMMS-based anomaly monitors distributed across the system were then used to localize the sources of anomalous behavior without the need for signatures or models of the underlying faults.

The plant was simulated using a physics based model, which was tuned using data collected from several actual TGV journeys. Simulations of that

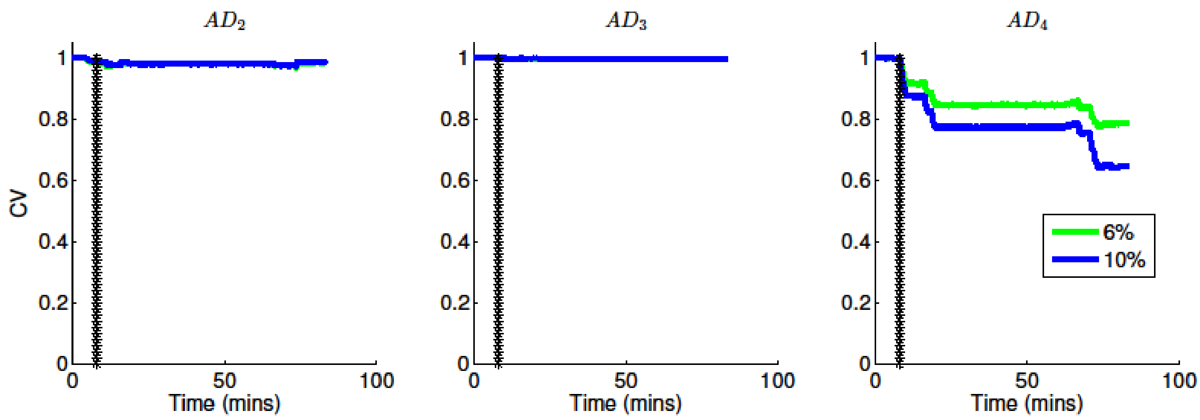

Figure 10: Gear fault localization at the first level of subsystems

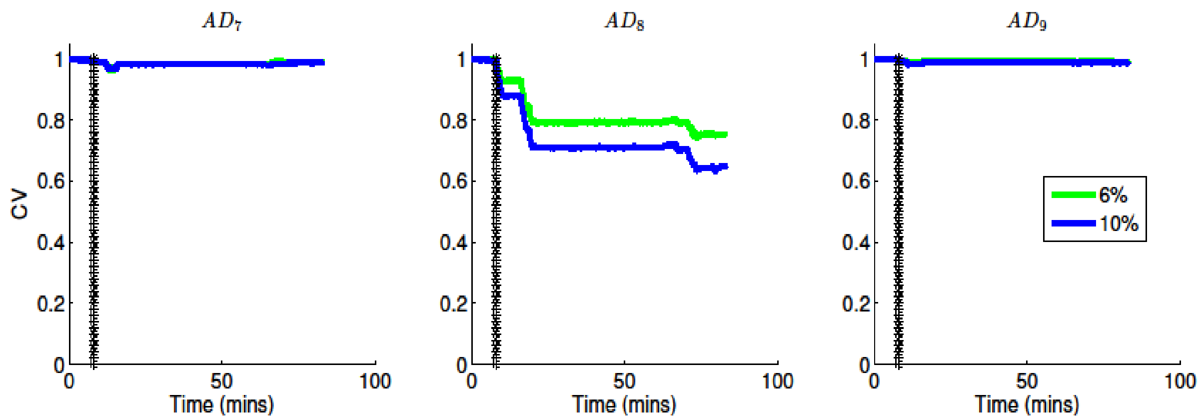

Figure 11: Gear fault localization within the mechanical transmission system

The CVs shown in Fig. 9 provide clear indication of the presence of a fault in the overall system. Then, the ADs whose CVs are shown in Fig. 10 localize the fault to the mechanical transmission, implicated by the falling CVs in AD4. Finally, in Fig. 11 the CVs of AD7 - AD9 isolate gear 2 as the source of the faulty behavior. Whenever the next maintenance opportunity

model were used to generate the data needed to build GSMMS based anomaly detectors for the drive train system and its subsystems. The results of the fault detection and localization accomplished using these ADs show that distributed anomaly detection successfully localizes the faulty subsystems, without any prior information regarding the underlying fault.

The results found here provide several directions for possible future work. Firstly, data generated in the presence of the faults can be used to build GSMMS models of the system behavior in the presence of those faults, based on which the faults could be positively recognized, thus accomplishing traditional fault diagnosis. Another natural extension of the work presented in this paper is the implementation of the precedent-free fault diagnostic approach to hardware-in-the-loop testing environments. Further, the local tractability of the GSMMS modeling approach may be exploited to develop a fault tolerant control scheme for performance recovery. The aforementioned problems are outside the scope of this paper, but are worth pursuing in future research.

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REFERENCES

[1] A. Jehanno, "High Speed Rail and Sustainable Mobility: A focus on environment and social issues," in International Practicum on Implementing High Speed Rail in the United States, Paris, France, 2011.

[2] US High Speed Rail Association, "Economic Benefits of High Speed Rail," US High Speed Rail Association, 2013. [Online]. Available: http://www.ushsr.com/benefits/economic.html. [Accessed December 2013].

[3] People's Daily Overseas Edition, "China to develop faster high-speed trains," People's Daily, April 2012. [Online]. Available: http://english.people.com.cn/90882/7800974.html. [Accessed November 2013].

[4] J. Liu, D. Djurdjanovic, K. Marko and J. Ni, "Growing structure multiple model system for anomaly detection and fault diagnosis," ASME Journal of Dynamic Systems, Measurement and Control, vol. 131, no. 5, pp. 051001-1 - 051001-13, 2009.

[5] M. Cholette and D. Djurdjanovic, "Precedent-free fault isolation in a diesel engine exhaust gas recirculation system," ASME Journal of Dynamic Systems, Measurement and Control, vol. 134, no. 3, 2012.

[6] The Infrastructurist, "JSC: High Speed Rail Lines," 2007. [Online]. Available: http://www.eng.hsrail.ru/abouthsr/trains/alstom/. [Accessed November 2013].

[7] SNCF, "SNCF TGV," [Online]. Available: http://www.tgv.com. [Accessed June 2013].

[8] D. Djurdjanovic, J. Liu, K. Marko and J. Ni, "Immune systems inspired approach to anomaly detection and fault diagnosis for engines," in International Joint Conference on Neural Networks, Orlando, FL, 2007.

[9] J. Liu, P. Sun, D. Djurdjanovic, K. Marko and J. Ni, "Growing structure multiple model system based anomaly detection for crankshaft monitoring," in Proceedings of the 2006 International Symposium on Neural Networks (ISNN), Chengdu, China, 2006.

[10] K. Carpenter, D. Djurdjanovic and A. Da Silva, "Fault detection and precedent-free localization in numerically discretized thermal-fluid systems," Expert Systems with Applications: An International Journal, vol. 39, no. 17, pp. 12858-12868, 2012.

[11] J. Liu, D. Djurdjanovic, K. Marko and J. Ni, "A novel method for anomaly detection, fault localization and fault isolation for dynamic control systems," Mechanical Systems and Signal Processing, vol. 23, no. 8, pp. 2488 - 2499, 2009.

[12] D. Djurdjanovic, C. Hearn and Y. Liu, "Immune systems inspired approach to anomaly detection, fault localization and diagnosis in a generator," in Proceedings of the 2010 Conference on Grand Challenges in Modeling and Simulation (GCMS), Ottawa, ON, 2010.

[13] T. Kohonen, "Self-organized formation of topologically correct feature maps," in Biological Cybernetics, The MIT Press, 1988.

[14] J. Principe, L. Wang and M. Motter, "Local dynamic modeling with self-organizing maps and applications to nonlinear system identification and control," Proceedings of the IEEE, vol. 86, no. 11, pp. 2240 - 2258, 1998.

[15] T. Johanssen and B. Foss, "Identification of non-linear system structure and parameters using regime decomposition," Automatica, vol. 31, no. 2, pp. 321 - 326, 1995.

[16] G. Barreto and A. Araujo, "Identification and control of dynamical systems using the self-organizing map," IEEE Transactions on Neural Networks, vol. 15, no. 5, pp. 1244 - 1259, 2004.

[17] B. Fritzke, "A growing neural gas network learns topologies," Advances in Neural Information Processing Systems, vol. 7, pp. 625 - 632, 1995.

[18] B. Fritzke, "Growing cell structures - a self-organizing network for unsupervised and supervised learning," Neural Networks, vol. 7, no. 9, pp. 1441 - 1460, 1994.

[19] D. Alahakoon, S. Halgamuge and B. Srinivasan, "Dynamic self-organizing maps with controlled growth for knowledge discovery," IEEE Transacitons on Neural Networks, vol. 11, no. 3, pp. 601 - 614, 2000.

[20] M. Cholette, J. Liu, D. Dhurdjanovic and K. Marko, "Monitoring of complex systems of interacting dynamic systems," Applied Intelligence, vol. 17, no. 1, pp. 60 - 79, 2012.

[21] G. McLachlan and D. Peel, Finite Mixture Models, Joh Wiley & Sons, Inc., 2000.

[22] Z. Zivkovic and F. van der Heijden, "Recursive unsupervised learning of finite mixture models," IEEE Transactions on Pattern Analysis and Machine Learning, vol. 26, no. 5, pp. 651 - 656, 2004.

[23] R. Kemp, "Drive systems for high speed trains," Transport Research Board, 1998.

[24] N. Urasaki, T. Senjyu and K. Uezato, "An accurate modeling for permanent magnet synchronous motor drives," in Applied Power Electronics Conference and

Exposition, New Orleans, LA, 2000.
[25] I. Guney, Y. Oguz and F. Serteller, "Dynamic behaviour model of permanent magnet synchronous motor fed by PWM inverter and fuzzy logic controller for stator hase current, flux and torque control of PMSM," in Electric Machines and Drives Conference, Cambridge, MA, 2001.
[26] K. Boby, A. Kottalil and N. Ananthamoorthy, "Mathematical modelling of pmsm vector control," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 2, no. 1, pp. 689 - 695, 2013.
[27] J. McKey, "Super high speed trains - TGV and AGV," September 2013. [Online]. Available: http://4rail.net/ref_fast_tgvagv.php. [Accessed September 2013].
[28] My Tracks, [Online]. Available: http://www.google.com/mobile/mytracks/. [Accessed June 2013].
[29] L. Jiang, E. Latronico and J. Ni, "A novel method for input selection for the modeling of nonlinear dynamic systems," in ASME Dynamic Systems and Control Conference, Ann Arbor, MI, 2008.
[30] R. Isermann, Fault-Diagnosis Systems, Springer Science & Business Media, 2006. 2013.

IMPROVING SERBIAN RAILWAYS: POLICY OPTIONS AND STRATEGIC DIRECTIONS

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Abstract *– Long term development policy of "Serbian Railways" is oriented toward faster development and modernization, reaffirmation of the role of railway traffic, using technical and technological balancing of railway resources and resources of railway networks of neighbour European railway governments through identification, planning and realization of developing projects. According to that, continuous and basic task is creation of conditions for safe, reliable and economically acceptable transport of users of transport services, including the mostly efficient use of available resources and lowest cost. Achieving of these objectives hindered during many years due to unfavourable financial position of the Enterprise and insufficient investment in infrastructure, transport capacities and informatics equipment over many years. Most of problems, which are financial by their nature, Serbian Railways are not capable to solve without more active involvement of state and governing ministry departments who should keep in mind that railway is a pillar of the development, economic progress and one of the strongest generators of economic recovery and employment of economy of every state. Therefore, main developing tasks of Serbian Railways for the period 2014-2018 are following: continuing of restructuring process; processes of revitalization and modernization of infrastructure, especially of Corridor X; repairing and modernization of driving vehicles; promotion of technology and working effectivity in all segments; alignment of regulations with UIC and EU standards; rationalization of number of employees and use of human resources; development of adequate informational systems as support for enterprise business. Conduction of these tasks would create conditions for increasing of involvement of Serbian Railways on transport market of Serbia and Europe, which could increase profitability.*

Keywords – Serbian Railways, modernization, profitability.

1. INTRODUCTION

Continuous and main task of Serbian Railways is to provide safe, reliable and economically acceptable transport for users, with mostly efficient use of available resources and lowest costs. Achieving of these objectives hindered during many years due to unfavorable financial position of the Enterprise and insufficient investment in infrastructure, transport capacities and informatics equipment over many years.

During previous period, Serbian Railways made efforts on system promoting. Some of results of Serbian railway sector, which are achieved during previous period can be reflected through following:

- New legal framework is aligned with EU directives;
- Analytical basis for long term Agreement on infrastructure, Agreement on obligation of public transport and Fee for accessing railway infrastructure was made;
- Restructuring program is in preparation. Predicted solutions for restructuring originate from need to focus on main activity, market orientation and rationalization in all areas.

Since strategic plan of Serbian Railways is to be respectable participant in transport and economic market, it is necessary to provide certain activities during next period in order to create conditions for involvement of our railway system in transport and economic system of Serbia and in European transport system.

It can be noted that the high level of transport services is a part of the culture of quality of contemporary society. In this society, intermodal and

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acceptable transport service is the right answer for social and economic demands for mobility.

Railway system suffers consequences due to small commercial speed, insufficient capacities, long keeping on national boundaries. All of that create lack of quality in service for passenger and cargo traffic. Small scope of traffic is specific for Serbian Railways business during previous period which provided poor business and financial results. The intensity of traffic in railway network of Serbian Railways is about 30% of the average intensity of such traffic in EU [1].

Short term strategic objective of Serbian Railways is conducting of numerous activities in business of railway in order to provide financial balance which is possible to achieve by decreasing of losses, providing planned transport, needed resources for maintaining of mobile capacities and infrastructural objects and activating of priority investments.

Basic development tasks for period 2014-2018 are following:

- Continuing of restructuring process in order to make Serbian Railways more oriented to users and competitive in markets within individual business wholes;
- Revitalization and modernization of railway infrastructure, especially of Corridor X;
- Repairing of driving vehicles;
- Promotion of technology and working effectivity in all segments;
- Alignment of regulations with UIC and EU standards;
- Rationalization of number of employees and use of human resources;
- Development of adequate informational systems as a support for enterprise business.

Conduction of these tasks would create conditions for increasing of involvement of Serbian Railways on transport market of Serbia and Europe, which could increase profitability.

Also, efficient and sustainable transport provides economic growth and new jobs. In order to realize that, global action including intensive international cooperation is needed [2].

Long term development policy of railway is oriented to faster development and modernization, reaffirmation of railway traffic role, using technical and technological balancing of railway resources with resources of railway networks of neighbor European railway governments through identification, planning and realization of development projects. According to aspect of development of infrastructural capacities, it is important for "Serbian Railways" to provide development and modernization of railways on Corridor X (railway defined by international agreements of SEECP, AGC, AGTC). Corridor X is a part of strategic infrastructure of Europe and strategic benchmark of development of national traffic infrastructure. On the other hand, it is important to develop, reconstruct and modernize network of regional railways regarding economy system of Serbia.

Modernization of towing and transportation capacities needs to be aligned with market demands (in cargo traffic using modern technologies and kinds of transported goods, in passenger traffic – higher speeds of transport, comfort and additional services) and international standards and norms which defined possibility of involvement into European traffic system.

By analyzing of position of Serbian Railways regarding environment, this work will especially highlight importance of finalizing of restructuring process and recovery and modernization of infrastructure capacities in order to increase productivity indicators as main strategic objectives of Serbian Railways by 2018.

2. STARTING ELEMENTS OF RAILWAY DEVELOPMENT

All railways of developed European states plan objectives, methods and speed of development in long term condition. Their most important strategic objective is increasing of scope and efficiency of railway transport on key transit directions that connect Europe and Asia [3].

During next 10 to 15 years, the important part of European gross national product will be directed to development of Pan-European traffic infrastructure in order to provide development of efficient traffic network which could provide sustainable mobility in entire Europe [4].

Such strategy for development of European railways is a chance for Serbian Railways since conditions can be created for following:

- Achievement of higher efficiency in infrastructure development and faster connecting with Europe,
- Faster flow of passengers and goods on national boundaries and faster transport,
- Obtaining of credit and help from International community in order to develop infrastructure at the Corridor,
- Involvement into planning of development dynamic from aspect of Europe and achieving of strategic objectives.

The first step in realization of development objectives includes analysis of position of Serbian Railways position in relation to the environment (southeast Europe states) and to developed railway governments in Europe using analysis of success indicators which are related to obtained productivity of the system.

Table 1. Comparable review of productivity indicators

Indicator	Average EU	Serbia	Southeast Europe	SR* compared the South East Europe	SR* Compared Average EU
[1000 residents/km]	2,1	1,9	3,1	-	-
[employees/km]	5,4	4,7	4,7	=	-
[vehicle kilometers/km]	14760	4988,2	4700,9	+	-
[vehicle kilometers/locday]	500,5	153,1	113,6	+	-
[vehicle kilometers/ employee]	3237,7	1055,6	1161,9	-	-
[1000rtkm/km]	3523,4	910,7	1082,9	-	-
[1000rtkm/locomotive]	97,3	28,0	25,5	+	-
[1000rtkm/ employee]	755,4	192,7	241,5	-	-

* SR – Serbian Railway

Regarding European states, our transport system is incomplete, poorly developed, inefficient and expensive. It is characterized by insufficient social rationality, low technical level and technological lagging, economic exhaustion and insufficient market orientation.

Regarding these facts, first step should include analyzing of position of Serbian Railways in relationto the environment in order to take appropriate place with its railway network and mobile capacities and place real objectives for successful development in the region.

As their strategic objective, Serbian Railways should be oriented to average indicators of business productivity that are specific for European states with similar geographic and traffic properties.

Table 1 includes comparable review of average indicators of productivity that are realized in railway governments of EU, railways in southeast Europe and in Serbia.

Productivity indicators in the region explained that we do not lack behind other states. In other words, average condition in railways of southeast Europe is almost the same as in Serbia.

It is interesting to note that Serbia and southeast Europe region have a slightly better indicator of number of employees by railways, while the region significantly lacks behind EU regarding other qualitative indicators. According to operative data collected on main and other railways of I order, Table 2 presented average use of planned driving schedule of trains. Number of employees by railways significantly varies and some railways include significantly greater number in relation to average of the EU, southeast Europe and Serbia.

It is estimated that from 2018, Serbian Railways should become respectable subject of sustainable mobility by realization of planned infrastructural projects. It is expected that productivity indicators will follow European average according to these estimations. Increasing of the reliability and quality level of railway infrastructure in Serbian Railways and improvement of all performances included in these processes would provide safe and regular traffic flow.

Expected effects could be observed in several ways. Probably the most interesting way for observing is time of travelling of passenger trains. For the objective that trains could use average speed of 100 km/h on main railways, it is expected that commercial speed would increase also.

Therefore, time of trains travelling will significantly decrease which will promote competitiveness of Serbian Railways in national and international transport market. This hypothesis can be confirmed by Table 3. It includes estimation of infrastructure parameters on electrified railways in Corridor X, which could be expected in 2018.

These parameters are related to projected speed, highest allowed speeds and time of travelling for passenger trains. Five cases of target value of commercial speed were observed for 55 km/h, 60 km/h, 65 km/h, 70 km/h and 75 km/h.

Table 2. Review of use of planned driving schedule and number of employees by km of the railway

Railway / railroad stocks	Length of the line [km]	Use of planned driving schedule [%]	Number of employees by km
(Beograd) Stara Pazova - Subotica	177	49.6	18
Beograd – Šid	123.50	61.9	19
Beograd – Velika Plana - Niš – Preševo	400.50	46.5	9
Beograd Centar – Pančevo Glavna	102.40	53.5	17
Beograd - Vrbnica	287.50	55.7	5

Defined objective, which is related to increasing of average commercial speed of 55 km/h can be observed as value which is the minimum expectation of the realization of infrastructure projects.

Table. 3. Existing condition and estimation of infrastructure parameters in 2018

Number	Railway / railroad stocks	Length of the line [km]	The projected speed (km / h)		The maximum permitted speed (km / h)		Travel time trains for passengers (hours)					
			Current situation	Evaluation after modernization	Current situation	Evaluation after modernization	Current situation	V_{kom}= 55 km/h	V_{kom}= 60 km/h	V_{kom}= 65 km/h	V_{kom}= 70 km/h	V_{kom} = 75 km/h
1	2	3	4	5	6	7	8	9	10	11	12	13
1	(Beograd)S.Pazova -Subotica	177	85-120	80-160	40-80	80-140	4,00	3,22	2,95	2,72	2,52	2,36
2	Beograd-Šid	117	85-120	80-160	30-70	80-140	2,83	2,12	1,95	1,80	1,67	1,56
3	Beograd-Velika Plana-Niš	243	80-120	80-160	50-100	80-140	4,67	4,41	4,05	3,74	3,47	3,24
4	Niš-Preševo	149	75-120	80-160	30-100	80-140	2,92	2,71	2,48	2,29	2,13	1,98
Travel time Subotica-Preševo (1+3+4):							**11,59**	**10,34**	**9,48**	**8,75**	**8,12**	**7,58**
Travel time Šid-Preševo (2+3+4):							**10,42**	**9,25**	**8,48**	**7,83**	**7,43**	**6,78**

The importance of achieving of average commercial speed of 75 km/h is especially important since it demanded more significant changes in way of Serbian Railways business, respecting and application of principles which all market oriented organizations use for their business.

It would mean, among others, that Serbian Railways are capable to offer high level of transport services, which would be the right answer to social and economic demands for mobility.

In that case, the travelling time of passenger trains on Corridor X would significantly decrease, which would provide the possibility for Serbian Railways to take more active role in European market of transport services on which organizations with long tradition make businesses. Also, these organizations could be used as a model of successful business.

On the other hand, railways could enhance their competitive position regarding bus and truck traffic which are dominant during last years.

In order to observe possibilities which realization of certain commercial speed could provide, Table 4 presents the comparison review of travelling time of passenger train for five values of commercial speed: V_{kom}= 55 km/h, V_{kom}= 60 km/h, V_{kom}= 65 km/h, V_{kom}= 70 km/h, and V_{kom}= 75 km/h and travelling time of bus on relations Subotica – Presevo and Šid – Preševo.

It is proven that railway can be competitive to bus transport of passengers with the commercial speed of Vkom= 55 km/h since it has shorter driving times on all relations except on relation Belgrade – Niš. In that case, the travelling time of trains on relations Subotica – Preševo and Šid – Preševo would be an hour shorter than travelling time of buses.

Each increasing of commercial speed which is

Table. 4. Comparable review of travelling time of train and bus on Corridor 10 after railway modernization

Number	Railway / railroad stocks	Travelling by train						Travelling by bus	
		Length of the line [km]	Travel time (hours)					Length of the line [km]	Travel time (hours)
			V_{kom}= 55 km/h	V_{kom}= 60 km/h	V_{kom}= 65 km/h	V_{kom}= 70 km/h	V_{kom} = 75 km/h		
1	2	3		4				5	6
1	Beograd-S.Pazova-Subotica	177	3,22	2,95	2,72	2,52	2,36	182	3,25
2	Beograd -Šid	117	2,12	1,95	1,80	1,67	1,56	121	2,16
3	Beograd -V.Plana-Niš	243	4,41	4,05	3,74	3,47	3,24	236	3,33
4	Niš-Preševo	149	2,71	2,48	2,29	2,13	1,98	164	3.92
Travel time Subotica-Preševo (1+3+4):			**10,34**	**9,48**	**8,75**	**8,12**	**7,58**	**-**	**10,50**
Travel time Šid-Preševo (2+3+4):			**9,25**	**8,48**	**7,83**	**7,43**	**6,78**	**-**	**9,41**

used by trains on observed relations create higher effects. The objective is to increase commercial speed to Vkom= 75 km/h, by which travelling time of train on relation Subotica – Preševo would be smaller for 2,92 hours than travelling time of bus on that relation.

Regarding relation Šid – Preševo, this time would be smaller for 2,63 hours. It means that railway would increase its competitivenes on all relations of Corridor X regarding passenger transport by bus.

3. CONCLUSION

In order to achieve more efficient and more effective development and realization of strategic objectives, there is a need to realistically observe and use all advantages and opportunities, and to remove weaknesses within the system and to eliminate obstacles in the environment.

It is obvious that Serbian Railways are expecting a very tough period during which they will be obliged to accelerate reforms and adapt business to market conditions due to influence of numerous internal and external factors.

Unfortunately, the time is passing and differences between developed railway governments and Serbian railways are becoming more dramatic. The most difficult issue for management is how to find the best way to align with developed railway governments. Such burden is the largest in these complex processes. These processes demand great expert knowledge and capabilities.

Actual moment in which Serbian Railways are currently situated imposes need for conduction of serious analysis in order to make the best observation of current position of the enterprise, as a development strategy for the following period. However, it is possible to make following conclusions as guidelines for acceleration of activities for transforming of railway into sustainable system, on all levels of functioning. The most important conclusions are following:

Define development strategies relating to environment, within the enterprise in order to improve all vital functions, with defined concrete objectives related to:

- promotion of traffic security and reliability of driving schedule for trains,
- promotion of level and quality of services of railway structure and transport,
- promotion of application of EU standards for interoperability for conventional railways,
- promotion of accessibility of railway infrastructure and transport services,
- promotion of environmental protection by mass use of the railway,
- promotion of contribution of railway to the regional development,
- increasing of readability of enterprise management and state to apply agreed strategic objectives,
- investment of more efforts and energy into realization of started restructuring process,
- parallel conduction of repairing process and development of railway network with process of restructuring in line with Regulation EU No. 440/91 related to liberalization of market on railways,
- defining of responsibilities for financing of maintenance and development of infrastructure with obliged dividing of costs and revenues for infrastructure and transport,
- paying attention on decreasing of number of employees and following of obligations while avoiding tendency to use social program by highly qualified labor force, which can provide engagement of unprofessional employees without previous experience in work on railways,
- promoting of partnerships with users, business partners and all railway companies in the region,
- efficient and strong use of obtained financial resources for modernization of infrastructure and railway resources,
- defining of priorities in conditions of limited financial resources, while rehabilitation and maintenance of railways are providing parallel with modernization and construction,
- precise defining of desirable standards regarding availability, level of security and level of services of transport networks,
- aligning of harmful emissions with objectives placed by EU, increasing of efforts for application and stimulating of environmental sustainable transport systems,
- adaptation of development and maintenance of infrastructure to environmental demands, in order to provide balance with natural and cultural environment,
- providing of increased role of private sector and defining of regulations in public sector and institutions regarding integration with EU, through clearly defined responsibilities, professional management and staff, and efficient control procedures.

In front Serbian Railways are complex tasks and embodiments above mentioned objectives create the conditions for it to become productive, technologically and economically efficient transport system, which will, by putting emphasis on the quality of the service, to become competitive on the domestic and on the international transport market.

REFERENCES

[1] Europien Commision, White Paper - Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system (2011)

[2] The EU in the world 2014, A statistical portrait, Eurostat Statistical books, EU 2014

[3] CER, "Reforming Europe's railways – an assessment of progress", Eurail press Tetzlaff-Hestra GmbH, 2005

[4] Transport 2050: 50 facts and figures, available on http://ec.europa.eu/transport/strategies/en.htm

IMPORTANCE OF COTIF FOR INTERNATIONAL RAIL TRAFFIC

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Abstract *– More than any other mode of transport, rail transport depends on technical compatibility between the infrastructure and the vehicles running on it. Harmonisation is therefore indispensable to enable uninterrupted international rail traffic. Today, international rail traffic is organised according to two concepts: the traditional concept, i.e. the traditional exchange of wagons and coaches at border-crossing stations (still mainly applied by OTIF's non-EU Member States) and the interoperability concept, i.e. uninterrupted movement of whole trains across borders (the basis of EU railway policy). This paper will reflect on the compatibility achieved between COTIF and the EU railway regulations in terms of the authorisation of vehicles. The cornerstone for this compatibility was the introduction of the equivalence principle for COTIF and EU technical vehicle requirements, which enables the mutual recognition of admitted vehicles. In addition to the harmonised technical requirements, the separation of responsibilities between all the entities involved in rail traffic is also harmonised to the extent necessary for international traffic. As a result of the above, manufacturers can now design and build standard vehicles to be used in all OTIF States (including EU Member States) if they comply with the UTP rules (provided there are no specific cases/open points or national technical requirements).*

Keywords – COTIF, interoperability, admission of vehicles, equivalence principle, railway actors.

1. INTRODUCTION

Economic growth and international transport are inextricably linked. More than any other mode of transport, rail transport depends on technical compatibility between the infrastructure and the vehicles running on it. Harmonisation is therefore indispensable to enable international rail traffic.

International rail traffic traditionally consists of the exchange of wagons and coaches. The exchange of wagons and passenger coaches across borders required only the harmonisation of the technical characteristics of these wagons and coaches, not of locomotives and operational rules.

The challenge now and for the future is to achieve the right balance between regulations imposed by the authorities on the one hand, and harmonisation of technical solutions by the rail industry and operators on the other. The key is to create a regulated basis, which ensures cross-border technical compatibility for all railway vehicles, including locomotives, and train sets, whilst not imposing unnecessary technical solutions.

This paper will explain the basic principles of COTIF[1] [1] Appendices APTU [2] and ATMF [3]. It will also reflect on the compatibility that has been achieved with the EU rail regulations.

The first part of the paper will introduce OTIF; compare two models for organising international rail traffic, i.e. the traditional approach of the exchange of vehicles at border crossing stations, and the interoperability model, in which entire trains cross borders. The second part deals with OTIF's requirements for the admission and use of vehicles, and at the same time describes the legal equivalence that has been achieved between the OTIF and EU provisions. The third part highlights the roles, responsibilities and duties of the main actors in the process of verification, admission, operation and maintenance of vehicles. Lastly, the benefits for the main actors when they are using COTIF and its appendices are also highlighted.

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[1] *COTIF stands for Convention concerning International Carriage by Rail*

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1.1 OTIF at a glance

The Intergovernmental Organisation for International Carriage by Rail (OTIF) was founded on 1 May 1985.

By ratifying COTIF, States become OTIF Member States. At the time of writing, 49 States are Member States of OTIF (Europe, Asia and North Africa) and the number is expected to increase. At present, international carriage by rail on rail infrastructure of around 270,000 km and the complementary carriage of freight and passengers on several thousand kilometres of shipping routes, inland waterways and (in domestic carriage) roads are concerned by the uniform law created by OTIF.

Member States of decide to which extend they wish to apply the Convention and may declare not to apply certain Appendices of COTIF. Member States that apply the technical Appendices APTU and/or ATMF are referred to as Contracting States. Currently 40 Member States are also Contracting States. Annex 1 illustrates how COTIF is applied throughout its geographical scope.

The headquarters of the Organisation are in Berne, Switzerland. The geographical scope of COTIF and its appendices is shown in Annex 1 of this paper.

2. THE LEGAL INTERFACE OF OTIF

One of OTIF's main tasks is to promote, improve, and facilitate international rail traffic. In order to achieve this, a uniform system of law has been established. These Uniform Rules are contained in the appendices to COTIF and cover the following fields of law:

- The contract of carriage of passengers and goods in international rail traffic by rail (Appendix A - CIV and Appendix B - CIM);
- The contract of use of vehicles as means of transport in international rail traffic (Appendix D - CUV);
- The contract of use of infrastructure in international rail traffic (Appendix E - CUI);
- Technical rules concerning vehicles for the carriage of dangerous goods (Appendix C - RID).
- The provisions on interoperability and technical harmonisation in the railway field and the technical approval of railway material intended for use in international rail traffic (Appendices F - APTU and G - ATMF).

Of the 49 Member States of OTIF, 26 are also EU Member State. The EU develops policy to establish a single, liberalised European railway market. The key element of the EU's policy is to bring about interoperability by harmonising technical parameters, rules and safety requirements.

On the other hand, the main tasks of OSJD, the international railway organisation of the Euro-Asian region, are the development of common international rail transport, the development of consentaneous transport policy as well as co-operation in economic, information, scientific, technological and ecological aspects of rail transport.

Despite different legal systems, what is common to all these organisations is that they deal with regulations on international rail transport, development of the rules for interoperability/dangerous goods and the regulation of transport contracts. As an intergovernmental organisation under international law, OTIF has the capacity to provide legal and technical support in overcoming differences. In COTIF 1999, and particularly since the EU acceded to COTIF in 2011, additional possibilities for closer cooperation and for some joint measures were created. Some good results/examples of such cooperation are:

- Creation of the common OTIF/OSJD consignment note, which allows goods to be carried from the Atlantic coast to the Pacific coast using a single document,
- Harmonisation (i.e. equivalence) of COTIF and EU regulations on the single admission of railway vehicles, which provide an interface between EU and non-EU States,
- Common registers between OTIF and ERA (EU), e.g. Vehicle Keeper Marking Register (VKM), Entity in Charge of Maintenance Register (ECM), National Vehicle Register (NVR), European Centralised Virtual Vehicle Register (ECVVR),
- Harmonisation between OTIF and OSJD on registration of vehicles in VKM Register,
- Administrative Arrangements between ERA, DG MOVE and OTIF to facilitate cooperation and formalise the exchange of information.

2.1 Interoperability vs. exchange of vehicles

As stated previously, EU railway policy promotes a liberalised railway market and aims to establish railway interoperability. This requires a harmonised definition of technical parameters, responsibilities of actors and operational requirements that apply within every EU Member State.

Most non-EU OTIF states organise international rail traffic according to a more traditional mode referred to as "exchange of vehicles". This model requires less harmonisation and is mainly used for fully integrated national rail railway companies, which manage infrastructure and are the monopolistic train operator. In the latter model, the national railway company (RU1) runs the vehicles on its network to the border where another state railway company

(RU2) takes these vehicles over and runs them on its own network. OTIF does not impose any model and therefore the challenge for OTIF is to develop regulations that are compatible with both the interoperability model as well as the exchange of vehicles model.

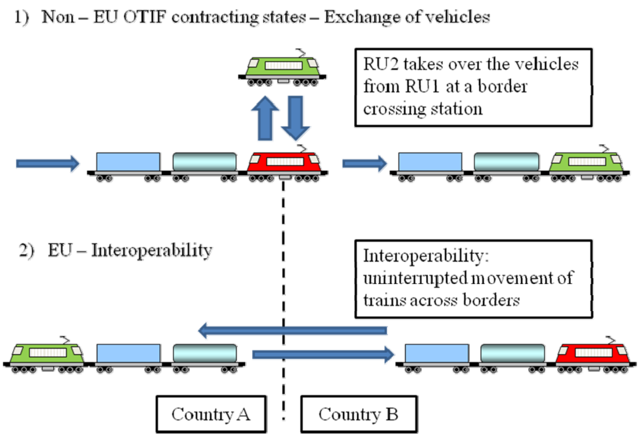

Figure 1: Exchange of vehicles (above) compared to interoperability (below)

2.2 Admission of vehicles - OTIF requirements in force

Before introducing APTU and ATMF, requirements for the technical admission of railway vehicles and the validation of technical standards applicable to rolling stock were mainly defined among rail companies through UIC (non-governmental union of railway companies). UIC developed the "Regolamento Internazionale Veicoli" (RIV) and "Regolamento Internazionale delle Carrozze" (RIC), which govern freight and passenger vehicles respectively. Rail companies which were members of UIC were competent (authorised) to legislate bindingly the admission of vehicles. The mutual recognition of homologation checks of passenger coaches (RIC) and freight wagons (RIV) between rail companies was based on UIC standards which, in essence, were a mix of technical and commercial requirements. Often these standards also described a technical solution. By doing so, innovative solutions for rolling stock could not be applied and consequently railways (manufacturers) were losing ground to technological progress.

With the introduction of APTU (technical requirements) and ATMF (admission procedures and use of vehicles), states (rather than railway companies) agree on minimum technical and safety requirements for rolling stock interoperability. All these minimum requirements are prescribed in Uniform Technical Prescriptions (UTP).

A full set of UTPs covering freight wagons has been in force since 1.12.2012 and a full set of UTPs covering locomotives and passenger rolling stock is foreseen to enter into force on 1.1.2015.

If the vehicle complies with UTPs, its admission will be recognised by all Contracting States. In practice, the principle of ATMF applies fully in each OTIF Contracting State, where the State takes responsibility for the admission of vehicles. At the same time rail companies and the railway industry may agree voluntarily on additional requirements.

Generally, APTU provides rules for the adoption of technical provisions applicable to vehicles intended to be used in international rail traffic. The aim is to create a set of requirements that will facilitate the admission of railway vehicles to international rail traffic. ATMF sets out the principles, objectives and procedures of technical admission of railway vehicles and the responsibilities in terms of using these vehicles.

A summary of the scopes of APTU and ATMF are shown in figure 2.

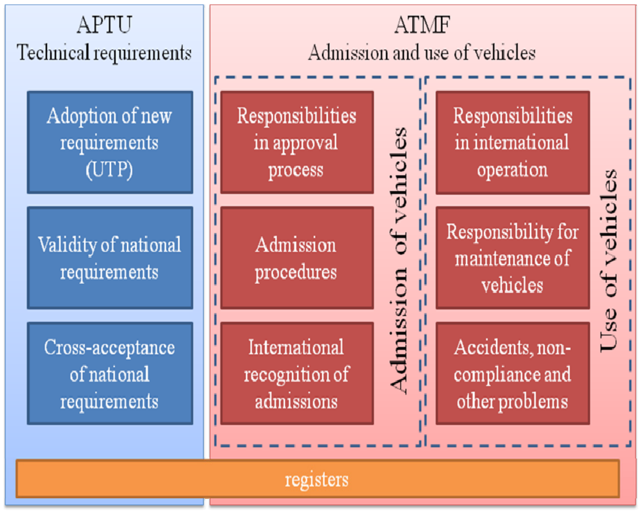

Figure 2: Scope of APTU and ATMF

2.3 OTIF Requirements in force and EU requirements they are based on

The UTP prescribes norms and essential requirements [4], which will provide uniform technical, operational and assessment rules for the rail system at international level.

Structural and functional UTPs are based on TSIs[2]. Although UTPs and TSIs have different formats practically their technical content is uniform, therefore by applying either UTPs or TSIs the same result will be obtained.

Instead of being equivalent to a TSI, some UTPs may be equivalent to (a set of) other EU regulations. Examples are UTP GEN-A and UTP GEN-B, which respectively are equivalent to Annex III and Annex II of the Interoperability Directive 2008/57/EC. Another

[2] *TSI stands for Technical Specification of Interoperability*

example is the UTP MARKING, which is equivalent to a combination of requirements taken from Appendix P of OPE TSI and Appendix 6 of the EU NVR Specification.

Annex 2 contains a list of all the OTIF requirements that are in force and the EU requirements on which they are based. All OTIF technical requirements are publicly available, free of charge, from the OTIF website http://www.otif.org/en/technology/regulations-in-force.html.

2.4 Equivalence principle of ATMF for fully UTP compliant vehicles

Free circulation of vehicles between OTIF Member States and Member States of the European Union and States which apply European Union legislation only works if there is legal equivalence between the OTIF and EU provisions..

In accordance with ATMF Art 3a, a railway vehicle admitted to operation in accordance with ATMF is deemed to be "authorised for placing in service" in the Member States of the European Union and in the States which apply European Union legislation as a result of international agreements with the European Union. The same applies *vice versa*, i.e. a railway vehicle placed into service in accordance with the applicable EU legislation and corresponding national legislation is deemed to be admitted to operation by all Contracting States according to ATMF (as illustrated in Figure 3). The conditions for these principles are:

a) full equivalence between the applicable UTP and the corresponding TSIs,
b) the set of applicable UTP/TSI against which the railway vehicle was authorised must cover all aspects of the relevant subsystems [5] that are part of the vehicle,
c) the UTP/TSI applied must not contain any open points in relation to technical compatibility with the infrastructure,
d) the vehicle must not be subject to derogation, and
e) the vehicle must not be subject to specific cases which limit the conditions of admission or "authorisation for placing in service".

If the conditions of a) to e) are not met, the vehicle is subject to authorisation according to the law applicable in the Member States. However, in such a case, the part of the vehicle which is compliant with the UTP has to be accepted by all Contracting States.

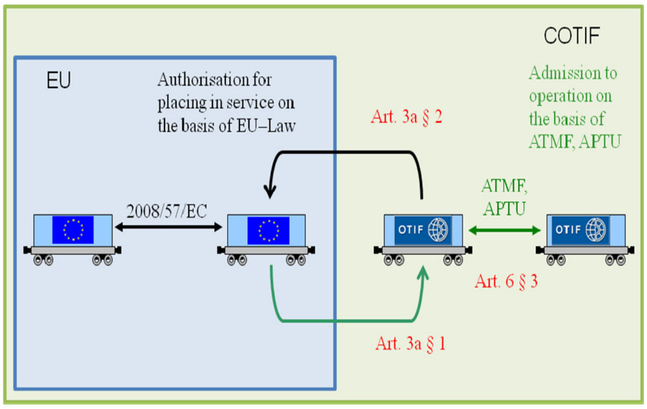

Figure 3: Equivalence principle of ATMF for fully UTP compliant vehicles

3. MAIN ACTORS IN CONFORMITY ASSESSMENT, ADMISSION AND OPERATION

3.1 Conformity assessment and admission

The competent authority is the national or international body which is competent and authorised by the State to carry out the technical admission of a vehicle.

The applicant is the entity (railway undertaking, manufacturer, or other entity) which requests a technical certificate, or the assessment of conformity of a subsystem or element of construction and therewith initiates the admission process.

Before a competent authority issues the first admission to operation, it must be ensured that the vehicle meets all the essential requirements. This is primarily done by ensuring compliance with UTPs.

UTP verification is the assessment procedure based on the assessment procedure modules (UTP GEN-D) [6], whereby an assessing entity or, depending on national law the competent authority, on the request of an applicant checks and certifies that the railway vehicle complies with the relevant UTPs and other applicable Regulations.

As the UTPs do not describe every detail of a vehicle, the first admission should also cover generic requirements in order to fulfil the applicable essential requirements[3]. For consecutive admissions these generic requirements have not to be checked again and therefore if there are no specific cases, open points or derogations, the (first) admission shall also be valid on the territories of other Contracting States[4].

Competent authorities are able to withdraw or suspend technical certificates in accordance with the provisions of ATMF Article 10a.

[3] *In accordance with ATMF Article 7 § 1*
[4] *In accordance with ATMF Article 6 § 3*

3.2 Operational responsibilities

The entities responsible for the vehicle after admission, i.e. the Keeper, the Railway Undertaking (RU) and the Entity in Charge of Maintenance (ECM), are responsible for ensuring that the vehicle is well maintained and kept in a compliance with the UTPs.

The Keeper is (usually) the owner of the vehicle. The Certificate of Operation relates to the vehicle and the keeper is the entity which holds this Certificate. In accordance with common practice in several Contracting States and in order to make more explicit the responsibilities of the keeper, the keeper is made responsible[5] for designating an ECM for his vehicles.

The RU is responsible for the correct use of the vehicle within its conditions and limits of use and other conditions of the admission. The RU must also ensure that the vehicle is operated only on compatible infrastructure. The operating RU must in due time, either directly or via the keeper, provide the ECM of the vehicle with information on the operation of the vehicle (including mileage, type and extent of activities, incidents/accidents).

The ECM must ensure, either directly or via the keeper, that reliable information about the vehicle concerning maintenance and restrictions affecting operations, which is necessary and sufficient to support safe operations, is available to the operating RU. The ECM (and not the keeper) must ensure that the vehicles for which it is in charge of maintenance are in a safe state of running by means of a system of maintenance.

Although all types of railway vehicles must have an ECM, the ECM certification system[6] need only be applied to freight wagons.

4. CONCLUSIONS

In order to serve its Member States, OTIF works closely together with other organisations working in the field of international railways. One of the major achievements is that OTIF technical rules provide a seamless interface between EU and non-EU railway systems, without imposing a particular market model.

By means of the COTIF Appendices APTU and ATMF, OTIF has also succeeded in introducing a clear separation of responsibilities between all the entities in charge of conformity assessment, admission and operation processes.

The application of COTIF enables States to create a legal environment that is favourable to both railway operations and the railway industry.

As the UTPs define minimum requirements, the level of uncertainty for manufacturers is also minimised. Based on the UTPs, manufacturers can design and build standard vehicles to be used in all OTIF States (including EU Member States). This broadens the potential market to a wider geographical area and provides good business opportunities for industry in both directions.

REFERENCES

[1] **COTIF** – Convention concerning International Carriage by Rail as amended by the Vilnius Protocol, in force from 1. July 2006 (link: COTIF 1999)

[2] **APTU** – Appendix F to COTIF 1999, in the revised version that entered into force on 1 December 2010. (Appendix F to COTIF 1999)

[3] **ATMF** – Appendix G to COTIF 1999, in the revised version that entered into force on 1 December 2010 (Appendix G to COTIF 1999)

[4] UTP GEN-A: General Provisions – Essential requirements, in force from 1. December 2011 (A 94-01A/1.2011 v.05)

[5] UTP GEN-B: General Provisions – Subsystems, in force from 1. May 2012 (A 94-01B/1.2012 v.06)
UTP GEN-D: General Provisions – Assessment procedures (Modules), in force from 1. October 2012 (A 94-01D/3.2011)

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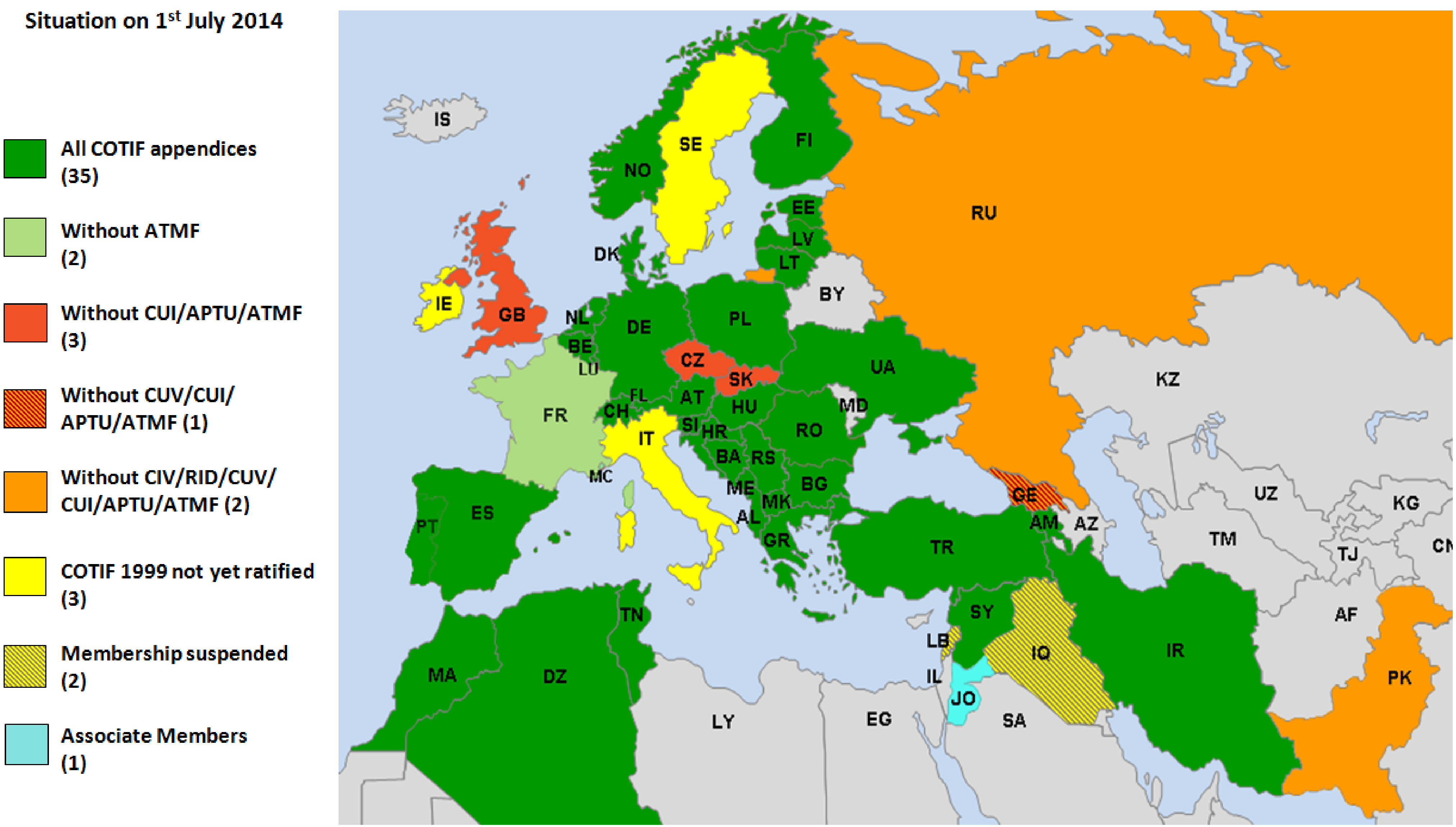
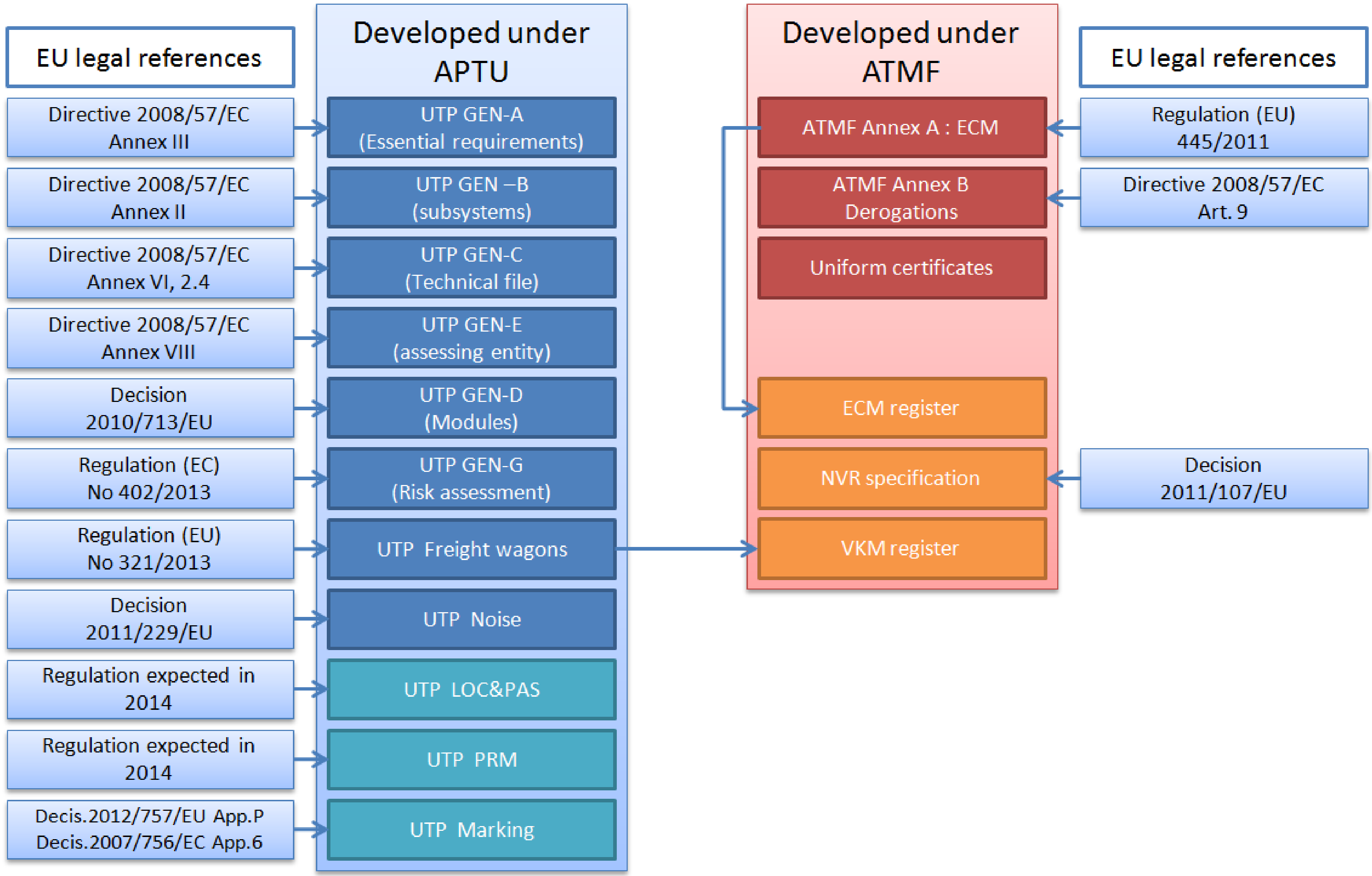
[5] *As decided by the 25th Revision Committee. This responsibility will be included in the revised COTIF of 2015.*

[6] *Annex A to ATMF*



Geographical scope of COTIF and its appendices



OTIF requirements in force and EU requirements on which they are based

Rolling stock

EXPERIMENTAL RESEARCH OF CHARACTERISTICS OF IMPROVED TYPE OF COMBINED TUBE ENERGY ABSORBER

Jovan TANASKOVIĆ [1]
Dragan MILKOVIĆ [2]
Vojkan LUČANIN [3]
Žarko MIŠKOVIĆ [4]

Abstract *– Crash energy absorber represents one of the main and necessary elements of body structure of modern railway vehicles. Intensive research in the field of passive safety produced more different types of collision energy absorbers using different shapes of deformations to absorb as much kinetic collision energy as possible. Different combinations of the shape of deformations lead to compact dimensions of absorber. Subject of this paper is combined energy absorber which works on the principle of shrinking and splitting the seamless tube at the same time, using special tools. Using shrinking-splitting process energy absorption occurs by elastic-plastic deformations of the tube and friction between the tube and the cone bush, respectively friction between the tube and the splitting tool. Energy absorption starts in the tube which is compressed into cone bush. After exactly defined stroke in the process of energy absorption by shrinking the seamless tube, the simultaneous process of splitting of the tube starts, so tube deforms in parallel shrinking-splitting mode during the rest of the stroke. This type of combined process gives gradually increase of the force without undesirable peaks which characterizes second phase of deformation of shrinking-folding combined absorber. Experimental research was realized via quasi-static tests in the laboratory conditions. During tests, reaction force and stroke were measured. Results of the investigations of combined shrinking-splitting absorber and shrinking-folding absorber were compared.*

Keywords – Crash absorber, Passive safety, Shrinking, Splitting, Experimental researches.

1. INTRODUCTION

The subject of this paper is process of improving absorption characteristics of the combined tube absorber using different shapes of deformations. Experimental investigations of combined absorber described in this paper based on the tube absorber that works on the principle of compressing the seamless tube into a cone bush [1, 2]. This type of absorber characterizes gradual increase of the force, without peaks until reaching the maximal value, when the force remains approximately constant with minor deviations to the end of the deformation process. As an idea for combined energy absorption served experimental investigations obtained by axial pressure of the tube of circular and square cross sections with parallel analyzes of inversion and splitting processes were presented in the paper [3]. Folding of the tube characterizes jagged force versus stroke curve. Experimental investigations directed to the shrinking-folding combined process of seamless tube are showing that the folding process not the best solution in combination with shrinking process [4-6]. Results of investigations showed that combination of these two processes may increase absorption power with compact dimension of absorber, but it is not possible to eliminate force peaks at the start of deformation (folding process) of each segments of the tube wall. Using a larger number of folding segments in the tube

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wall, could alleviate jagged effect on the force versus stroke diagram. Reduction of peaks does not mean their elimination, so the further investigations were directed toward research of other possible combinations. Experimental and theoretical analysis of splitting process of the tubes made by aluminum and mild steel were presented in the paper [7-9]. These investigations were realized on the samples with different wall thickness and lengths. Splitting tube, using different top angles of the special cone die, were realized. The angle of the top of cone die has direct influence on the correct flow of splitting tube, so appropriate design of angle is very important. Force vs. stroke diagram characterizes peak at the start of deformation process. After that, force value decreases to approximately half of the initial value and stays on that level with minimal deviations to the end of deformation process. Using above-mentioned facts, quasi-static tests were performed on two different types of combined tube energy absorber. Results obtained by these experimental investigations (shrinking-folding and shrinking-splitting the tubes) were analyzed and main differences between them are presented.

2. EXPERIMENTAL INVESTIGATIONS

Quasi-static tests were realized on servo-hydraulic machine ZWICK ROELL HB250 at the University of Belgrade Faculty of Mechanical Engineering, Fig. 1. Maximum load which can be realized on this machine is 250kN. Acquisition system may record up to 8 measurement channels with sampling frequency up to 10 kHz. During experimental investigations deformation resistance (reaction force) is measured on the defined stroke.

Fig.1. Testing machine Zwick Roell HB250

2.1. Shrinking-folding combined absorber

This type of combined tube absorber uses shrinking and folding processes to absorb kinetic collision energy. Working principle of combined absorber is shown in the Fig. 2. During the collision, process of energy absorption first starts mode of tube shrinking (Item 1) during the stroke of ≈ 63 mm. After the stroke of 63 mm, starts the second mode of energy absorption, using folding of the tube (Item 2). In that moment, energy absorption continues in parallel working mode, compressing and folding the tubes on the stroke of 40 mm (Item 1 and 2).

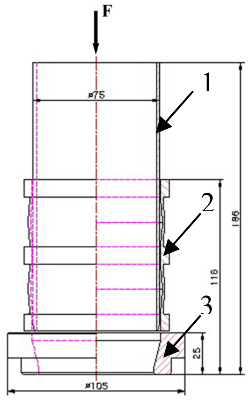

Fig.2. Working principle of shrinking-folding absorber

The following elements were used for this investigation: seamless tube (Item 1, material S355J2G3) with dimensions Ø75x2x160mm, segments tube (Item 2, material S355J2G3) with dimensions Ø86x90mm and the cone bush (Item 3) from quenched and tempered carbon steel (material C45E) with dimensions Ø105/68x13°, Fig. 2. Samples are separated in five groups: a) seamless tubes with two folding segments with cone walls (Item 1), b) seamless tubes with two folding segments with plane walls (Item 2), c) plane seamless tubes of length L = 160 mm (Item 3), d) plane seamless tubes of length L = 71 mm (Item 4) and e) cone bush (Item 5), Fig. 3. Different geometries of the folding tubes are created to show influence of the wall geometry on the starting values of the deformation resistance.

Fig.3. Samples

2.2. Shrinking-splitting combined absorber

This type of tube absorber uses shrinking and splitting processes for energy absorption. Working principle of combined absorber can be described using

Fig. 4. During collision, process of energy absorption first starts with the tube (Item 1) shrinking using cone bush (Item 2) at the stroke of ≈ 50 mm. After stroke of 50mm, second mode of energy absorption, i.e. splitting of the tube, starts with contact between predeformed tube and the die (Item 3). In that moment, energy absorption continues in parallel working mode, compressing and splitting tube at the stroke of 40mm. The absorber was installed in the special tool (Item 4) which was used as a support during the testing.

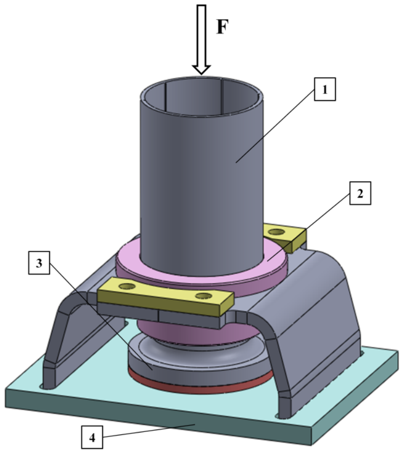

Fig.4. Working principle of shrinking-folding absorber

The following elements were used for this investigation: seamless tubes (Item 1 and 2) from low carbon steel (material P235T1), cone bush (Item 3) with dimensions ø75/68x13° and die (Item 4) with dimensions ø61/r8 from quenched and tempered carbon steel (material C45E), Fig. 5.

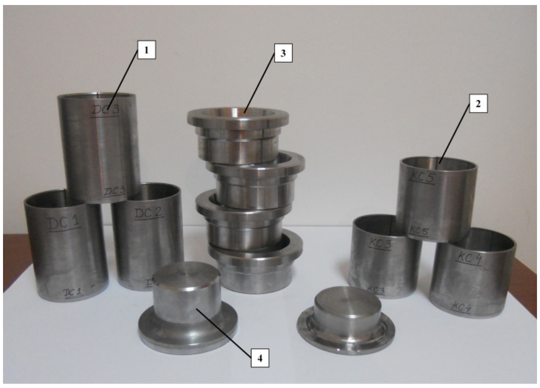

Fig.5. Samples shrinking-splitting absorber

Seamless tubes are separated in two groups according to the lengths: a) seamless tubes with dimensions ø75/70 of the length L = 100 mm (Item 1) and b) seamless tubes with dimensions ø75/70 of the length L = 70 mm (Item 2), Fig. 5. Shorter tubes were used for the control tests and for the check in shrinking process that was used as a base for evaluation of the combined process. Six grooves on the inner wall were made on all tube samples in the inner wall. These grooves were used as initial places for tube wall cracking during splitting process of deformation.

3. RESULTS

3.1. Shrinking-folding absorber

Deformed shrinking-folding absorber shown in the Fig. 6.

Fig.6. Deformed shrinking-folding absorber

Charateristic diagram obtained by experimental investigations is shown in Fig. 7. This diagram characterizes two clear separated phases. The first phase is compressing the tube into a cone bush at stroke of approximately 60 mm. The second phase characterizes parallel work of the shrinking tube and the folding tube at the stroke of approximately 35 mm.

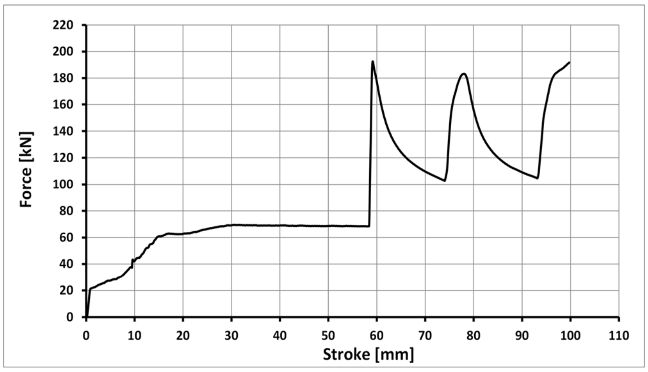

Fig.7. Force vs. stroke diagram: shrinking-folding absorber

3.2. Shrinking-splitting absorber

Fig. 8 shows the sample after deformation. Three samples were tested with the combined shrinking-splitting process and force-versus stroke diagrams obtained by these investigations are shown in Fig. 9. The diagram clearly shows two separate phases of deformation. The first phase of deformation process, until the stroke of ≈50 mm, has the characteristics of shrinking. After this phase, the splitting process starts on part of the tube that was plastically deformed during the first phase. Until the end of the test at a stroke of ≈90 mm, energy absorption occurs in parallel shrinking and splitting processes.

Fig. 8. Deformed shrinking-splitting absorber

At the moment the splitting process starts (there is a transition in the region 50-55 mm stroke) the force increases sharply from ≈100 kN to ≈194 kN. With the appearance of the first cracks at the end of the tube, along the inner grooves, the force drops to ≈150 kN at the stroke of 60 mm. After this, the splitting of the tube along the inner grooves is more controlled and the force again increases gradually to ≈210 kN at the stroke of 80 mm, remaining thereafter at this value until the test ends at 90 mm stroke.

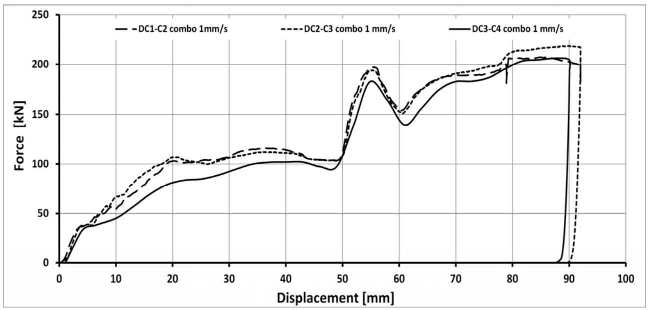

Fig. 9. Force vs. stroke diagram: shrinking-splitting absorber

These two diagrams (Fig. 8 and 9) show similar curves during analysing two clearly separately phases. Second phase serves as a base for the evaluation of characteristics of combined absorbers. The jagged part of diagram, which characterises folding process, was eliminated using splitting process of deformations. On the other side, absorbed energy given by shrinking-splitting process is higher than shrinking-folding absorber. This was the main improvement of the combined absorber.

Absorbed energy in the first and the second phase was calculated as the work of force at defined stroke (amount of absorbed energy is equal to area under curve):

$$W=F_{sr}\ x\ h$$

where: F_{sr} – average value of the force at defined stroke, h – stroke of deformation.

The average calculated value of the total absorbed energy was 11,52 kJ for the shrinking-splitting process and 8 kJ for the shrinking-folding process. The energy absorption of the improved absorber is increased by ≈ 40 %.

4. CONCLUSION

Using combined principle of energy absorption leads to better absorption characteristics. Improved type of absorber may absorb significantly higher amount of collision energy in comparison with using combined shrinking-folding process. Using shrinking-splitting process it is possible to eliminate jagged characteristic which is very important in terms of gradual introduction of the force in the vehicle structure.

ACKNOWLEDGEMENT

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REFERENCES

[1] Simić G., Lučanin V., Tanasković J., Radović N., Experimental research of characteristics of shock absorbers of impact energy of passenger coaches, Journal of Experimental Techniques, Volume 33, Issue 4, 2009.

[2] Tanaskovic J., Lučanin V., Milkovic D., Simic G., Milos M., Experimental Research of Characteristics of Modified Tube Absorbers of Kinetic Collision Energy of Passenger Coaches, Journal of Experimental Techniques, Volume 38, Issue 3, page 37-44, 2014.

[3] Alghamdi A.A.A., Collapsible impact energy absorbers: an overview, Thin-Walled Structures, Volume 39, Issue 2, Pages 189-213, February 2001.

[4] Reid S.R., Plastic deformation mechanisms in axially compressed metal tubes used as impact energy absorbers, International Journal of Mechanical Sciences, Volume 35, Issue 12, 1993.

[5] Tanaskovic J., Milkovic D., Lucanin V., Miloradovic N., Experimental and numerical analysis of the characteristics of combined collision energy absorbers, Journal FACTA UNIVERSITATIS - Series Mechanical Engineering, Vol.10, No 2, 2012.

[6] Salehghaffari S., Rais-Rohani M., Najafi A., Analysis and optimization of externally stiffened crush tubes, Thin-Walled Structures, Volume 49, Issue 3, 2011.

[7] Huang X., Lu G., Yu T. X., On the axial splitting and curling of circular metal tubes, International Journal of Mechanical Sciences, Volume 44, Issue 11, 2002.

[8] Reddy T. Y., Reid S. R., Axial splitting of circular metal tubes, International Journal of Mechanical Sciences, Volume 28, Issue 2, Pages 111-131, 1986.

[9] Atkins A. G., On the number of crack in the axial splitting of ductile metal tubes, International Journal of Mechanical Sciences, Volume 29, Issue 2, 1987.

HYBRIDIZATION - THE WAY OF DECREASING CARBON DIOXIDE EMISSION AND FUEL ECONOMY

Martin MIKOLAJČÍK [1]
Daniel KALINČÁK [2]

Abstract *– This article analyzes the driving performance shunting locomotives with conventional internal combustion engine (ICE) and suitable substitutes of conventional ICE for ICE with lower performance combined with hybrid propulsion.*

Installed performance of the ICE in shunting locomotive is high, the maximum power is used only for minimum working time of locomotive and it´s leading to high fuel consumption and increasing operating costs and emission of carbon dioxide. Due to the introduction of stricter emission limits for rolling stocks are placed demands on more effective fuel efficiency and reducing greenhouse gases emissions.

For this reason, there is an effort to introduce hybrid propulsion into rail vehicles operating in a wide range of performances, which replace the ICE with high performance. Hybrid drive consists of ICE, which is more powerfull than average power of shunting (non hybrid) locomotive in shunting and hybrid system, which covers performance peaks. In this case, the ICE works most of the time in the optimal mode which results in a reduction in fuel consumption and emissions. It is also possible to recuperate kinetic energy of locomotive and subsequently stored it in a suitable storage of energy for later use and achieving high efficiency operation. A suitable storage of energy can be batteries, ultracapacitors, flywheel, pressure accumulator and their combination and the most suitable alternative should be chosen according to the power transmission of shunting locomotive (electric, hydraulic, mechanical).

Keywords – Hybrid traction drive of rail vehicles, Utilization power of ICE, Hybrid locomotives, Fuel utilization, Accumulation of energy.

1. INTRODUCTION

Railway systems always have been described as competitive, sustainable and environmentally friendly modes of transportation. However, diesel engines appear more and more like the weak point in this good picture. Fortunately, fast-growing technologies offer everyday new opportunities for improving such a technical domain as railway [1].

Most diesel locomotives used on railways using outdated types of ICE that do not meet today's emission limits for this type of vehicle and using of their installed power is low. As suitable and cheaper solution to this problem, instead of buying a new rail vehicle seems to use a hybrid system in upgraded diesel locomotives and it brings the desired reduction in fuel consumption and reduce emissions. For suitable design of a hybrid propulsion of specific rail vehicle, it is necessary to know the operating parameters and make the analysis of operating parameters to determine the most appropriate design of the hybrid system and accumulators of energy. Improper design of a hybrid system would be extended return of investment in rebuilding and hybrid system could not be fully utilized. It is best use hybrid systems in rail vehicles, which often stop and then starting up again. In the following paper we will present the possibility of using a hybrid system in shunting locomotives.

2. ANALYZATION OF SHUNTING LOCOMOTIV´S OPERATION PARAMETERS

It is known that the use of installed power capacity of ICE in motive power units (especially in shunting locomotives and locomotives for industrial transport) is very low. Average utilisation of engine power is

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usually less than 20% of the installed power capacity and nominal engine performance is utilised only during minimal period of the total time of engine operation (at the level of approx. 1%). The result of this is that most of the operational time the internal combustion engine works in regimes that are far from optimum mode. It means that specific fuel consumption is high. At this type of locomotives operation the frequent and fast changes of engine regimes occur, which results in increased fuel consumption and imperfect fuel combustion with increased quantity of harmful emissions [2].

2.1. Shunting service of locomotive Class 742

The measurements were carried out on the locomotive class 742 (ČKD) on Fig. 1 in shunting service at railway station Trencianska Tepla [3]. This class of locomotives has 883 kW nominal output of engine.

Fig. 1. Shunting locomotive class 742 in service[4]

The distribution of traction generator output is shown in the Fig. 2. The mean output of traction generator was only about 102 kW, which represents about 11.5 % of the nominal output of ICE [2].

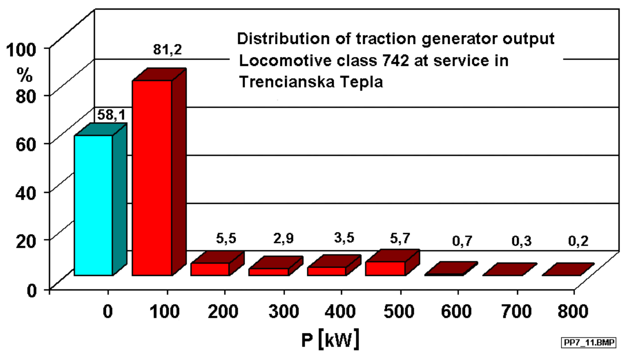

Fig. 2. The distribution of traction generator output of locomotive class 742 in the shunting service at Trencianska Tepla [2]

As we can see at the Fig. 2, the maximum power of locomotive is using only short time period and main engine operation is idling and work with power output up to 100 kW. More efficient is using hybrid locomotives for these types of rail operations. In this case can be used ICE with power about 200 kW and it will cover 86.7% of power needs. The rest 13.3% have to be covered by energy from accumulator which will be charged during idling operation of ICE and recuperation braking.

The accumulator should be able give short-time power about 680 kW, what is ambitious requirement. This high power of accumulators is needed for keeping up maximum traction effort of locomotive. The high power of accumulators is necessary for charging during regeneration of braking power as well.

By this way we can achieve that ICE will be working at optimal conditions and it will cause lower fuel consumption and emission. The next step in designing hybrid locomotive is to choose correct accumulator of energy, which can be fast charging and discharging with high power, which will not damage storage of energy during years of using. For shunting services is suitable use flywheel, ultracapacitors and superconducting magnetic energy storage system and Ni-MH or LiFePo4 batteries as storage of energy, because they can be charged and discharged by high power in short period.

2.2. Shunting service of locomotive Class 770

Another example of output distribution of locomotive class 770 (ČKD) on Fig. 3 during shunting operation on hump in railway station in Zilina is shown in the Fig. 4 [5]. The mean output of the locomotive with nominal rating of 993 kW was only 61 kW in this case, what represents only 6% of nominal output of ICE [2].

Fig. 3. Shunting locomotive class 770 in service[6]

The Fig. 4 shows that ICE shunting locomotives working for a not insignificant duration in the idling mode (approx. 37%) in the area of high specific fuel consumption. This is from reason to power peripheral devices such as compressor.

In the case of a hybrid propulsion would be peripherals driven by an electric motor and, if it is necessary, could be powered by energy from accumulator with turn off ICE. This would achieve the operation of the ICE in area of low specific fuel consumptions.

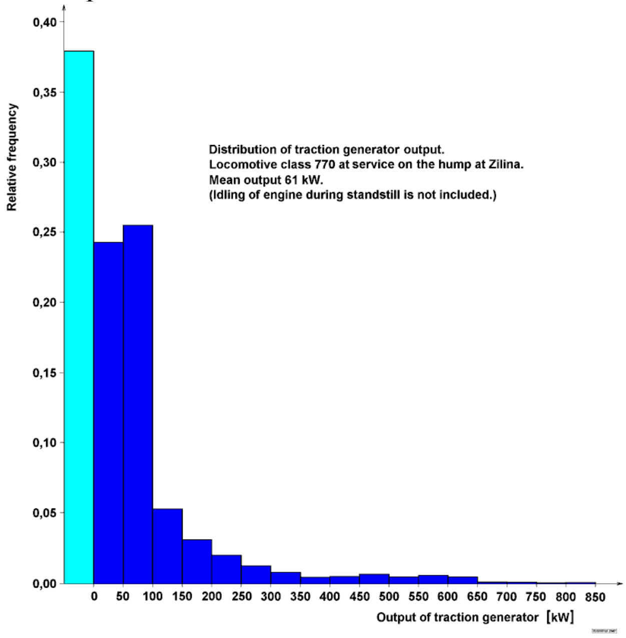

Fig. 4. The distribution of traction generator output of locomotive class 770 shunting at Zilina[5]

2.3. Comparation between shunting hybrid locomotiv Class 718 and non-hybrid locomotive Class 730

In the former Czechoslovakia was in 1986 built the hybrid locomotive Class 718, shown in Fig. 5. There were carried out measurements for comparison this hybrid locomotive and non-hybrid locomotive Class 730. Design and operational properties of locomotive Class 718 was based on locomotive class 730. Basic features of class 718 is shown in Tab. 1. and 730 in Tab. 2.

Fig. 1. Hybrid locomotive Class 718[7]

Tab. 1. Basic features of locomotive class 718 [7]

Locomotive Class 718	
Wheel arrangement	Bo´Bo´
Drivetrain	AC/DC
Engine type	Liaz M 637
Rated engine power	189 kW
Traction batteries	480 NSK 300
Batteries performance	360 kW
Capacity of batteries	300 Ah
Battery voltage	576 V
Auxiliary battery	75 NSK 150
Auxiliary battery voltage	110 V
Max. speed	65 km/h
Continuous tractive effort	104 kN
Max. tractive effort	161 kN
Mass	64 t

Tab. 2. Basic features of locomotive class 730 [8]

Locomotive Class 730	
Wheel arrangement	Bo´Bo´
Drivetrain	AC/DC
Engine type	ČKD K 6 S 230 DR
Rated engine power	600 kW
Max. speed	80 km/h
Continuous tractive effort	104 kN
Max. tractive effort	205 kN
Mass	69,5 t

The results of measurements showed that hybrid locomotive is more effective in all type of shunting except of shunting to hump as it is shown in Tab. 3. It is possible to save approximately 16-22% of fuel compare to non hybrid locomotive.

Increasing fuel consumption of hybrid on shunting to hump is caused by using of hybrid traction drive on maximum. In this operational regime is regenerative braking rare.

To reduction of fuel consumption significantly contributes using of regenerative braking, which save braking blocks or braking pads and achieves higher efficiency of hybrid drive. The measurements at this hybrid locomotive were executed with various loads up to 2500 t.

Tab. 3. Comparation of fuel consumption in shunting service [9]

Type of shunting	Fuel consumption dm^3/h		Ratio of fuel consum-ption
	Class 730	Class 718	
Shunting on hump	14,92	13,09	0,88
Pushing off and allocation of load	13,62	10,33	0,76
Shunting to hump	23,53	25,56	1,09
Pulling of load	12,87	10,86	0,84

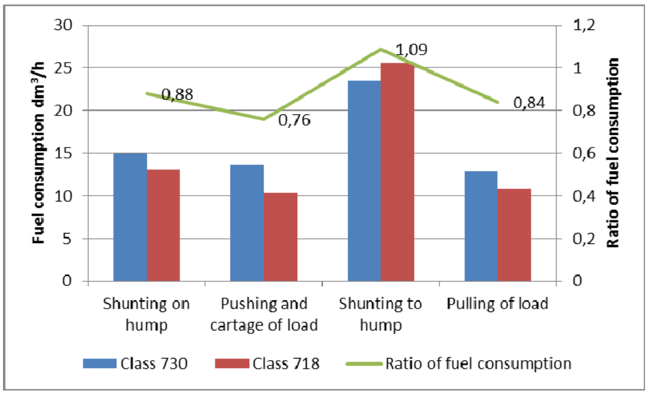

Fig. 2. Graphics processing of data from Tab. 3

Locomotive class 718 has ICE with power only 189 kW and replaced original ICE with power of 600 kW. It is only 31.5% power of original ICE which cause lower fuel consumption and emission compared to original ICE.

3. CONCLUSION

Rising prices of fosil fuels force designers and producers to improve efficiency of diesel locomotives. Better utilization of fuel and decreasing of greenhouse gases emission are required by strict emission limits for rolling stocks. One of the way for better fuel utilization is introducing hybrid propulsion to rolling stocks. With hybrid propulsion it is possible to change kinetic energy of vehicle to electricity through regenerative braking. Kinetic energy is normally changed to heat in non-hybrid locomotives and it is lost during braking process. Another advantage of hybrids are possibility of replacing ICE with high power and fuel consumption with new ICE with lower power and fuel consumption, but with equal traction effort. The hybrid locomotives in shunting operations can reduce the fuel consumption up to approximately 22% and in some case even more.

The most reasonable is using hybrid propulsion in shunting services or at the regional railways where the needs of power are periodically changing and vehicles are still stopping and starting in short period during services. The power peaks are covered from energy stored in accumulators of energy and another power needs are covered by ICE.

Introduction of hybrid locomotives will probably rise in the future, but is necessary to solve problem with high prices of energy accumulators. We can hope that Tesla motors [10] will start massive production of batteries for electric vehicles and it will be possible to use those batteries for hybrid locomotives. Finally hybrid locomotives will cost less than now.

REFERENCES

[1] Chabas, J., Environmentally friendly technologies for railway application, SNCF, Paris, 2001.
[2] Kalinčák, D., Bartík, Ľ., Grenčík, J., Some ways of fuel consumption reduction of diesel railway vehicles, Autobusy – Technika, Eksploatacja, Systemy Transportowe, Nr. 3/2013, Instytut Naukowo-Wydawniczy „SPATIUM“ sp. z o.o., Radom, ISSN 1509-5878, 2013.
[3] Palko, P., Hybridné systémy pohonov v koľajových vozidlách. Thesis. University of Žilina, 2008.
[4] Vyskočil, V., Lokomotíva řady 742 (ex T 466.2), online, http://www.vlaky.net/zeleznice/spravy/003232-Lokomotivy-rady-742-T-4662/, 2009.
[5] Müller, J., Kalinčák, D., Pohl, R., Rybičková, D., Truban, M., Šebo, L., Divišová, H.,Herzáň, F., Smolková, A., Balala, L., Spoľahlivosť pojazdu koľajových vozidiel. Report No SET – KKVMZ/2/85. VŠDS Žilina 1985
[6] Foltín, R., Lokomotiva 770412 - 5, online, http://trainweb.cz/foto/lokomotiva-770-412-5-petrovice-u-karvine-11255, 2008.
[7] Kolmačka, R., Řada 718 (ex TA 436.05), online, http://www.prototypy.cz/?rada=718, 2013.
[8] Kolmačka, R., Řada 730 (T457.0) ČD, online, http://www.prototypy.cz/?rada=730, 2007.
[9] Pohl, J., Výsledky výzkumu hybridního diesel-akumulátorového pohonu lokomotiv, Železniční technika 17/1987, pp. 206 - 211, Praha, 1987
[10] Horčík, J., Tesla nestíhá vyrábět, chce postavit největší továrnu na li-ion baterie, online, http://www.hybrid.cz /tesla-nestiha-vyrabet-chce-postavit-nejvetsi-tovarnu-na-li-ion-baterie, 2013.

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '14

NEW STADLER "FLIRT³" EMU'S FOR SERBIAN RAILWAYS

Fadi KHAIRALLAH [1]

***Abstract** – The FLIRT³ (**F**ast **L**ight **I**nnovative **R**egional **T**rain) meets the highest standards with respect to comfort and safety for the passengers. It represents an evolution in compliance with the latest applicable standards, especially TSI and the crash norm EN 15227. The entire vehicle structure is strictly modular, thus making it possible to fulfil customer needs, such as car body lengths, floor heights and the number of doors or windows, in a simple manner. Furthermore, the interior of the FLIRT³ from the front to the rear end entrance is continuously accessible, in compliance with the TSI PRM. FLIRT³ is available either as an EMU, DMU or HYBRID version. FLIRT³ is equipped with Jacob's trailer bogies. The main advantage of using Jacobs bogies is that the number of axles can be reduced, which leads not only to a reduction in the weight but also reduces maintenance. The vehicle is designed to allow simple maintenance and the use of cost efficient spare parts. Stadler has focused on a light build power traction system which also allows brake energy to be recuperated and fed back into the grid.*

Keywords – Railway vehicle, Crash norm, Jacob's bogie, Maintenance.

1. INTRODUCTION

Worldwide, the demand for EMU's (Electric Multiple Units) is increasing. This type of train is designed for interregional and commuter transportation. Requirements for such trains regarding safety, energy consumption and reliability are thus high.

The Stadler Rail Group is in a position to offer the market complete vehicle concepts. Every aspect of production is carried out under one roof, from body and bogie production, through to the final assembly. State-of-the-art technologies, paired with lightweight and service-friendly designs help to keep energy consumption, and operating and maintenance costs low, while modular concepts cater to the recurring specific requirements of rail companies – one of the reasons for the success of the Stadler Rail Group.

2. CRASH NORMS REQUIREMENTS

The car body must meet the requirements of EN 15227:2008 for crashworthiness, category C-1. The following scenarios have to be considered:

- Scenario 1: Head-on collision at 36 km/h with an identical vehicle
- Scenario 2: Head-on collision at 36 km/h with an 80t freight car
- Scenario 3: Head-on collision at 110 km/h with a side-on deformable barrier (e.g. 15t truck at a railway crossing)
- Scenario 4: Collision with a low object (static load on obstacle deflector)

2.1 Head of vehicle

The head of the vehicle is an aerodynamically optimised fibre reinforced plastic composite element with a modern design.

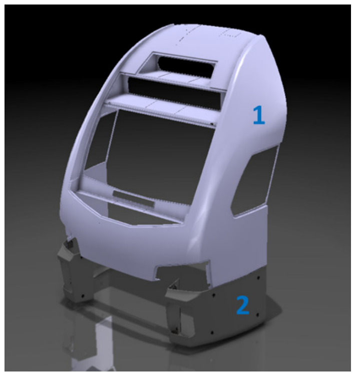

Figure 1: Head of vehicle

No	Explanation
1.	Head of vehicle: aerodynamically optimised fibre reinforced plastic composite element
2.	Cover profile: fibre reinforced plastic composite element for the crash modules

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Figure 2: Head of Vehicle FLIRT[3]

This non-load-bearing cabin is bonded to the aluminium car body as well as to the aluminium crash structure. It provides all necessary mechanical connection points for windows, mirrors, windscreen wiper, etc. for example.

2.2 Crash concept

In the event of a collision, energy absorption takes place in multiple, progressive stages: first within the front coupling, then over the bolted crash modules and finally over the welded crash boxes. Thus, the crash modules can easily be replaced after minor collisions.

The coupling, the crash boxes and the crash modules take effect one after another or with a slight overlap, depending on the collision scenario, and absorb all energy resulting from the collision. With head-on collisions as described in EN 15227, no structural damage occurs up to 10 km/h. In this case, it is not necessary to replace the front coupler.

2.3 Crash front

Normally, a collision initially affects the coupling. The draw and buffing gear are first pushed in by 100 mm, though reversibly, before the irreversible but exchangeable coupling crash element is compressed a further 250 mm. If the impact is more severe, the draft bar of the coupling breaks at a defined location and is pushed backward into the vehicle underbody, compressing the crash modules and then later the crash boxes.

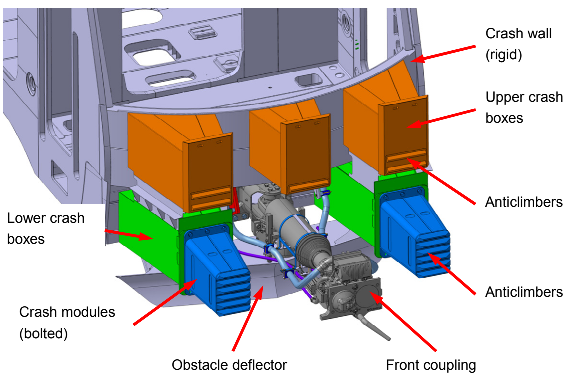

Figure 3: Design of the Crash Front on the End Car

The curved crash wall, as well as the entire underlying front end with the A-pillars, guarantees a rigid, deformation-free structure, which is not part of the crash front that absorbs the energy. The curved crash wall protects the driver's survival space. The crash modules are bolted to the crash boxes, allowing the modules to be easily replaced after minor collisions.

Explicit finite element simulations reveal the behaviour of the vehicle structure for the different collision scenarios described in EN 15227. For the energy absorption modules subject to the largest deformations resulting from collisions, dynamic crash tests were performed. The results of the finite element simulations were then verified by means of the results of the dynamic crash tests.

3. JACOBS TRAILER BOGIE

The Jacobs trailer bogie is placed at the ends of two adjacent car bodies, supporting their weights directly via the four air springs of the secondary suspension stage, two for each car body. This solution cuts down the weight. Moreover, this subsequently reduces the LCC costs, which are due mainly to the maintenance of the bogies.

The traction connection is realised by a Watt's linkage fitted to the car body articulation joint. The brake system consists of four wheel disc brakes.

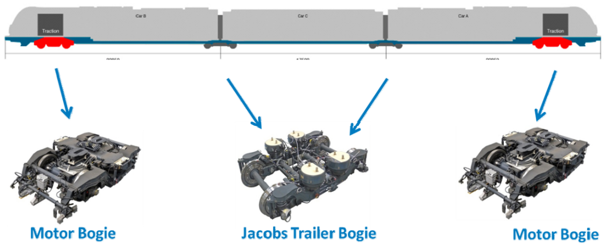

Figure 4: Position of Bogies

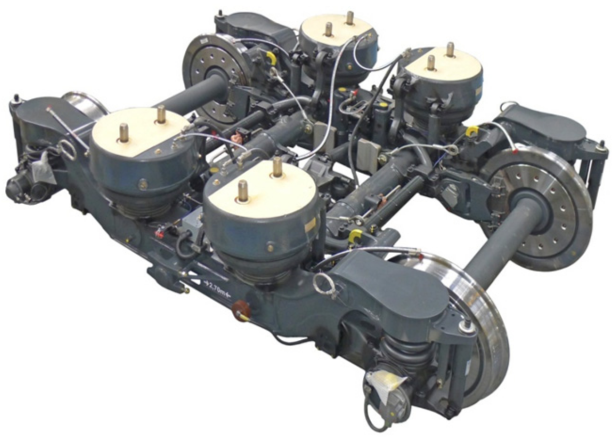

Figure 5: Complete Jacob's Trailer Bogie

Tab. 1. Principal Technical Data of Jacobs Trailer Bogie

No	Item	Explanation
1.	Wheel base	2 700mm
2.	Wheel diameter	New 760 mm – worn 693 mm
3.	Weight	Approx. 6 500 kg
4.	Primary suspension base	2 100 mm
5.	Maximum static axle load	18 tons

3.1 Bogie frame

All connection parts on the bogie frame which are relevant for the following are machined within the required tolerances:

- Parallelism and alignment of the wheel sets
- Safe and reliable operation of the drive units
- Correct function of the brake units

This also ensures that the components installed in the bogie frame can be replaced as required without expensive setting and adjustment work. Furthermore, bogies of the same type are interchangeable within the vehicles. The bogie has been designed for 5g shock.

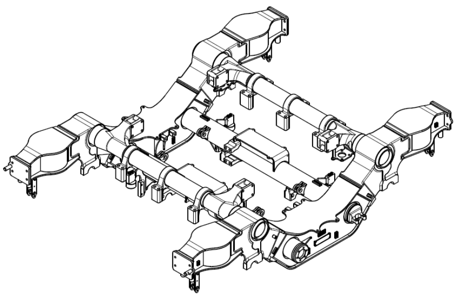

Figure 6: Bogie Frame of Jacobs Trailer Bogie

3.2 Manufacturing

The bogie frames have a welded design. The construction of the bogie frame is carried out according to EN 15085 Parts 1 – 5.

3.3 Material Inventory

The frames consist of components of listed materials:

- Construction sheet metal, grade S355J2+N (EN 10025), DIN material designation 1.0570 (old St 52-3), e.g. sheet metal in longitudinal beam
- Forged parts, grade S355J2G3F (EN 10025), DIN material designation 1.0572 (old PSt 52-3), e.g. axle box supports on motor bogie
- Cast steel, grade GS-20 Mn5 V, DIN material designation 1.1120, e.g. brake supports in bogie frame

3.4 Strength verification and Testing

The bogie frames have been tested for strength and endurance according to current standards, e.g. EN 13749 and EN 15827. Based on standards, a load case document is created for both trailer and motor bogie, which is used for finite element calculation of the bogie frames. The finite element calculation will investigate fatigue load cases and provide static strength proof for the frames. The loads on the bogie frame and adjacent structures are calculated using standard EN 15827. The permissible stresses for welded details are adapted from the listed guidelines of IIW publications and the FKM guideline.

3 MAINTENANCE

EN 50126 defines maintainability as the probability that a given active maintenance action for an item under given conditions of use can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources.

Maintainability is, according to the definition, a product quality that will be largely determined right from the start of and during the product development process. Initial missed opportunities for creating optimal maintainability can only, if at all possible, be remedied with great effort and increased costs. Should maintainability be hindered or not achieved, the consequence is a significant increase in costs during the product's lifecycle.

In order to prevent this from occurring, Stadler directs the attention to the following topics to enable a constant synchronisation and optimal development of the functional and non-functional goals of the entire system and its components during the development of the vehicle:

Interchangeability, Manageability, Modularity, Assembly / Disassembly, Testability, Cleanability, Robustness, Standardisation, Accessibility.

RAM LCC management is an integral part of Stadler's management system. Reliability, availability and maintainability as far as life cycle costs are in direct dependence and always influencing each other and must be considered as a whole.

Effective RAM LCC management is strongly based on proven vehicle design. All vehicle projects are based on a product family established on the market, which is continuosly improved with each further project.

Stadler Rail has had long term experience in the optimisation of maintenance activities for several customers. At the project start, general requirements for maintainability given by customer documentation and Stadler's experienced pool are defined for the engineers involved.

The RAM LCC process defines activities over the whole life cycle of the vehicles, starting at the design and development phase and ending with the disposal of the vehicles.

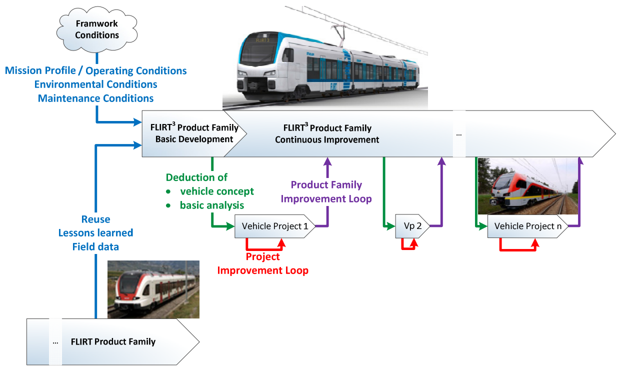

Figure 7: Continuous Improvement of Product Family

The process is applied during all phases of the life cycle of the project. To ensure the best results related to RAM LCC, active participation is required from the beginning in the concept phase by all involved parties:

- Stadler (vehicle integrator)
- Key sub suppliers (traction, HVAC, etc.)

During the design process, Stadler's engineers analyse the actual maintainability performance, following a process based on RCM (Reliability Centred Maintenance) while using the maintainability checklist:

- Accessibility
- List of maintainability critical items
- Time of replacement of the components
- Special tools
- Detectibility of failures
- Modularity
- Maintenance interval
- Availability of spare parts

Based on the customer driven trend to minimise maintenance time to keep to the scheduled timetable, Stadler is accustomed to ensuring service performance in terms of availability instead of reliability. Despite it being accepted that failures on technical systems occur, it is far more important that a component failure does not affect the safety or operability of a vehicle. This results in tough requirement levels regarding availability, which Stadler vehicles achieve with their reliable and redundant vehicle design.

The main condition for maintaining low LCC costs is a high quality product with low energy consumption and high availability, which in turn, depends on the quality of maintenance.

4 CONCLUSION

The FLIRT^3 meets the highest standards of comfort for the passengers. It represents an evolution in compliance with the new TSI standards, especially the crash norm EN 15227. Based on the long experience in building trains and fulfilling the various challenging requirements for customers in many countries all over the world, the entire vehicle structure is strictly modular at all levels, including the bogies. Stadler RAM management rigorously adheres the processes defined in the EN 50126 standard within its own organisation and demands the same of its suppliers. This process starts at the design and development phase and ends with the disposal of the vehicles, thus making it possible to reduce the maintenance costs.

ACKNOWLEDGEMENT

The relevant contract with Serbian Railways was signed in March 2013. According to the schedule, the first EMU Flirt Serbia is to be delivered by Stadler in September 2014.

REFERENCES

[1] B. Schmid, P. Bruderer, H. Welte, G. Wennig, *Tender documents Flirt Serbia*, Bussnang, 2013.

[2] Documents Stadler Rail.

REQUIREMENTS FOR CUSTOMER FRIENDLY RAILWAY INTERIORS

Bernhard RÜGER [1]

Abstract *– Within the project „FLEXICOACH“, in cooperation with Technische Universität Wien, Fachhochschule St. Pölten, Fachhochschule Joanneum, Siemens, netwiss and ÖBB Personenverkehr AG, passenger opinion surveys regarding their wants and needs were conducted. The aim of those surveys was to obtain information about everything a passenger requires; in order to get all information needed various subjects such as duration and frequency of journeys, activities during journey, well-being, stress factors, age, gender and group dimensions, were interrogated.*

Keywords – Passenger needs, expectations, experiences, comfort.

1. INTRODUCTION

Overall 3.826 questionnaires were analyzed. All questionnaires were conducted in summer 2012 on the Austrian Westbahn-line between Vienna and Linz. Due to the summer holidays a lower participation of students must be considered methodically. Furthermore and also due to summer vacations less rides to or from work are expected.

Approximately 50% of travellers undertake a trip lasting several days, around 10% are free time trips without an overnight-stay. Journeys in connection with education or work (rides from / to work, rides from / to education facilities, business trips either one-day or with a several day’s duration) account for 25% of all journeys. The remaining 10% are to be allotted to private settlements.

Rail travellers mostly are young, approximately 12% are aged between 13 and 18 years, almost half of all interviewees are between 19 and 39 years old. 27% are part of the “40 to 60 years of age” group and around 12% are older than 60 years. The fact that children under the age of 12 are underrepresented is simply because they rarely fill in questionnaires.

54% of travellers are female, 46% are male. With the exception of people older than 60 years, in all age-groups female passengers form the majority.

Approximately one third of the passengers travel alone. Another third travels in a group of two persons. Around 11% travel in a group of three, 7% in a group of four and 12% in a group of five or more people.

The journeys were classified in journeys up to 30 minutes, 30-60 minutes, 60-90 minutes, 90-120 minutes, 2-3 hours, 3-4 hours, 4-5 hours and more than 5 hours. Most journeys (respectively 20-30%) in all age-groups last between two and three hours. With increasing age the duration of journey as well increases slightly, short-term rides mostly are done by younger people. Summing up all general information gained, elderly people take the train less frequently, but if they do, they go for longer free time rides. In opposition, younger people take the train more often, and mostly for short business trips.

The better part of all interviewees quoted “comfort” as the major reason to take the train, around 40 % of all passengers declared “environment”, “no car” and “price” as their major reasons to choose the train (see Fig. 1). “Safety” and “duration of journey” are an inferior aspect.

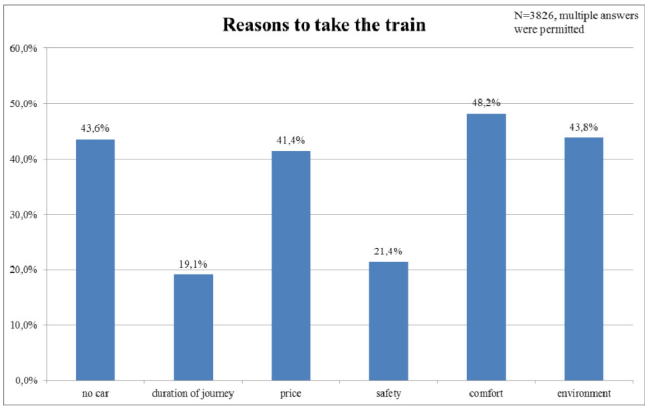

Fig. 1: Reasons to take the train

2. BAGGAGE

Regarding baggage, most information were attained from a diploma thesis [1], which treats issues of baggage transport on an extensive data basis. Amongst other things, various pieces of luggage were

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weight and measured. The accumulated x-, y- and z-dimensions of all luggage measured (not included is carry-on baggage) are demonstrated in Fig. 2.

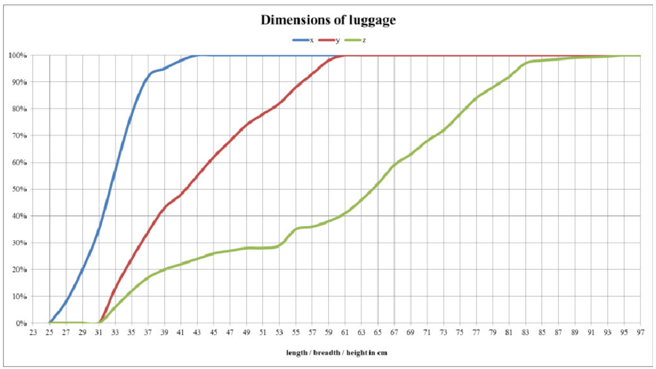

Fig. 2: Dimensions of luggage

Those accumulated measurements can be used in order to design adequate storage between the seat backs or baggage racks.

Analysis show that there are two main issues regarding baggage room. First passengers do not want to lift their luggage, and especially not to the height of overhead storage. This attitude is more common amongst women and increases with age.

Second and due to security reasons, passengers wish to have their luggage in visual range. If these requirements are not met, passengers are very willing to store their luggage in not-intended place, like seats or corridors. This behaviour leads to a lower quality level and to a loss in capacity due to occupied seats.

3. ACTUAL USE OF JOURNEY TIME

A major aspect was the purpose of the journey (business trip or free time ride). Every other business traveller declares to use his laptop, smart phone or tablet while travelling, while only one quarter of travellers on a free time ride uses those devices. Fig. 3 shows the details.

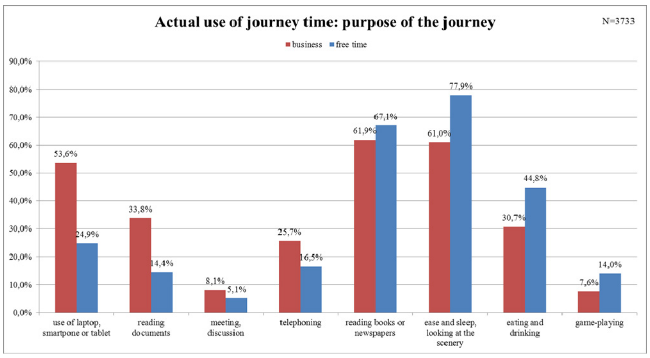

Fig. 3: Actual use of journey time - influence of the purpose of the journey

Another major aspect regarding the use of the journey time is the age of the traveller. Generally speaking there is a slight decrease regarding actually performed activities with rising age. However activities need to be considers separately, while using electronic devices decreases with increasing age, activities like "looking at the scenery" or "reading a book / the newspaper" increase with increasing age.

4. EXERCISES ON THE TRAIN

The longer the journey, the higher need to move. Around 20% of passengers travelling up to an hour wish to exercise during their journey. The percentage rises to 40% when the duration of the journey rises up to five hours or more.

5. DESIRED USE OF JOURNEY TIME

Analysis (Fig. 4) shows that there is a connection between the use of journey time and the purpose of the journey.

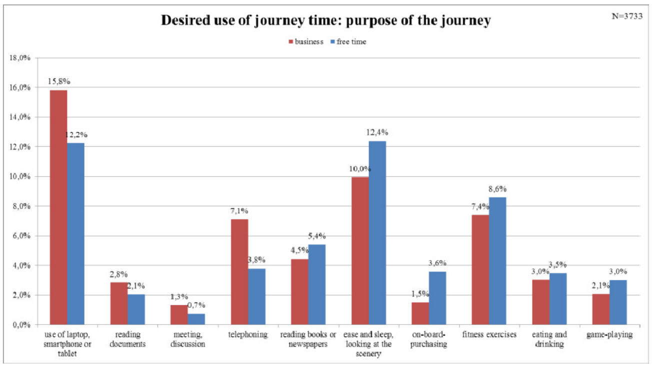

Fig. 4: Desired use of journey time: influence of the purpose of the journey

All too often (around 20% of all interviewees) passengers criticize missing mobile services. Because of several comments it is obvious that a missing WLAN-connection is intended. Together with the absences of tables (respond 12% of all interviewees), this is the biggest obstacle when it comes to using tablet, smartphones and laptops. Around 17% of all interviewees criticize uncomfortable and fixed seats as well as absent silence, which holds them from their desired activity "ease and sleep". The need to move reflects in the desire for a possibility to exercise.

The age has significant influence regarding the desired use of travel time. The younger the interviewee, the more non accomplishable activities are quoted. Anterior passengers are significantly more satisfied with the possibilities offered, respectively less frequently express a wish to use the time in another way.

In Fig. 5, every desired activity is marked in a different colour (the lowest layer indicates "using the laptop", the second lowest "using tablet or smartphone" and so on).

Similar images with heavy age-related variation often occurred in the course of the examination, for instance regarding questions about well-being, stress factors, activities, etc.

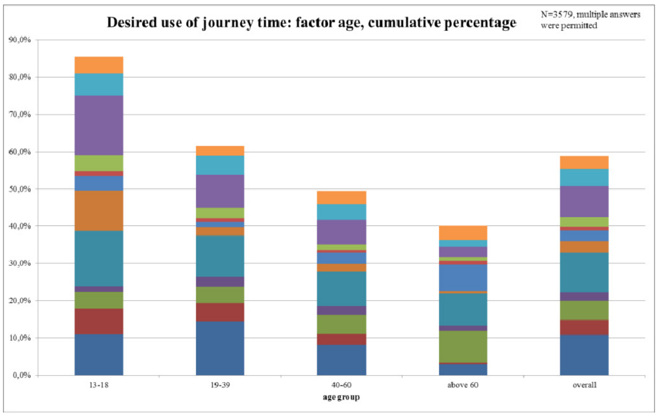

Fig. 5: Desired use of journey time: factor age, cumulative percentage

The journey time is a major aspect when it comes to desirable use of time. The longer the journey time, the more requirements were quoted, in particular if the duration excesses two hours.

6. TIME WELL-BEING

Around 33% of the interviewees feel “very well” when travelling by train, about 52% feel “rather good”, 14 % feel “rather bad” and only 1 % of the passengers do not feel well during train journeys.

The assumption that those outcomes correspond with the fact that younger passengers mostly are on business trips, while anterior passengers use the train prevailing for free time trips, is unfounded. Around 50% of all train journeys are leisure time trips, lasting several days. Interviewees between 13-18 years, the group that feels most uncomfortable during train journeys, mostly goes on free time rides without an overnight stay. Thus there is no obvious connection between the purpose of the journey and the well-being.

Passengers travelling first class are feeling better than passengers travelling second class. Furthermore there is a strong connection between the well-being of the passengers and the degree of capacity. Therefore on weekdays from Monday to Thursday passengers mostly feel “rather well” or “very well”, while travellers on Fridays and weekend feel “rather bad” or “not well”. The higher degree of capacity during weekends leads to an oftener nomination of stress factors like “high degree of capacity”, “search for seat”, “noise” and “fellow passengers”.

7. STRESS FACTORS

The stress factor most frequently nominated was “search for a seat”, around 20% of the passengers feel stressed (see Fig. 6). Also sensed as stress factors were “high degree of capacity”, “noise” and “fellow passengers”. The factors most frequently mentioned are those which appear at a high degree of capacity and obviously lead to a deterioration of the well-being.

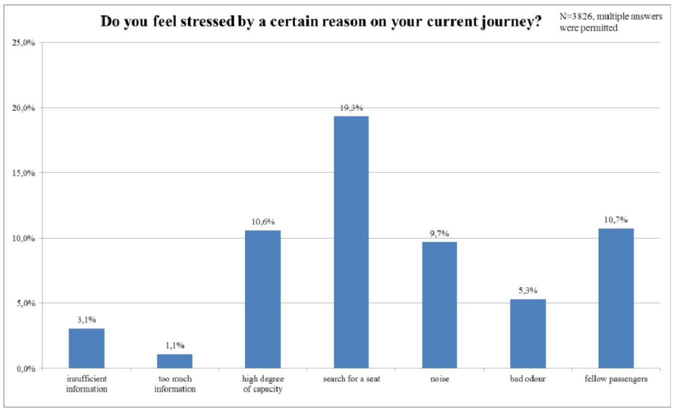

Fig. 6: Stress factors during the current journey

Analogue to the well-being, the age of the passengers is crucial when it comes to cognition of stress. Younger passenger are more stressed than anterior passengers, at least they quote it more often. With increasing age (groups from 13-18 years, till 60 years) the nomination of arising stress factors during an actual train journey decreases under 50%. Considering the most frequently quoted stress factor “search for seat”, the nominations in the age group “over 60 years” decrease even to a third of those from passengers between 13-18 years. This is a very notable fact, because precisely this stress factor was assumed to arise with increasing age, also in terms of luggage.

Generally speaking, anterior passengers are more satisfied with the frame conditions than younger ones.

8. SERVICE FEATURES

Most frequently nominated when it comes to service features were „reasonable priced meals” (31%), “purchase of newspapers” (24%), “transmission of knowledge” (23%), “entertainment” (20%), “possibilities to exercise “ (18%), “relaxation practises” (17%). With increasing age the interest in service features heavily decreases.

With increasing journey duration, the interest in service features increases as well. Passengers on a free time ride show more interest in service features than travellers on a business trip. Around two-thirds of all respondents show interest in healthy nutrition during their train journey. This desire is more common under female passengers than under male ones.

9. ATMOSPHERIC ENVIRONMENT

The outcomes of this particular subject won’t be discussed any further. Generally speaking, the nominations made by the passengers are very subjective and do not always refer to any comprehensible objective criteria. For instance, in every sort of train the temperature was between 25 and 26 °C, nevertheless there are different sensations and evaluations regarding the temperature, which can be connected to the sort of train. The highest percentage of satisfied passengers is to be found in trains of the private operator Westbahn (over 80% satisfaction). The average registered temperature is exactly identical to the temperature registered in the Railjet-trains of ÖBB. However, Railjet was evaluated ten percentage points less than Westbahn. It is obvious that not only the temperature, but rather the general well-being or the consciousness of a deliberately taken decision to travel with a new operator (Westbahn war operating only eight months at the moment of the opinion survey) contributed to this outcome.

The opposite way around also Railjet was not only evaluated regarding temperature, but rather general well-being (for that matter Railjet scores rather low).

There is a similar effect notable when it comes to train categories (first or second class). Passengers travelling first class rated the atmospheric environment higher than passengers travelling second class, there was no objective difference however.

It has to be considered that subjective sensations had a great influence also on questions regarding well-being, illumination and stress factors. Advanced studies would be very helpful in order to interpret the outcomes in the right way.

10. CONCLUSION

Compared to other modes of transportation the railway system has got the big advantage that passengers are able to use the travel time efficiently. This is one of the biggest advantages of competition. Unfortunately today's vehicles hardly offer the requested equipment which allows the best possible time use. Train passengers are very interested in using the travel time for working, mostly on technical devices like one note books or tablets, for reading or for relaxing. For efficient time use the investigations have shown that the individualisation of the space in the train is essential. It is important that all passengers can follow their requested activities without affecting other passengers. For example people who are working may produce noise but on the other hand need calm for concentration. Additionally they need light whereas people who want to sleep need it dark and calm. So further investigation must focus on how the space in the vehicle can be individualized in a best possible way.

ACKNOWLEDGEMENT

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REFERENCES

[1] Viktor Plank: Dimensionierung von Gepäckanlagen in Reisezügen, Wien 2008

[2] Viktor Plank, Bernhard Rüger, "Grundlagen für eine optimierte Gepäckunterbringung in Reisezügen"; ETR - Eisenbahntechnische Rundschau (eingeladen), 07+08 2009 (2009), 07+08; S. 417 - 421

[3] Flexicoach, Endbericht AP2, Nutzerbedürfnisse, Wien 2013

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '14

EXPERIMENTAL MEASUREMENTS AND NUMERICAL SIMULATIONS OF THE WHEEL-RAIL ANGLE OF ATTACK

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Živana JAKOVLJEVIĆ [4]

Abstract *– Angle of attack is important wheel-rail contact parameter and serves for estimation of the rolling stock curving performance. Together with wheel-rail contact forces, angle of attack influences the wear index. This paper presents experimental on-track measurements of the angle of attack using specially designed laser device installed on track. Experiments were performed on three type of rail vehicles: shunting locomotive series 631-301, motor unit 412-077 and trailing unit 416-077 of the electromotor train 412/416. Experimental measurements were compared with multibody system (MBS) simulations using specialized computer package VAMPIRE Pro. We found good agreement between the results obtained experimentally and by simulations.*

Keywords – Angle of attack, Measurements, Multibody simulations, Wear index.

1. INTRODUCTION

Criteria for estimation of the railway vehicle dynamics during curve negotiation including derailment safety, depend on ratio between lateral Y and vertical Q forces in the wheel-rail contact (Y/Q), as well as on the wheel-rail angle of attack α [1]. These parameters, together, influence wear intensity expressed using wear indices. Considering the importance of these parameters for experimental research and prototype testing of the railway vehicles in this paper we present the developed device for angle of attack (AOA) measurements and experimental results obtained by its use. The device for measurement of the wheel-rail contact forces and appropriate wayside system for measurement is more detailed presented in [2].

2. DEVICE FOR AOA MEASUREMENTS

Developed device for angle of attack measurements identifies position of the wheel relative to some surface or axis using Micro-Epsilon optoNCDT 1700 laser device (Fig. 1). Angle between the wheel and defined reference, which represents longitudinal rail axis, defines wheel-rail angle of attack α. Considering lasers's accuracy and measurement principle, this device should be positioned normaly to rail longitudinal direction.

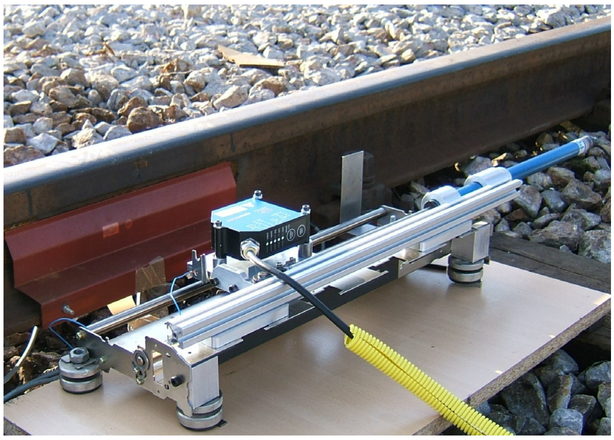

Fig. 1. Laser device positioning relative to rail

3. IN-SITU MEASUREMENTS OF THE AOA

Characteristic results recorded for shunting

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locomotive 621-301 and electromotor unit 412/416 are presented in the paper.

Immediately before measurements, direction of the laser beam was checked relative to rail (Fig. 2). It appeared that deviation from the 90° was 12,4 mrad (0,71°). According to analysis performed in [3], such a small deviation has negligible influence on measurement accuracy (less than ± 1%), so it was not necessary to correct laser position.

In the following paragraphs, we will use example of the measurements on electromotor train's trailing unit 416-077 to present the method for data processing, as an example are presented complete results of measurements on electromotor train's trailing unit 416-077.

Fig. 2. Trailing unit EMU 416-077– angle of attack measurement device without protective cover

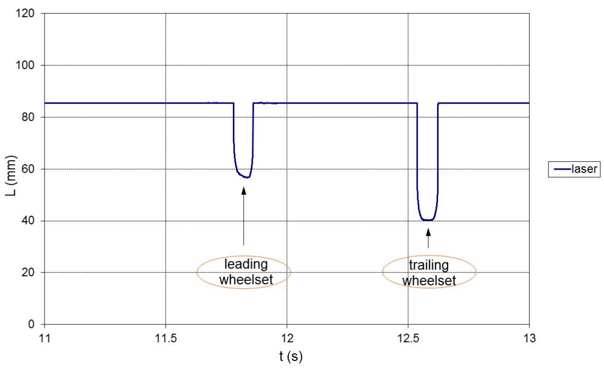

Fig.3. Trailing unit EMU 416-077 outer wheels – recorded data

In Fig. 3 is presented outer wheel position of the leading and the trailing wheelsets relative to rail in time domain recorded using laser device.

For obtaining of the wheel-rail angle of attack recorded data were transformed from time domain to spatial domain using measured speed of the train. Passing of the outer wheels in spatial domain after transformation is presented in Fig. 4 and Fig. 5. From these diagrams could be derived angle of attack and the wheel position relative to rail. Angle of attack α was estimated based on the linear regresion slope of the central segment of the recorded line with 100 mm length, which is far enough from rounded zones caused by flange passing by the laser.

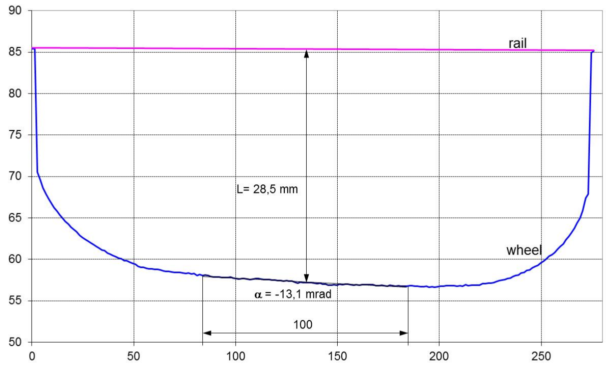

Fig. 4. Trailing unit EMU 416-077 – relative position and angle of attack of the outer wheel of the leading wheelset

Measured angle of attack was α=-13,1 mrad for outer wheel of the leading wheelset and α=1,0 mrad for the outer wheel of the second wheelset. Relative position between the back surface of the outer wheel and the side of the outer rail in the mid position of the wheel, defined as distance between wheel and the rail measured 10 mm below TOR (top of rail), was 28,5 mm for the leading wheelset and 45,0 mm for the second wheelset of the leading bogie.

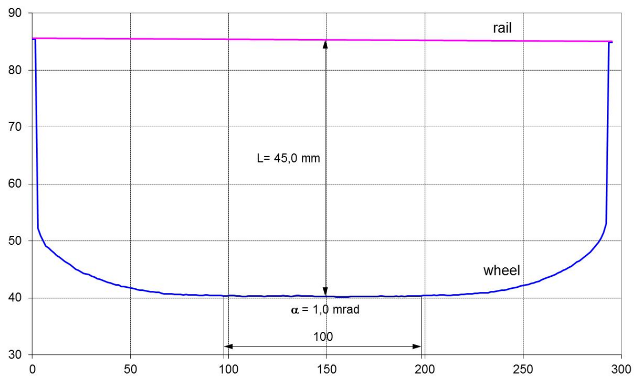

Fig. 5. Trailing unit EMU 416-077 – relative position and angle of attack of the outer wheel of the second wheelset

3.1. Wheel-rail wear indices

All three vehicles were tested under the similar or even the same conditions (same location) and all the vehicles while passing over the measurement section were pushed or hauled or with turned off traction. In this subsection we present relative comparison of the wear characteristics of the outer wheels of the leading wheelset for each of the tested vehicles. For comparison diferent authors have defined diferent wear characteristics, which are called wear indices. Starting from expressions for wear index given in [4], which includes work of tangential forces in the wheel-rail contact, for comparison of the wear characteristics of the diferent vehicles with diferent wheel profiles, with some approximations we used product of lateral force and angle of attack according to following expression:

$$I_h = k \cdot Y \cdot \xi_y = k \cdot Y \cdot \frac{V_y}{V} = k \cdot Y \cdot \alpha \quad (1)$$

where: k – constant, Y – measured lateral force, ξ_y – creepage in lateral direction, V_y – speed component in lateral direction of the wheelset, V – speed of the wheel forward movement, α - angle of attack.

Relation between the creepage ξ_y and angle of attack α was established based on kinematics and geometric relation shown in Fig. 6. Approximation and asumption based on which expression (1) was derived are:

- Creepage in genereal represents ratio between speed component in the creep direction and speed of the wheel forward movement,
- During curve negotiation with turned off traction, wear is influenced dominantly by work of tangential force in lateral direction.

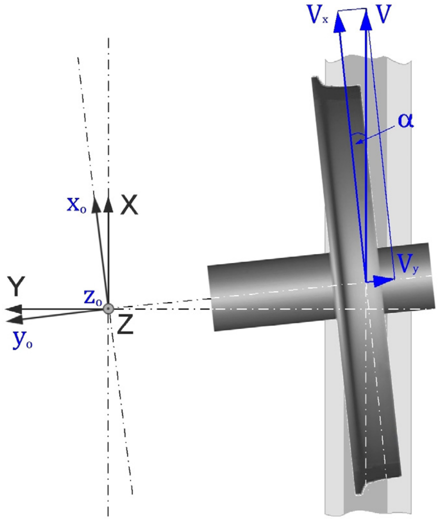

Fig. 6. Creepage in lateral direction

Obtained results of the relative wear index for the three tested vehicles are presented in Tab. 1.

From the table it can be seen that the lowest value of the angle of attack and the best wear performance and lowest wear index has trailing unit 416-077.

Tab. 1. Relative wear index I_h of the tested vehicles

	V (km/h)	Y (kN)	α (rad)	$Y \cdot \alpha$ (N rad)	Relative wear index I_h
Shunting locomotive 631-301	13	26900	16.6	446.54	1.00
Motor unit 412-077	14	23300	14.7	342.51	0.77
Trailing unit 416-077	13	15400	13.1	201.74	0.45

4. NUMERICAL ANALYSIS

Simulation of the railway vehicle dynamics using some of the specialized computer simulation packages may also serve as a good design tool. Depending on the scope of an analysis, simulation can have very detailed vehicle models and at the same time use some simplifications of the track model, such as considering it either as rigid or as installed on uniform elastic foundation. The others focus on the track analysis using 2D models, while the excitation influence of the vehicle is approximated using some simplified vehicle models [5, 6]. There are also simulations that consider vehicles and tracks as a multibody system (MBS), while considering only vertical vehicle/track interaction [7–9]. Within our research, we used the computer programme Vampire Pro [10] for the curving analysis during passing through the sharp curve with a 214 m radius, on the track without superelevation, excluding the influence of any other geometric imperfections. Below we present an overview of the performed simulations and obtained results. Fig. 7 shows non-linear model of the EMU series 412/416 indicating detail of one bogie with suspension elements. Bogie frame and wheelsets are presented transparently in order to provide better overview of the suspension system and link elements.

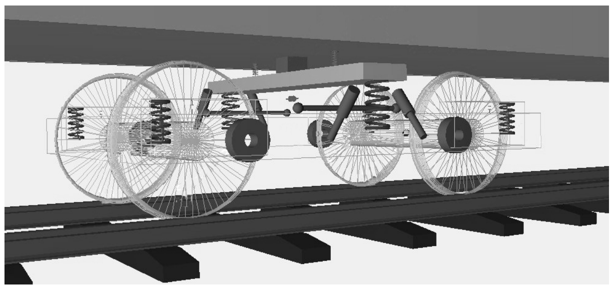

Fig. 7. Model of EMU– detail of the bogie [2]

Vampire Pro allows linear stiffness and damping terms to be specified between the rail and sleeper and sleeper to ground as shown in Fig. 8. Damping terms are not important for quasi-static curving analysis. They just support convergence of the simulation results. The most significant stiffness terms used in simulations for lateral rail to sleeper stiffness were experimentaly obtained, while lateral sleeper to ground stiffness, as less important for this analysis, was adopted from literature [10]. The rails and sleepers are considered to be massless degrees of freedom, which is appropriate for the steady-state curving analysis.

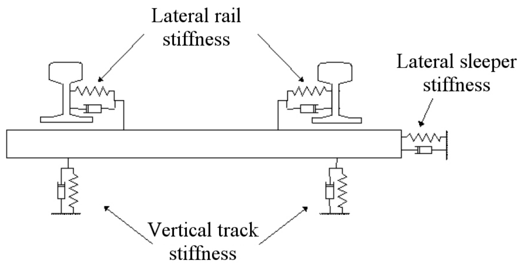

Fig. 8. Track model [10]

The majority of the vehicle and track parameters used in the simulation are selected based either on performed measurements, or the available technical documentation and only several parameters of the track, due to the lack of experimental results, are selected on the basis of the literature review.

For the modelling of the wheel-rail contact, Non-Linear Creep law was used. This creep law uses a pre-calculated contact data table which describes the contact data parameters with respect to wheelset lateral shift across the track at rail level. For that purpose real wheel and rail profile data measured using profilometer were used as input for the computation of the actual creep forces.

The results of steady-state curving analysis have shown fairly good agreement having in mind strong dependence of the simulation results on various input parameters of the simulation model. Although this programme was benchmarked during several internationally recognized benchmarking exercises and the results have shown fairly good agreement, the simulation results should be interpreted with caution.

From the research performed on the traling unit of the electromotor train 412/416 it can be seen that angle of attack of the leading wheelset obtained by simulation was equal to -12,0 mrad while the experimental result was -13,1 mrad. Angle of attack of the second wheelset of the trailing unit obtained using simulation was -0,5 mrad, and the appropriate measured value was 1,0 mrad.

5. CONCLUSION

Based on the obtained results it can be concluded that for curving analysis of the railway vehicles and for control of the wheel-rail wear, it is necessary to know vertical Q and lateral Y forces, as well as angle of attack α. The most reliable method for the determination of these parameters is to perform experimental measurements. However, it also appeared that by using quality dynamic model and reliable simulation software, with as accurate as possible values of the simulation parameters of the railway vehicle and the track, it is possible to predict vehicle's dynamic behaviour in the phase of design and to apply changes in order to obtain favourable dynamic behaviour.

ACKNOWLEDGEMENT

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REFERENCES

[1] EN 14363 Railway applications - Testing for the acceptance of running characteristics of railway vehicles - Testing of running behavior and stationary tests, June 2005.

[2] Milković, D., Simić, G., Jakovljević, Ž., Tanasković, J., Lučanin, V., Wayside systems for wheel-rail contact forces measurements, Measurement 46, pp. 3308-3318, 2013.

[3] Milković, D., The influence of wheel-rail contact parameters on railway vehicle dynamic behaviour (in Serbian), Doctoral Dissertation, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, 2012.

[4] Kumar, S., Prasana Rao, D. L., Wheel-Rail Contact Wear, Work, and Lateral Force for Zero Angle of Attack—A Laboratory Study, Journal of Dynamic Systems, Measurement, and Control, Vol. 106, pp. 319-326, 1984.

[5] Grassie, S. L., A contribution to dynamic design of railway track, In: G. Sauvage (Ed.): The Dynamics of Vehicles on Roads and Tracks, Proc. 12th IAVSD Symposium, Lyon, France, August 1991, Supplement to Vehicle System Dynamics Vol. 20, Swets and Zeitlinger Publishers, Lisse, pp. 195-209, 1992.

[6] Kerr, A. D., On the determination of the rail support modulus k, International Journal of Solids and Structures 37 pp. 4335-4351, 2000.

[7] Ripke, B., Knothe, K., Simulation of high frequency vehicle–track interactions, Journal of Vehicle System Dynamics, Supplement 24, pp. 72–85, 1995.

[8] Sun, Y. Q., Dhanasekar, M. A., A dynamic model for the vertical interaction of the rail track and wagon system, International Journal of Solids and Structures 39 (2002) 1337-1359.

[9] Zhai, W., Sun, X., A Detailed Model for Investigating Vertical Interaction between Railway Vehicle and Track, Vehicle System Dynamics 23 (1994) 603- 615.

[10] VAMPIRE® Pro Version 5.50 Programme, DeltaRail Group Ltd., Derby 2011..

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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DETERMINATION OF FRICTION HEAT GENERATION IN CONTACT OF WHEEL-RAIL SET USING FEM

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Abstract – *The modeling of the friction heat generation has become increasingly important in product design process including areas such as electronics, automotive, aerospace, railway (e. g. wheel and rail rolling contact, braking systems, and so on), medical industries, etc. Determintation of generated friction heat in the contact of wheel and rail is important for understanding the damage mechanisms on this two bodies such as wear. This paper presents a method to determine the friction generated heat in contact of wheel and rail during normal operaton using transiental structural-thermal analisys in Ansys software.*

Keywords– wheel-rail system, contact temperature, friction heat, FEM.

1. INTRODUCTION

Today, computer simulation has allowed engineers and researchers to optimize product design process efficiency and explore new designs, while at the same time reduce costly experimental trials. Generatied friction heat is some physical process like contact of rail and wheel during operation is important factor for damage forms and other processes.

There is a great number of studies and research papers that deal with this problem of rail and wheel contact.

Knote [1], in his study, analysed contact temperatures and temperature fields of components in relative sliding motion by Laplace transforms and the method of Green's functions. He investigate the case of loadings with fluctuations due to surface roughness and indents.

Ertz [2] has concuded that the contact of wheel and rail can be investigated very efficiently with Hertzian contact with polynomial approximation. He also presented methods for the calculation of contact temperatures using Blok's flash temperature formula. The bulk temperature of the wheel increases with time by continious friction heat. He presented that the wheel temperature during normal operating condition cannot be more than double the average temperature of the cold wheel.

Sundh [3] analyse wear of wheel and rail focusing on *contact temperature, elemental and morphological analysis of the airborne particles, and surface-layer microstructure of test specimens by using several analytical techniques*.

Tombergera [4] presented in his paper wheel-rail contact model. His model computes *local mechanical and thermal stress distributions and resulting traction–creep curves under consideration of interfacial fluids, surface roughness and contact temperatures*. His model shows that contact temperatures become significant above the saturation point, where the complete contact zone slips with an average slip velocity equal to the creepage between wheel and rail.

Wu [5] analysed wheel rail contact using thermal-elastic-plastic deformation and residual stress after

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wheel sliding on a rail. He simulated sliding contact process by translating the normal contact pressure and the tangential traction across the rail surface. His results indicated that the friction thermal load of contact between wheel and rail has a significant influence on the residual deformation, plastic strain and residual stress at the rail surface.

2. GEOMETRY

2.1. Rail profile

Standard EN 13674-1:2011 specified 23 rail profiles. This European Standard specifies Vignole railway rails of 46 kg/m and greater linear mass, for conventional and high speed railway track usage.

Two classes of rail straightness are specified, differing in requirements for straightness, surface flatness and crown profile. Two classes of profile tolerances are specified. Figure 1. represent rail profile 50E2 which is used in further analisys.

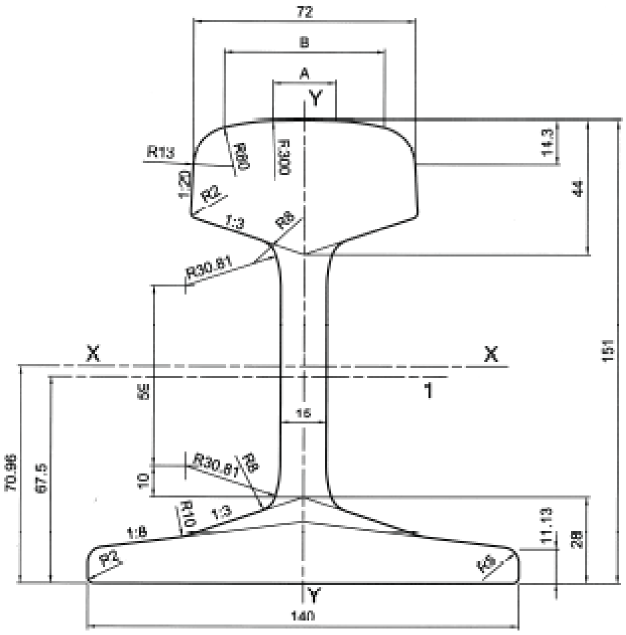

Figure 1. Rail profile 50E2 [6]

2.2. Wheel profile

UIC CODE 510-2 [7] contains the conditions relating to the design and maintenance of wheels and wheelsets for coaches and wagons used on international services. It covers wheel diameters from 330 to 1000 mm, and indicates the permissible axle loads from the standpoint of stresses of the metal used for the wheel and the rail.

UIC CODE 510-2 contains detail coordinates of wheel rim line. It is valid for a nominal track gauge of 1435 mm and cannot be readily transposed to apply to other track gauges. Figure 2. represent wheel profile which is used in further analisys.

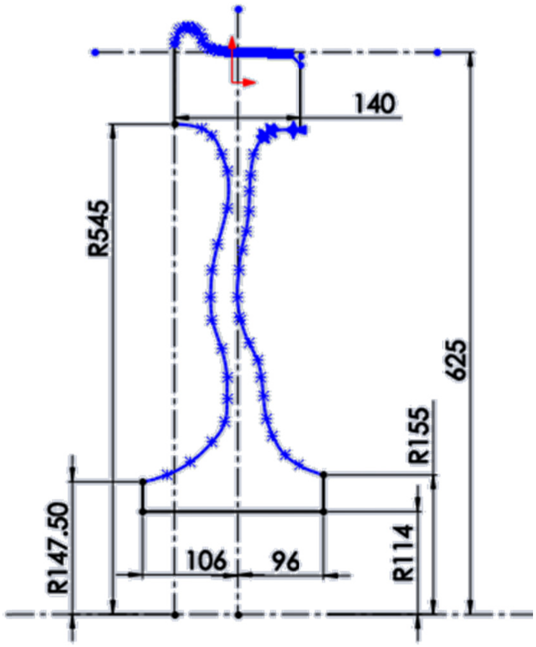

Figure 2. Wheel profile

3. ANALISYS SETUP

Basic model of wheel-rail set was made in Solidworks and than it is exported in Ansys. As higher order element was used due to computational limitations only a fraction of wheel model was considered in analysis. For the FEM analysis was used only upper part of rail long 10 meters and outer ring of wheel.

In analise were used Ansys elements SOLID226 (Figure 3) and SOLID227 that supports the thermoplastic effect, "which manifests itself as an increase in temperature during plastic deformation due to the conversion of some of the plastic work into heat". Thermoplastic analysis exists in the following Ansys elements:

- SOLID226 - 3-D 20-Node Coupled-Field Solid
- SOLID227 - 3-D 10-Node Coupled-Field Solid

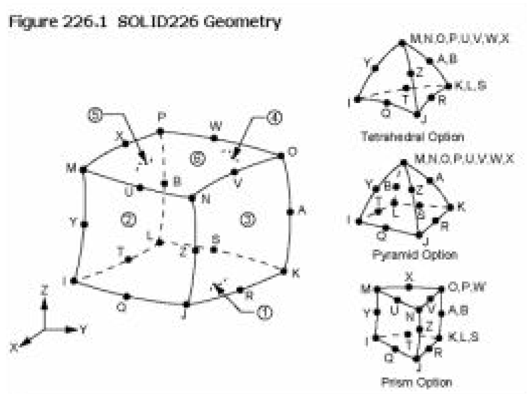

Figure 3. Elements SOLID 226 used in analysis

For mesh of rail body was used SOLID 226. Complicate geometry of wheel body forced use of SOLID 227 instead od 226 (Figure 4). In the Table 1. was given numbers of elements and nodes.

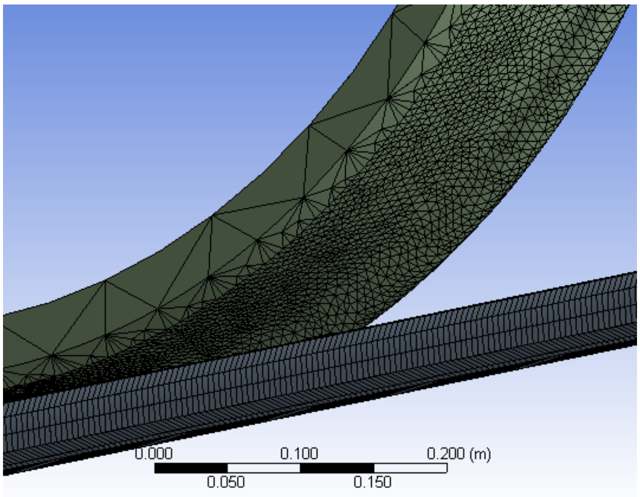

Figure 4. Mesh of wheel and rail

Table 1. Number of elements and nodes

	wheel	rail	Sum
elements	76502	62400	138902
nodes	114735	94820	209555

$$q = FGHT \cdot \tau \cdot v \tag{1}$$

where τ is the equivalent frictional stress, v the sliding rate and *FGTH* the fraction of frictional dissipated energy converted into heat (the default value of 1 was used).

Due to limited resources analises were limited on 0.6 sec which is enough for wheel to make more than one whole rotation. During normal operation there is sliding between wheel and rail. In the same time rail is moving in the same direction 1%, 2% or 3% which represent some of slip ratios used in paper [10]. This moving of rail represents sliding that is expected during normal train operation. Wheel has speed of 30 km/h. But with slip ratio wheel has speed of 29.7 km/h in case when sliding is 1% respectivly 29.4 km/h for 2% sliding and 29.1 km/h for 3% sliding. In the same time pressure load on wheel is 49050 N which represent the weight of the wagon. Friction between wheel and rail is 0.1.

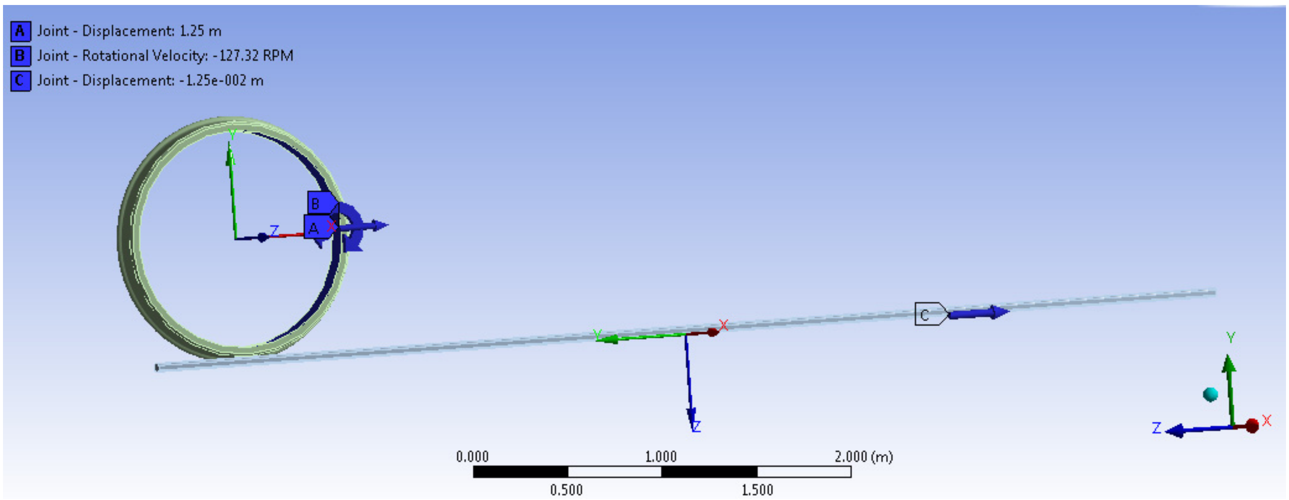

Figure 5. Analisys setup of wheel and rail set for case with sliding 1%

The properties of the materials used in the analysis are listed in Table 2.

Table 2. The mechanical properties used in this study

Density [kg/m^3]	7850
Coefficient of thermal expansion [C^{-1}]	$1.2 \cdot 10^{-5}$
Young's modulus [Pa]	$2 \cdot 10^{11}$
Poisson's Ratio	0.3
Tensile Yield Strenght [Pa]	$2.5 \cdot 10^{8}$
Tensile Ultimate Strenght [Pa]	$4.6 \cdot 10^{8}$
Isotopic Thermal Conductivity [W/mC]	60.5
Specific Heat [J/kgC]	434

Analysis was defined as direct coupled transient structural-thermal analysis. The rate of frictional dissipation in contact elements in Ansys is evaluated using the frictional heating factor and is given by:

4. RESULTS

In Tables 3. and 4. are given results of generated temperature on wheel and rail. In Table 4. are relative increase of temperature since the normal temperature is 22 ^{o}C. Temperatures on wheel are greater than temperatures on rail. Compared with temperatures on rail, temperatures on wheel are for circa 66 – 68 % higher.

Comparation of generated temperature show that the increase of sliding leads to increase of generated temperature on wheel and rail. Temperature on wheel is circa 3 times for 3% sliding, respectivly circa 2 times for 2% sliding higher compared with generated temperature in case when sliding is 1%.

Figure 6. shows relative temperature increase in function of sliding.

Table 3. Temperature on wheel and rail [°C]

sliding	wheel	rail
1%	28.4	26.3
2%	35.1	30.7
3%	41.5	35.2

Table 4. Relative temperature on wheel and rail [K]

sliding	wheel	rail
1%	6.4	4.3
2%	13.1	8.7
3%	19.6	13.2

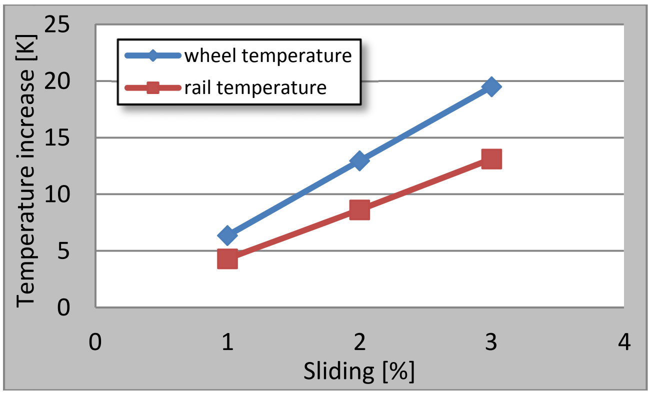

Figure 6. Relative temperature increase

In Table 5. are given Maximal equivalent stress on wheel and rail in Pa. Maximal equivalent stress on wheel is 2.8% and on rail is 4.2% higher when sliding is 1%, respectivly for 3% sliding on wheel 3.5% and on rail 5.8% compared with Maximal equivalent stress in case when sliding is 2%. Maximal equivalent stress on wheel are greater than maximal equivalent stress on rail. When sliding is 1% Maximal equivalent stress on wheel are 3.9% resprectivly 5.3% for sliding 2%, and for sliding 3% Maximal equivalent stress are 3.7% higher comparing with Maximal equivalent stress on wheel.

Table 5. Maximal equivalent stress [10^8 Pa]

sliding	wheel	rail
1%	4.04	3.89
2%	3.93	3.73
3%	4.07	3.95

In Table 6. are given Contact pressure on wheel and rail in Pa. Contact pressure is higher for 3 % when sliding is 3% and 1.7% when sliding is 2% compared with contact pressure in case when sliding is 1%.

Table 6. Contact pressure [10^8 Pa]

sliding	wheel - rail
1%	6.47
2%	6.58
3%	6.65

5. CONCLUSION

The paper present approach to determine the friction generated heat in wheel rail contact by using of FEM.

Analysis shows that temperatures on wheel are greater than temperatures on rail in all cases of slip ratio. Increase of sliding leads to increase of generated temperature on wheel and rail.

Maximal equivalent stress on wheel is slightly higher when sliding is 1% and 3% compared with Maximal equivalent stress in case when sliding is 2%. Maximal equivalent stress on wheel is greater than maximal equivalent stress on rail.

Contact pressure is slightly highest when sliding is 3%, and the lowest contact pressure is in case when sliding is 1%.

Further research should compare temperatures of simulation with real temperatures. Also, it would be very interesting to calculate generated heat in case of acceleration and braking of train.

REFERENCES

[1] Knothe, K., Liebelt, S.: Determination of temperatures for sliding contact with applications for wheel-rail systems, Wear, Volume 189, Issues 1–2, October 1995, pp 91–99

[2] Ertz, M., Knothe, K.: A comparison of analytical and numerical methods for the calculation of temperatures in wheel/rail contact, Wear 253 (2002) pp 498–508

[3] Sundh, J., Olofsson, U.: Relating contact temperature and wear transitions in a wheel–rail contact, Wear, online (2010): www.elsevier.com/locate/wear

[4] Tombergera, C., Dietmaierb, P., Sextroc, W., Sixd, K.: Friction in wheel–rail contact: A model comprising interfacial fluids, surface roughness and temperature, Wear, online (2010): www.elsevier.com/locate/wear

[5] Wu, L., Wen, Z., Li, W., Jin, X.: Thermo-elastic–plastic finite element analysis of wheel/rail sliding contact, Wear, online (2010) www.elsevier.com/locate/wear

[6] EN 13674-1:2011: Railway applications - Track - Rail - Part 1: Vignole railway rails 46 kg/m and above, approved 10. December 2010.

[7] UIC CODE 510-2: Trailing stock: wheels and wheelsets. Conditions concerning the use of wheels of various diameters, May 2004

[8] Milošević, M., Stamenković, D., Milojević A., Tomić, M.: Modeling Thermal Effects In Braking Systems Of Railway Vehicles, Thermal Science, Year 2012, Vol. 16, Suppl. 2, pp. 515-S526

[9] Miltenović, V., Banić, M., Miltenović, A.: Prediction of Heat Generation in Meshing of Crossed Helical Gears, International Conference Gears. VDI-Society for Product and Process Design. October 7th to 9th, 2013, Munich, Germany pp.586-597

[10] O. Arias-Cuevas, Z. Li, R. Lewis, E.A. Gallardo-Hernandez, Rolling–sliding laboratory tests of friction modifiers in leaf contaminated wheel–rail contacts, in: 2008 International Joint Tribology Conference, October 20–22, Miami, Florida, USA, 2008.

ANALYSIS OF THE RESULTS OF THEORETICAL AND EXPERIMENTAL STUDIES OF FREIGHT WAGON FALS

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Valeri STOILOV [3]
Sanel PURGIĆ [4]

***Abstract** – Comparative analysis based on the results from strength-deformation analysis of wagon body, series Fals, and on the results from the real wagon test was made. Calculations were carried out in the Department of Railway Engineering at Technical University of Sofia and are based on the finite elements method. Two computational models of wagon design were developed. One of them consists of shell elements (triangular), and the second one of solid elements (tetrahedral). Experimental studies on real wagon were conducted at the National Transport Research Institute. It was found that the results obtained for the stresses are similar, which proves that the models are appropriate and they can help to solve a wide range of issues, for example those related to lightweight design of railway vehicles.*

Keywords – Railway wagon, strength analysis, FEM, tests.

1. INTRODUCTION

The paper is a comparative analysis [1,2] of the static strength analysis of the supporting steel structure of Wagon series Fals and actual tests carried out.

This comparison is to determine which of the theoretical models that emerged in recent years in the calculation of railroad structures, describes more accurately the actual test article. The first model was built with the type of finite elements "Solid" and the second with "Shell" finite elements. Stress-strain analysis was performed by the method of finite elements [3,4,5,6] in the Department of Railway Engineering of Technical University of Sofia. Theoretical and experimental studies have been done in full compliance with international requirements described in the European standard DIN EN 12663[7], TSI (Rolling stock)[8] and code 577 of the International Union of Railways (UIC)[9]. According to these regulations, 13 static load cases and 8 fatigue load cases were carried out on the wagon.

Due to the limited volume, the report presents the results of only two of the obligatory load cases: Compressive force at buffer height 2000 kN (provisionally marked LC-1) and Tensile force in coupler area 1500 kN (provisionally marked LC-2) [7,8,9,10]. In the present research, the comparison of the two models was done in a limited number of zones. In the real prototype, the same areas where the strain gauges were located were then tested with our two theoretical models and relatively high stress values were measured.

2. ANALYSIS OF THE RESULTS

For the purpose of this study, two complicated calculation models for strength analysis were developed.

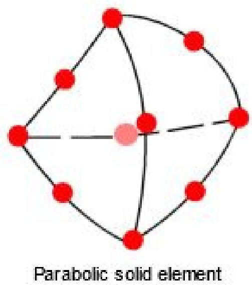

Fig.1.

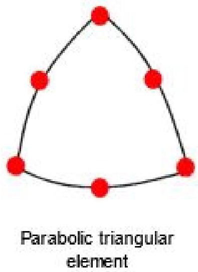

Fig.2.

The first model (fig. 3) was built up from a type of finite element 3D solids (fig. 1) and consists of 697 047 nodes and 349 371 elements. The maximum size of the finite elements is 42,6 mm. All theoretically required ratios between the parameters of

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finite elements that allow modeling of the structure of the body with 3D solids were observed.

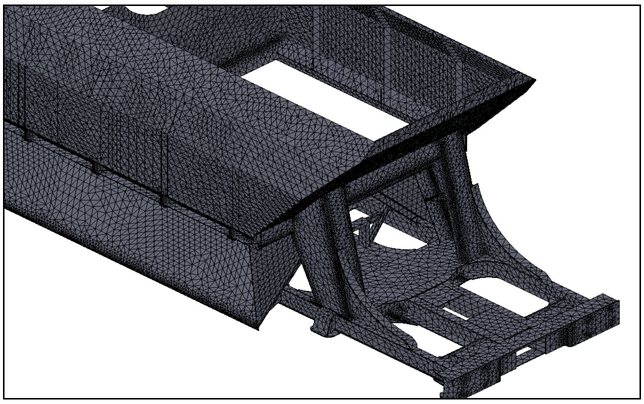

Fig.3. FEA model with solid elements

In the second model the generated mesh parameters were: maximum size – 31,8mm; minimum size – 10,6mm; Rate of increase -1,5; number of finite elements - 401 874; number of nodes - 801 408. Fig. 4 shows the finite element mesh (shell FIG. 2) in the computing model.

The models were optimized by studying the convergence of the solution [11,12,13,14].

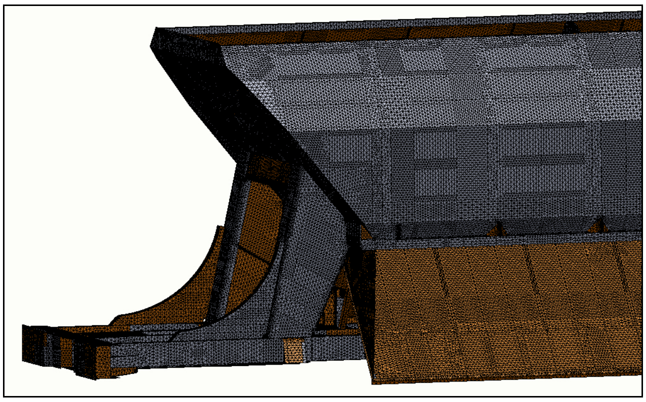

Fig.4. FEA model with shell elements

The third major component of this research is the real test of the structure [15]. Fig. 5 shows the plan and the locations of the strain gauges through which the values of stress were measured in experimental wagon used in this report for comparative analysis.

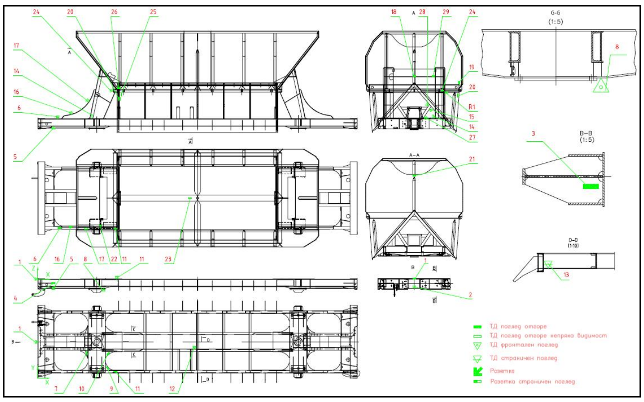

Fig.5. Measuring points

The horizontal loads were applied by means of hydraulic cylinders in the buffer and draw gear.

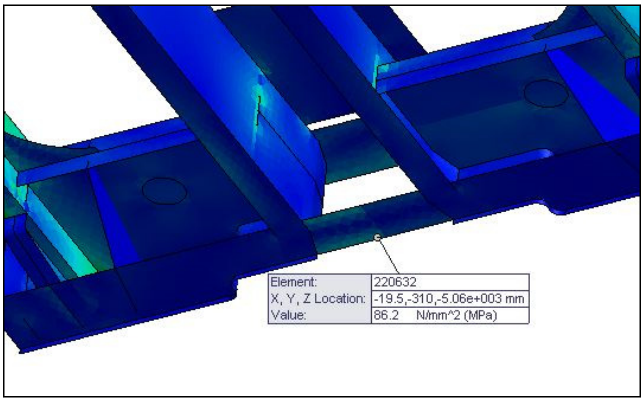

Fig.6. Stress value in shell model

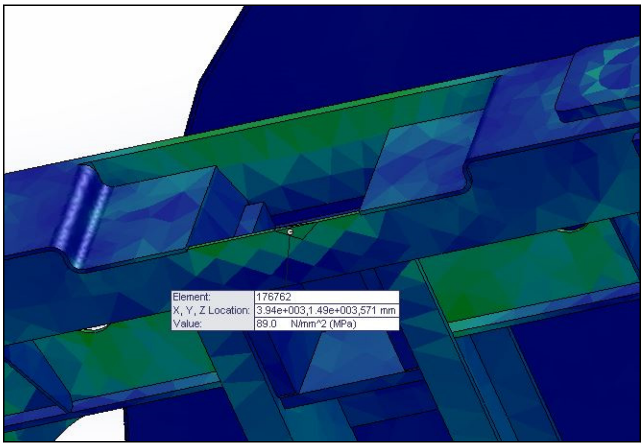

Fig.7. Stress value in solid model

Fig.8. Strain gauge No2

To achieve more precise comparative analysis, so-called "clear load cases" were selected, i.e. those in which the forces are applied only in one of the coordinate axes. This allows us to avoid some subjective factors arising from the improper positioning of the force producing elements.

In the analysis of the two theoretical models the forces and restrictions [16,17,18] on transfer were not compared in the boundary areas, as the stress values obtained might be unrealistically high due to modeling. These stress values do not have to be taken into account in the analysis of the results [13].

It is advisable that the comparison of the results from the two computing models is to be performed by elements not by nodes. The elements cover the area where the strain gauges are located and stress value contains the information of the value of its constituent nodes. This in turn leads to a slight problem with the shell model when deploying strain gauges on the thin side of the profile. The analysis shows that it is practically impossible to make a comparison because of the way the shell model was built - with shell elements defined by the mid surface of the profile. Analysis of other problems related to modeling and FEM analysis with shell elements the authors have published in [19].

Tab.1. Stress values

	LC- 1			LC- 2		
	FEM	FEM	Test	FEM	FEM	Test
No	Shell	Solid		Shell	Solid	
1	118,6	105,7	91,4	129,8	132,1	105,3
2	86,2	89,0	80,0	98,3	160,8	149,7
4	48.6	148,4	67,9	52,5	12,4	103,5
6	127,1	139,8	283,1	70.5	51.9	67,9
8	52.1	72.6	67,5	101,9	93.8	55,9
9	64.7	53,6	77,8	133	108,7	107,5
11	138,7	249,2	205,2	107,3	126,5	151,3
12	50.2	58.3	55,1	107.1	89.5	107,3
16	***32.3***	***29.8***	***69,1***	***8.3***	***4.7***	***25,9***
19	29.9	16.5	17,1	15.1	13.8	13,5

The analysis of the results obtained shows relatively high correlation of the stress values obtained in the two models. In most cases, the stress values in the shells model are lower than those constructed with 3D solid. Table 1 represents the data of the stress values from FEM analysis calculated in those areas with the highest stress values, obtained from the test of the wagon in both horizontal load cases.

Fig. 6 and 7 show the stress values measured in the zone of gauge No. 2 for the shell and 3D solid models respectively. Fig. 8 shows the arrangement of strain gauges on the wagon structure.

All three types of results (theoretical of the two types of finite elements and physical measurements) show significant similarities. The analysis for all load cases shows a significant difference between the FEM values (Fig. 9 and 10) and the values obtained by strain gauge No. 16 (Fig. 11).

Possible reasons for the differences, according to the authors, are defects in the welding located underneath the strain gauges, structural changes in the material because of bending and welding during the manufacturing of the wagon and possible inaccurate reporting caused by strain gauges installed in the bent part of the piece.

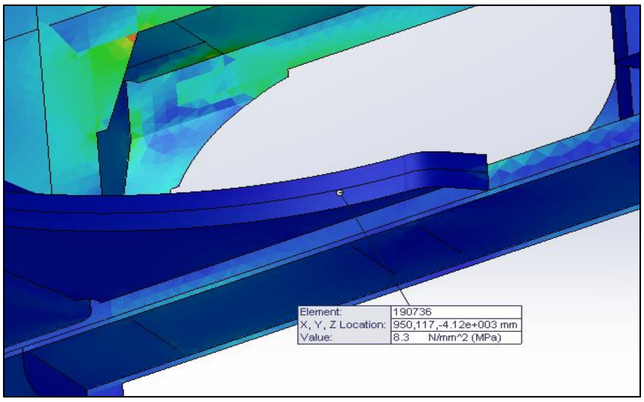

Fig.9. Stress value in shell model

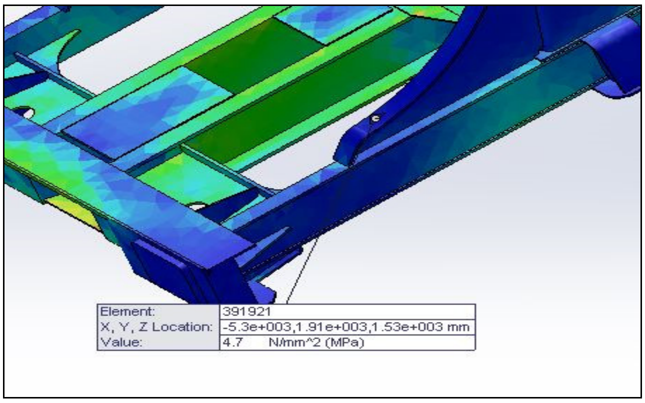

Fig.10. Stress value in solid model

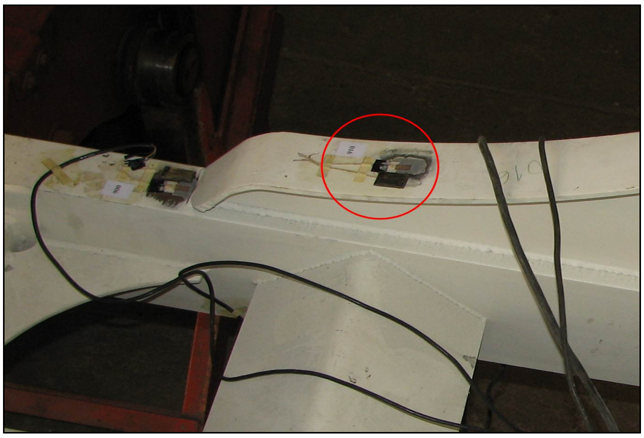

Fig.11. Strain gauge No.16

However, the results of FEM analysis correctly reflect the general nature and distribution of stresses in the wagon structure.

3. CONCLUSION

3.1. Computational models for strength analysis of the construction of a specialized wagon series Fals were developed. Strength calculations were computed and the results were analyzed. A comparative analysis of the results obtained by calculations and those obtained in actual tests of the wagon. The stress values were compared for a limited number of zones.

3.2. A high correlation between the results from the theoretical models and the actual tests were found. In both theoretical models identical distribution stress values in the wagon structures were observed. This allows the developed computational models to find application in the design of new constructions of the wagons of the same series as well as more effectively to optimize the parameters of the supporting construction of this type of wagon.

3.3. Certain shell model problems were identified in the strength analysis due to modeling, correct mesh generation, stress values etc. Detailed information about these and other issues can be found in [18].

3.4. Based on the analysis and conclusions, a simple answer cannot be given as to which model – Shell or 3D solid – should be used for FEM analysis of the wagon. It is a matter of experience and personal preference as to what finite elements – shell or 3D solid – should be used to build a computational model. The authors recommend the use of 3D solid finite elements, which show greater similarity with test data for large values of stresses. They have a number of advantages: a more precise and easy construction of the geometry; a clear visualization of the elements of the structure; fewer restrictions in modeling.

Construction of the hybrid model (if possible), composed of 2D and 3D finite elements for strength-deformation analysis of the wagon structure is appropriate and will reduce the modeling errors.

REFERENCES

[1] Slavchev S., V. Stoilov. *Comparative analysis of the results of the static strength calculations and strength tests of a wagon series Lagrs*. Sozopol, TRANS&MOTAUTO'08, 2008.

[2] Slavchev S., V. Stoilov. *Comparative analysis of the results of the static strength calculations and strength tests of a wagon series Zans*. Sozopol, BULTRANS-2012

[3] Stoilov V., A. Mayster. *Strength analysis of the body of wagon series Falns*, S., MOTAUTO'03, 2003.

[4] Stoilov V., A. Mayster. *Strength calculation of the body of freight wagon series Falns by Finite Element Method*. Plovdiv, MOTAUTO'04, 2004.

[5] Slavchev S., V. Stoilov. *Strength analysis of the body of wagon series Lagrs with finite elements method*. Sozopol, TRANS&MOTAUTO'08, 2008.

[6] Slavchev S., V. Stoilov., S. Purgic. *Static strength analysis of the body of a wagon, series Zans*. Sozopol, BULTRANS-2012, 2012.

[7] DIN EN 12663-2:2010, *Railway applications - Structural requirements of railway vehicle bodies - Part 2: Freight wagons*.2010

[8] TSI *Rolling stock- freight wagons*.Brussels, 2007.

[9] UIC leaflet 577 – *Wagon stresses*. 2005.

[10] ERRI B12/ RP17 8th Edition of April 1997

[11] Zenkiewicz O.C. *The Finite Element Method in Engineering Science*. McGraw-Hill, London, 1971.

[12] Segerlind, L. *Applied Finite Element Analysis*. New York, 1976.

[13] Tenchev R., *Operation manual for COSMOS/M*, Sofia, 1998.

[14] Stoychev G. *The Finite Element Method the strength and strain analysis*, Sofia, 2000.

[15] Report on Contract for testing the freight wagon *Fals*. Sofia. NRIT, 2010.

[16] COSMOS/M User's Guide, Revision 1.65, Santa Monica, California, USA, 1991

[17] Software COSMOSWorks – User manual. 2012

[18] Kurowski P., *Engineering Analysis With COSMOSWorks 2005*. Schroff Development Corporation, 2005

[19] Slavchev S., K. Georgieva, V. Stoilov.*Issues of wagon modeling with shell elements*. Niš, RAILCON'14, 2014

ABOUT THE PROCESS OF BRAKED WEIGHT LOSS IN THE FREIGHT TRAINS

Kiril VELKOV [1]
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Abstract *– This study is dedicated to the process of braked weight loss in freight trains, a phenomenon observed on freight trains with increased length. Our research is based on results received from test bench for train braking systems stationed in Laboratory of Department of railway engineering. Using these results the braking efforts were calculated for different track gradients and different initial braking velocities. The analysis of the calculated braking forces allows identifying the points at which the braked weight is getting lost.*

Keywords – Railway, braking systems, braked weight, long train.

1. INTRODUCTION

Many studies conducted by UIC have shown that with increasing length of freight trains braked in "P"(passenger) position a phenomenon of braked weight loss occurs. This process results in reduced braked weight percentage λ, increased braking distances s and lack of control over the braking system. In certain cases, this phenomenon can conduct deteriorations of safety operation of the trains.

UIC has conducted a lot of researches on this issue and in their leaflet UIC 544-1[1], chapter 9.2.2, the calculations of variations in braked weight according to the legth of the train are given. In the case of freight trains more than 500 m in length the actual braked weight required for operating purposes is calculated by multiplying braked weight of the train by a correction factor κ, which is a function of the actual length of the train:

$$B_{corrtr} = \kappa . B_Z \tag{1}$$

where:
B_Z - braked weight of the train [t],
B_{corrtr} - corrected braked weight of the train [t],
κ(Kappa) - correction factor in respect of train length.

The correction factor κ as specified in the length of the train is shown in figure 1 und shall be valid only up to the train length indicated in the figure.

The equivalent brake response time and resulting average deceleration of the train at a given brake equipment is dependent by the transmission time of signal along brake pipe and the brake pipe length.

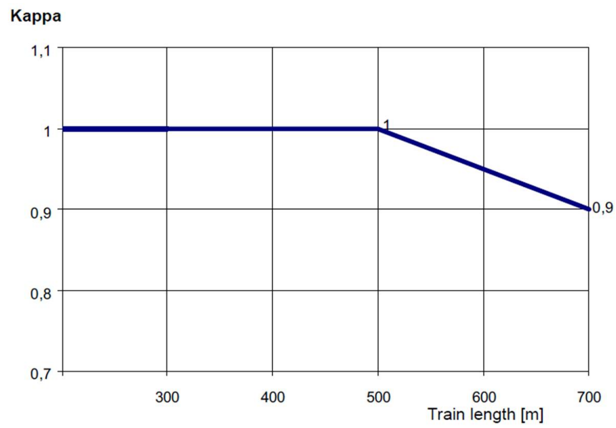

Fig.1. Correction factor κ (Kappa)

In order to specify the relationship between the length of the train and braked weight of long freight trains, experiments were conducted in Department of "Railway Engineering" of Technical University Sofia.

2. EMPIRICAL STUDY

2.1. Test bench for train braking systems

Test bench for train pneumatic braking systems [2] is built in the Laboratory of Department of Railway Engineering. At this test bench is possible to simulate processes in pneumatic braking systems for different train compositions. The general structure of test bench is shown in figure 2.

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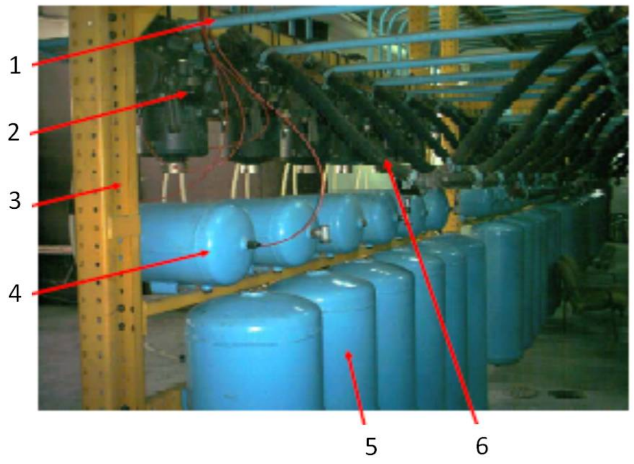

Fig.2. Test bench for train pneumatic braking systems

Test bench is built up of following main components as illustrated on figure 2: 1 is brake pipe, 2 is distributor valve, 3 is supporting structure, 4 is brake cylinder, 5 is auxiliary reservoir and 6 are couplers (brake hoses).

On this test bench is possible to simulate different train lengths by varying the number of wagons from one to 45. All wagons are fitted with distributor valves of type Knorr KE1cSL. Brake cylinders are replaced with reservoirs with air volumes equivalent to real ones. In order to conduct reliable tests, the brake pipe is made of steel pipe with prescribed parameters, while keeping the actual length of 15,5 m (average length of the four-axle freight wagon). All other components of the system used, are same as actually mounted on freight wagons. This is the so-called principle of nature reproduction of brake systems.

Driver's brake valve mounted on test bench is one of the most used driver's brake valves in European railway administrations and it is a type Knorr D2.

Test bench for train pneumatic braking systems meets all conditions according to UIC Code 540 [3].

For capturing experimental data received from test bench, specialized multichannel measurement system was developed [2]. It is built based on pressure transmitters (sensors) installed in different control points of the braking system. The signal produced by the transmitters enters the virtual instrument based on the programming environment *LabView 7.1.*

Virtual instrument [2] for measurement of pressure received from test bench has 8 analog channels, each including a transmitter for pressure measurement. It is based on a standard computer system with functional measurement module *PCI NI6221* and software *LabView 7.1*. The latter has 16 analog voltage inputs, of which eight are used for the eight channels.

Virtual instrument has a scanning frequency of 0,1 seconds, so that is possible to receive big amount of measured values in relatively short time, which also allows a big accuracy of later calculations.

The measured voltage values are being saved in a *Excel* file and then calculated in pressure unit *bar* or other unit suitable for different calculations.

2.2. Experiment methodology

The tests were conducted for both full (emergency) and ordinary (graduated) brake applications for "P"- (passenger) position. First experiment was conducted for only one wagon, and for each next experiment the number of wagons was gradualy increased. So we were able to variate the length of train composition from 1 wagon (15,5 m) up to 45 wagons (697,5 m). The pressure transmitters were placed first along brake pipe in first, eighth, fourteenth, twentysecond, thirtysecond and fourtyfifth wagon and the pressure in this points of brake pipe was measured. Then the transmitters were placed in brake cylinders of same wagons and pressure in brake cylinders was measured.

2.3. Experiment results

Due to limited volume of this paper only results for full brake application are shown and discused in this chapter. The experiment results for graduated brake application are analogue to results for full application.

Obtained values for pressure in brake pipe are shown in figure 3.

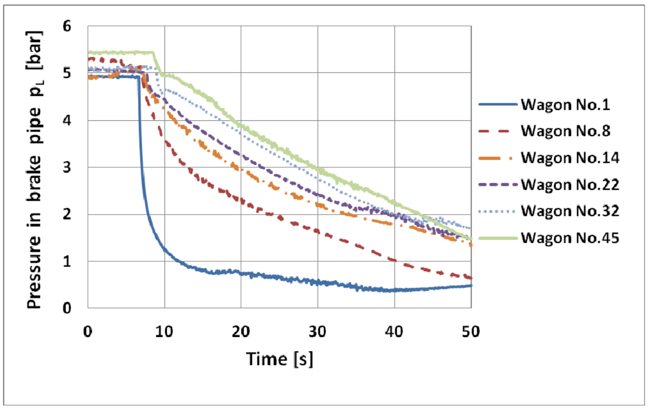

Fig.3. Pressure in brake pipe $p_L=f(t)$

From the figure can clearly be seen, that as expected, the pressure in brake pipe of first wagon drops much faster then in following wagons. Also the signal strength decreases with increasing length of the train. The drop of pressure in last wagon is significantly smoother than the drop in first wagon, i.e. it does not have the same run typical for full brake application. As a consequence, the pressure in brake cylinders rises respectively to pressure drop in brake pipe as shown in figure 4. Both pressure distributions depend directly on transmission speed of braking signal.

This transmission speed is determined when we divide length of brake pipe circuit that runs from driver's brake valve on locomotive upto air shut-off cock at the end of the train, with time that ticks from the moment when driver has put the handle of a driver's brake valve in braking position till the moment when air begins to enter into brake cylinder of the last vehicle circuit [4]. The required transmission speed is 250 m/s [3].

Time elapsed from entering of air in the first cylinder of the first vehicle circuit till entering of air in the last train cylinder is 2,6 s (figure 4) which represents transmission speed of 697,5 m/2,6 s = 268,2 m/s. Achieved transmission speed is more than minimal expected and required in [3] - 250 m/s.

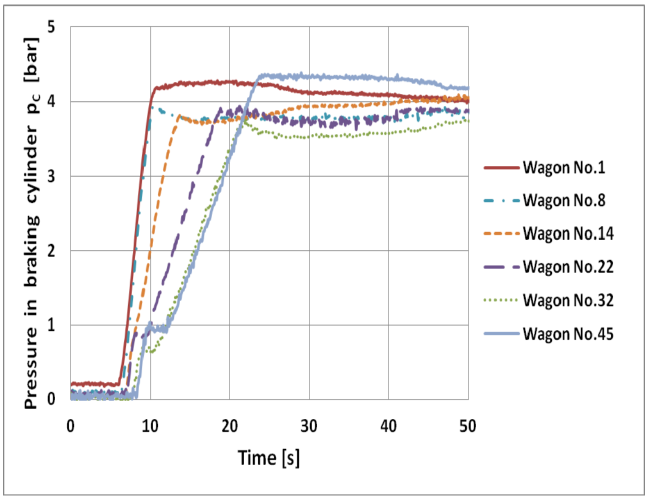

Fig.4. Pressure in braking cylinder p_C=f(t)

The moment when driver has put the handle of a driver's brake valve in braking position is also the moment when pressure in braking cylinder of first wagon begins to rise. This happens at time 5,8 seconds. The maximum pressure value in braking cylinder of first wagon is reached at time 10,6 seconds. Pressure in braking cylinder of last (45th) wagon begins to rise at time 8,4 seconds and maximum pressure value is reached at time 24 seconds.

In this way obtained values for pressure in brake cylinders were used to calculate brake weight according to [1]:

$$B = \frac{k.\Sigma F_{dyn}}{g} \tag{2}$$

where:

B – braked weight [t],

k – assessment factor for determining the braked weight [-],

ΣF_{dyn} – sum of all the brake block forces during the run [kN],

g – acceleration due to gravity [9,81 m/s^2].

The assessment factor for determining the braked weight k is given by a mathematical formula [1]:

$$k = a_0 + a_1.F_{dyn} + a_2.F_{dyn}^2 + a_3.F_{dyn}^3 \tag{3}$$

The constants a_0, a_1, a_2 and a_3 depend on type of brake blocks and their values are given in table in chapter 2.2.2.1 of [1].

Sum of all the brake block forces during the run ΣF_{dyn} is calculated as given in [1] using the formula:

$$\Sigma F_{dyn} = (F_t.i_G - i^*.F_R).\eta_{dyn} \tag{4}$$

where:

F_t – effective force at the brake cylinder [kN], calculated using measured values for pressure in brake cylinders and cylinder geometry,

i_G – total multiplication ratio for the brake rigging (in our case 11,2 for loaded wagon),

i^* – multiplication ratio after the central rigging (normally 8 for bogie wagons),

F_R – counteracting force of the brake rigging regulator (generally 2 kN),

η_{dyn} – mean efficiency of the rigging while the wagon is moving. With standard rigging the value is 0,83.

In the calculation, following requirements were met:

- maximum speed ≤ 120 km/h,
- maximum axle load 22,5 t,
- wheels are braked on both sides and have a minimal diameter of 920 to 1000 mm,
- brake blocks are made of P10 cast iron,
- rolling stock is 100 % braked, i.e. all brake blocks are active.

In this way is possible to receive values of brake weight for each wagon, in which the pressure was measured, dependent on time, as shown in figure 5. The distribution of braked weight is similar to distribution of pressure in brake cylinders.

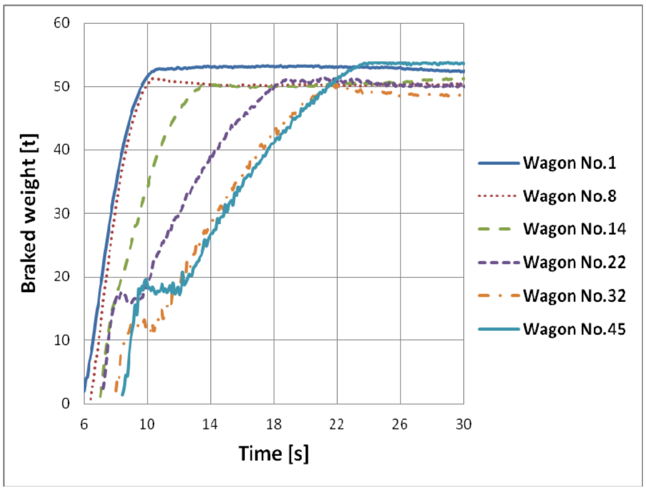

Fig.5. Calculated braked weight

The average value of braked weight is 51 t. By assuming the homogenity of train composition, for 45 wagons total braked weight will be 45 x 51 t = 2295 t.

Otherwise, by grouping the wagons and approximating the calculated values for braked weight of single wagons is possible to obtain the dependence of braked weight from the time for whole train composition built of 45 wagons as shown in figure 6.

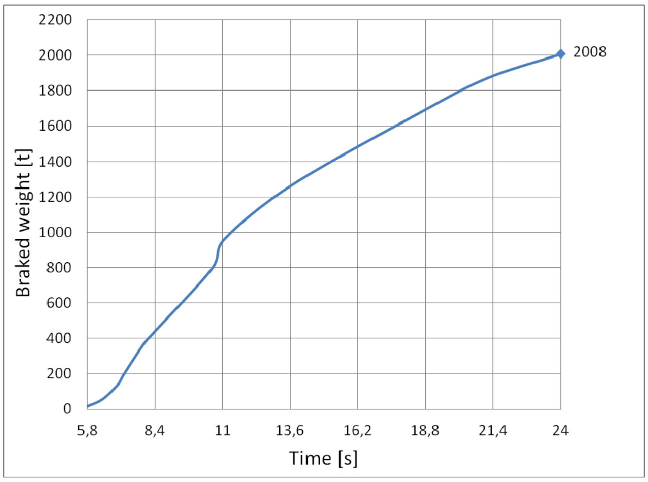

Fig.6. Total braked weight f(t)

As it can be seen from the figure 6, the total braked weight develops in total time of 18,2 seconds and has a value of 2008 t. This value is smaller than value for total braked weight of 2295 t as calculated above and this is the exactly how the braked weight is getting lost. For different moments of the braked weight development, is possible to determine number of wagons with fully developed braked weight and from there to determine the length of train at which this braked weight is fully developed. Finally, this value is divided with nominal average value of braked weight for each wagon (51 t) multiplied with number of wagons (train length respectively). In this way, the correction factor kappa can be calculated as shown in figure 7.

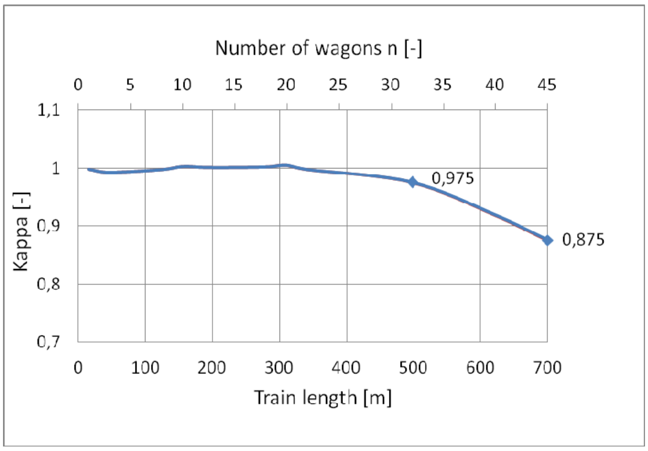

Fig.7. Calculated kappa

The run of the curve of correction factor κ in figure 7 is similar to those in figure 1, as given in [1].

The loss of braked weight according to our calculations begins at point 350 m, earlier than 500 m as shown in figure 1. The value of κ in points 500 m (0,975) and 700 m (0,875) is by 2,5% smaller than given in [1].

3. CONCLUSION

Dissipation of the brake signal leads to deceleration of the braking wave. The conducted bench tests confirmed that with increasing train length the development time of the brake weight delays, and therefore the braking distance also increases. The results obtained for correction factor κ are similar to those given in the UIC Code 544-1, but there are small differences in begin point of decrease and in final values.

REFERENCES

[1] UIC Code 544-1, *Brakes - Braking power*, 4th edition, 2004.

[2] Velkov, K. *Study of the braking processes in long freight trains in order to improve their braking efficiency*. PhD Thesis, Technical University of Sofia, Sofia, 2007 (in Bulgarian).

[3] UIC Code 540, *Brakes- Air Brakes for freight trains and passenger trains*, 4th edition, 2002.

[4] Vukšić, M. *Effect of Response Time on Stopping Distance*. FME Transactions, Vol. 32, No. 1, Belgrade, 2004.

ISSUES OF WAGON MODELING WITH SHELL ELEMENTS

Svetoslav SLAVCHEV [1]
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Abstract *– The report contains an analysis of the issues occurred using shell elements in the modeling of wagon series Falns. All load cases specified in the TSI, DIN EN 12663-2 and ERRI B 12/17 were analyzed. Sophisticated three-dimensional calculation models have been developed describing precisely the body geometry. The software products SolidWorks and CosmosWorks were used. This allows the development of the most suitable models with regard to visualization of the object geometry, input of the applied pressures and reactions and obtaining precise enough results concerning the distribution of deformations, displacements and stresses.*

Keywords – Railway wagon, strength analysis, FEM, shell elements.

1. INTRODUCTION

Commissioning of any new wagon design is a complex and lengthy process, spanning a number of stages required. One of them is the strength analysis of the supporting structure. Theoretically, it can be done using any internationally approved methods, but in practice the authorizing bodies are approving the results carried out only by the finite element method. Moreover - most of them have preferences, which software, type of finite element, their minimum and maximum size, their number, etc., has to be used. In case of deviations from the accepted stereotypes, serious justification for chosen solution has to be undertaken and a big amount of theoretical and practical evidence has to be presented.

One of these stereotypes refers to the type of finite element used. Traditionally, in the construction of computational models for strength-deformation analysis, most teams uses elements of type Shell. Taking into account: the current state of software for FEM-analysis [1,2,3] and hardware, load cases of wagon structure; structural features of the vehicles; way of distribution of internal forces and stresses; experience in FEM-analysis of a big number of ordinary and specialized wagons - we consider and prove [4,5,6,7,8,9] that the use of both Shell and Solid 3D elements is equivalent. Crucial for the accuracy of the results for the studied variables are the theoretical training of researchers, good understanding of the structure, analysis of boundary conditions and experience in developing computational models.

In light of the above, this paper provides an analysis of some of the issues in modeling wagons with Shell elements and gives concrete solutions to overcome them.

2. ESSENCE OF MODELING WITH SHELL ELEMENTS

The shell has a body delimited by two surfaces, the distance between which (thickness t) is less than the other two dimensions. Geometrically, the shape of its middle surface and thickness describes it [1,10,11,12]. The modeling was performed by the separation of the shell into small flat elements. It is well known that the accuracy of solution increases with increase in the number of components or the number of nodes. When establishing the models built up of Shell elements with arbitrary spatial configuration, most commonly finite elements with a triangular or quadrangular shape are used.

Wagon structure is built up of many hot-rolled, cold formed and welded profiles and plating - from sheet steel. Consequently, much of the details correspond to the requirements of the shell and can be modeled as such.

3. ISSUES OF MODELING

In the preliminary analysis of the design documentation and during work on an analytical model a number of problems were found, the most important of which are summarized below:

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3.1. Connecting parts with different thickness

In accordance with the theory, the geometric positioning of the shells is in the coordinates of the middle surface. For complete definitions, also parameter thickness is set. The issue is indicated (appears) at butt joint of two or more parts with different thickness and difference in the mid level of the surfaces (Fig. 1) - a common design solution in the manufacturing of wagon structures.

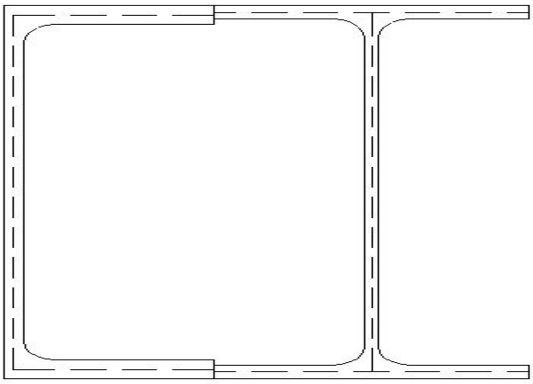

Fig.1. Connection between profiles

Therefore, in the modeling of the shells on their mid surfaces, the two pieces will not have contact with each other, wherein the continuity of the supporting structure getting lost (Fig. 2).

Option to solve this problem is introducing of additional connections (Fig. 2) with elements that do not exist. The main disadvantages of this solution are: imaginary additional elements, i.e. non-existent; they are usually small, making it difficult to build a finite element mesh and a prerequisite for registration of areas with large stress concentrators in the calculation.

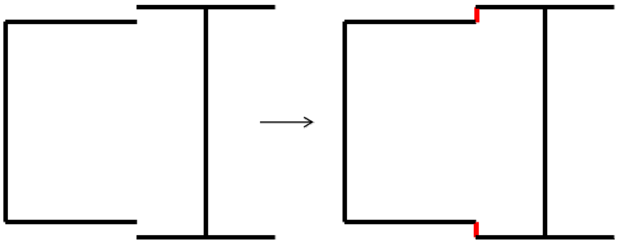

Fig.2. Connection between mid surfaces

This can lead to unrealistic calculated values for displacements and stresses in this zone and in the model as whole.

Based on theoretical and extensive practical experience, the authors recommend two parts to be joined in the middle surface of the more massive and longer component. In the case that none of them meet the two conditions, the priority is given to the length, and i.e. connection is along the mean surface of the longer part.

3.2. Geometric modeling of overlapping profiles or sheet steel

Cases of overlapping sections or steel plates are visualized in fig.3.

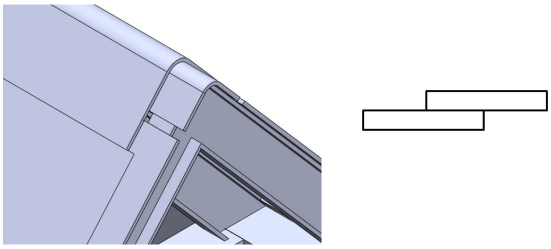

Fig.3. Overlapping profiles

The essence of the issue is analogous to that of 3.1, i.e. the details will not be connected with each other, wherein the continuity of the supporting structure is getting lost.

Introduction of additional connections (Fig. 4) is not only impractical (for the reasons mentioned in 3.1), but it is impossible because you have to use the entire area of overlap.

In this case, it is recommended in modeling to use the mean surface of the more massive and longer component and the thickness of the overlap should be equal to the sum of the thicknesses of the two profiles or sheets (Fig. 5).

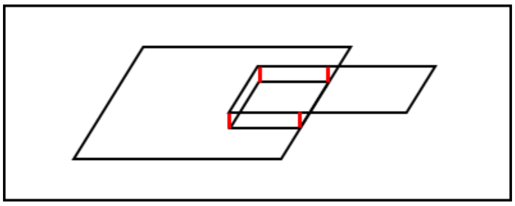

Fig.4. Connection between surfaces

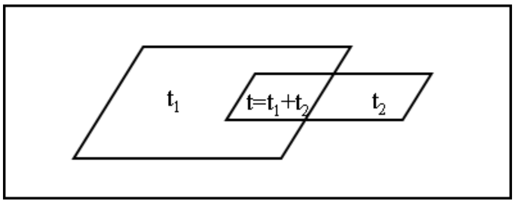

Fig.5. Connection between surfaces

3.3. Modeling of hot-rolled profiles

Hot rolled profiles (Fig. 6) are characterized by variable thicknesses of the layers and the presence of various curvatures. In this respect, the precise modeling with shell finite elements is practically impossible.

This issue can be solved if standard profile is replaced with an equivalent one, built of rectangular zones (Fig. 6), which cross section has the same geometric characteristics (height, width, area, static and moments of inertia, etc..) as the original.

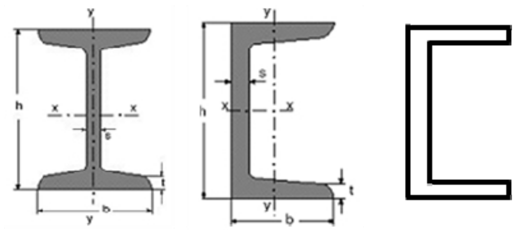

Fig.6. Profile and equivalent profile

3.4. Modeling of parts and details of great thickness

Typical in this respect for each wagon structure are absorbing sets of buffers (Fig. 7), the supports of the draw gear and automatic couplings and other units involved in loading.

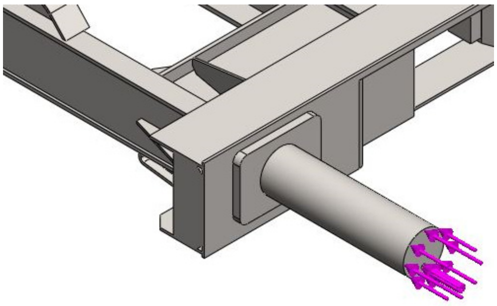

*Fig.7. Model of f*orce *applied* to the buffer

Similar parts do not meet the theoretical formulation for finite element type Shell.

Solutions to this issue are two:

- Construction of a hybrid model composed of 2D and 3D finite elements;

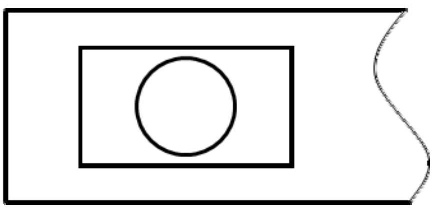

Fig.8. Regions with different thicknesses

- Presentation of the part with its contact patches to the corresponding structural element and load application in so defined area (Fig. 8).

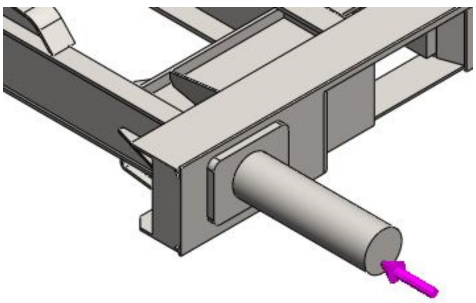

Fig.9. Force applied 50 mm below the buffer axis

The first solution gives results that are more accurate. Additionally it should be noted that it is possible to assess the structure also for obligatory load case, known in the special literature [13,14,15,16] under the name "eccentric compression force of 750 kN applied 50 mm below the buffer axis" (fig. 9) .

The main disadvantage is that some software products do not allow the use of hybrid models or do not give satisfactory results when applied.

The second solution is simpler to use and gives satisfactory results in the calculations. The "eccentric pressure" is modeled by reducing and shifting the area of force application. The disadvantages are: it is necessary to properly define the area of application of force in load case "eccentric pressure" and in the same area local unrealistic stress values are received that should not be considered in the assessment of the wagon structure.

3.5. Defining the thickness of the shell in the areas of overlap of the parts

When creating a spatial calculating wagon model using finite element of type Shell was found that during overlapping of areas of the parts (see Fig. 3), the thicknesses of the shells are not accumulated automatically by the software. Two independent areas are being defined, which causes the continuity loss of the supporting structure. This fact was established when visualizing the mesh. It turned out, that for each of the overlapping parts independently from each other two meshes, built up from different elements, are being formed, superimposed one over another and without connection between them (fig. 10).

The existence of this problem requires that each overlapping area of two parts has to be detached as a separate surface and later to set its thickness corresponding to the sum of the thicknesses of the overlapping parts (fig. 11).

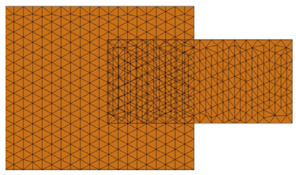

Fig.10. Failure of mesh

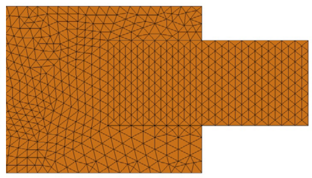

Fig.11.Correct mesh

3.6. Issue in surfaces intersection

At the intersection of two surfaces calculation module does not perceive them as connected and similar to the problem of 3.5., sees them as separate structural parts, and i.e. in the intersection is no connection between the individual elements of the two surfaces (Figure 12).

To solve this problem it is appropriate to define manually line penetration between two parts. In this way, connections between intersecting surfaces are being forcibly made (Fig. 13). This operation should be performed for all such areas, which increases the model built-up time and may result in lot of subjective errors.

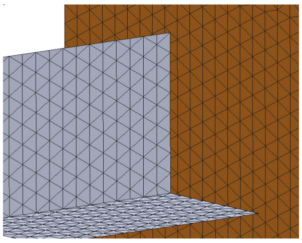

Fig.12. Failure of mesh

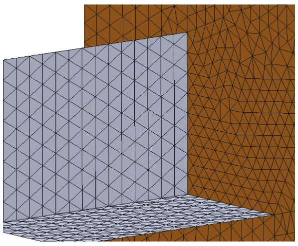

Fig.13. Correct mesh

3.7. Issue of model lines length limitation

This problem is a specific for some software products for strength-deformation analysis including *CosmosWorks*. The reason for this stems from the need to build an optimal mesh of finite elements with approximately same and small as possible size. It was found that in the software the limit is set, that the smallest element dimension model must be equal to or greater than 1/100 of the largest dimension. The modeling of objects with large dimensions (such as wagon structure) this limitation cannot be met. There is need to identify the minimum dimension and based on this to comply all the other dimensions. The identification process is done periodically during modeling and, if necessary, the dimensions of long lines can be adjusted (represented as composition of several shorter lines).

Fig. 14 shows the final version of the calculating model of wagon series Fals.

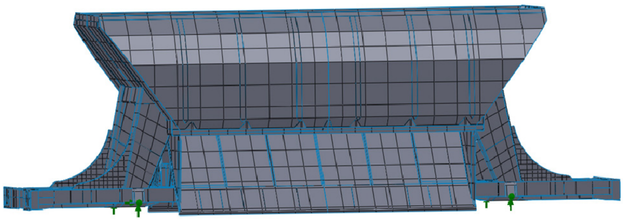

Fig.14. CAD geometry

3.8. Orientation of the shell surfaces

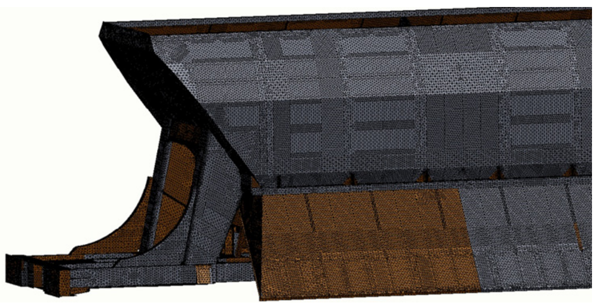

Fig.15. FEM geometry

In spatial structures, built-up by inclined structural parts and by the use of options for symmetry the geometry and automatically form a mesh of finite elements, phenomenon of "variation of the orientation of the surface" is commonly observed. It is well known that the shell is characterized by an upper, lower and middle surface. When changing the orientation, some of the finite elements have properly oriented upper surfaces, and others - wrongly, in the opposite direction.

The phenomenon is illustrated in fig. 15, where improperly oriented elements are colored brown. This disadvantage should be controlled, because it can lead to serious errors, as in applying of load cases as on the results obtained.

The adjustment of the model is carried out manually, which leads to a further loss of time.

4. CONCLUSION

In this paper, eight serious issues in the development of computational models using the finite element type Shell were analyzed. Disregarding those issues leads to serious errors in the strength-deformation analysis of wagon structures and other objects.

REFERENCES

[1] Tenchev R., *Operation manual for COSMOS/M*, Sofia, 1998.

[2] COSMOS/M User's Guide, Revision 1.65, Santa Monica, California, USA, 1991

[3] Kurowski P., *Engineering Analysis With COSMOSWorks 2005*. Schroff Development Corporation, 2005

[4] Stoilov V., A. Mayster. *Strength analysis of the body of wagon series Falns*, S., MOTAUTO'03, 2003.

[5] Stoilov V., A. Mayster. *Strength calculation of the body of freight wagon series Falns by Finite Element Method*. Plovdiv, MOTAUTO'04, 2004.

[6] Stoilov V., Sv. Slavchev. *Strength analysis of the body of special flat wagon series Lagrs*. Sozopol, TRANS&MOTAUTO'08, 2008.

[7] Slavchev S., V. Stoilov. *Strength analysis of the body of wagon series Lagrs with finite elements method*. Sozopol, TRANS&MOTAUTO'08, 2008.

[8] Slavchev S., V. Stoilov, Valcheva Ts. *Application of the methodology for assessment of stress using numerical method*. Sozopol,BULTRANS-2011.

[9] Slavchev S., V. Stoilov., S. Purgic. *Static strength analysis of the body of a wagon, series Zans*. Sozopol, BULTRANS-2012, 2012.

[10] Zenkiewicz O.C. *The Finite Element Method in Engineering Science*. McGraw-Hill, London, 1971.

[11] Segerlind, L. *Applied Finite Element Analysis*. New York, 1976.

[12] Stoychev G. *The Finite Element Method the strength and strain analysis*, Sofia, 2000.

[13] DIN EN 12663-2:2010, *Railway applications - Structural requirements of railway vehicle bodies - Part 2: Freight wagons*.2010

[14] ERRI B12/ RP17 8th Edition of April 1997

[15] TSI *Rolling stock- freight wagons*. Brussels, 2007.

[16] UIC leaflet 577 – *Wagon stresses*. 2005.

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FRICTION CHARACTERISTICS OF THE FRICTION PAIRS IN DISC BRAKES

Vasko NIKOLOV [1]

Abstract: *The results of tests of the friction characteristics of the friction pairs of the disc brake systems in railway rolling stock are presented. A method for performing the tests is described. The change of the friction coefficient in friction pairs is studied. An evaluation of the impact of the material of pads and thermal condition of the discs is performed. The brake pads wear is analyzed.*

Keywords: disc brake system, brake pads, friction, friction pairs.

1. INTRODUCTION

Disc brake systems of coaches refer to high-performance brakes. They have several advantages over the widely used rail brakes and are particularly suitable for high-speed movement of railway vehicles. The article studied the friction characteristics of the friction pairs in disc brake systems and the factors on which they depend.

2. METHODS AND TEST MODES

Friction characteristics of the friction pair in disc brakes are tested on an inertia bench having a moment of inertia of the swing mass 142 Nm/s, which corresponds to the load on the wheel at 60 kN and wheel diameter of 950 mm. On the bench were tested discs and pads used in the operation with area of friction of the discs 0,2 m^2, nominal area of the brake pad 0,0425 m^2, i.e. by a factor of 0,213 to mutually overlap.

Tests of disc brakes have been performed in both of braking to stop and prolonged braking modes. When is performed braking to stop traction motors on the bench is off when reaching a certain speed and by pressing the brake pad to the disc shaft is braked to stop. Braking to stop are performed by speeds of 30, 70, 100, 120, 140, 160 and 180 km/h (in three attempts for each speed).

In continuous braking (steady friction), imitating the operation of the brake on long downhill, traction engine is switched off, but the set speed (60 km/h) and brake power (26 kW) are regulated by the compressive force of the pad on the brake disc and power consumed by the traction motor. In this mode, the time for performing the test is 20 minutes. After mode of steady friction speed has been increased to 140 km/h, then emergency braking has been performed.

In the process of braking to stop and prolonged braking modes measurements of torque, braking distance, surface temperature of the disc and the pads are performed. The temperature of the friction surface of the disc before any braking is 35-40°C.

During the operation on the surface of the friction discs and brake pads, moisture falls which reduces braking efficiency. Therefore, experiments were performed to evaluate the influence of humidity on the coefficient of friction of the pads. On the surface of the friction discs moisture is fed in an amount of about 4-6 ml/s through four nozzles. For the bench test are used brake discs made of cast iron, labeled A, high strength iron labeled B and alloy gray cast iron, labeled C. Coupled with these discs are tested and treated pads. The pads are made of a different material, provisionally designated with the numbers 1 to 9.

3. INVESTIGATION OF THE COEFFICIENT OF FRICTION

The friction coefficient of friction pairs with disc brakes is:

$$\varphi = \frac{M_T}{2KR_T} \qquad (1)$$

where:
M_T – braking moment, Nm;
K – compressive force, N;
R_T – radius of load application to the pad.

Tests have shown that when the sliding speed increases, the friction coefficient of the friction materials decreases, as a rule, and the temperature in the contact point increases too (Table 1). It is typical of the friction material in contact with a friction disc of high strength cast iron and an alloy cast iron.

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Table 1

Material of the pads	Coeffitient of fricion at pressure of 0,38 MPa and initial speed of braking, km/h					Maximal temperatures in °C on the surface of friction of the disc at initial speed of braking, km/h			Maximal temperatures in °C on the body of the disc at initial speed of braking, km/h			Wear of the pads, mm^3/kWh
	30	**70**	**100**	**120**	**160**	**70**	**120**	**160**	**70**	**120**	**160**	
1	0,39	0,34	0,34	0,35	0,33	300	400	450	70	150	270	1500
2	0,32	0,31	0,29	0,28	0,31	340	500	600	50	120	180	3825
3	0,37	0,32	0,29	0,29	0,34	350	600	750	50,	110	210	4275
4	0,32	0,32	0,31	0,29	0,31	300	600	700	60	110	220	3375
5	0,24	0,23	0,35	0,33	0,32	400	480	560	40	120	180	4575
6	0,34	0,38	0,37	0,38	0,35	200	300	520	50	180	280	1125
7	0,55	0,52	0,44	0,37	0,35	250	400	450	80	120	220	1050
8	0,49	0,47	0,46	0,39	0,37	250	350	470	70	110	250	900
9	0,43	0,40	0,40	0,37	0,34	320	450	520	70	120	250	2775

Comparing the friction characteristics of the various friction pairs indicates that pads of material 7 have the greatest frictional heat resistance. This determines the most stable coefficients of friction and does not damage the friction surface of the disc. Therefore, further development of tests of the discs are performed with and pads of material 7 compared with those ones of material 1.

Coefficient of friction pairs brake disc – pads 7 is amended in the process of initial braking speed from 100 km/h from 0,4 to 0,47, speed from 160 km/h from 0,38 to 0,44. In pair with disc B the friction coefficients vary respectively from 0,41 to 0,48 and from 0,35 to 0,42. The coefficients of friction of the disc B with pads 1 during the first braking from 100 and 160 km/h are respectively in the range from 0,34 to 0,4 and from 0,32 to 0,36. By increasing the speed to 180 km/h the friction coefficients reduced to 0,28.

Major impact on the value of the coefficient of friction has the temperature of the friction surface at the beginning of the braking. In experiments on friction pairs disc C – pad 7 depending on the temperature in the contact friction coefficient varies from 0,18 to 0,4 (Table 2).

Table 2

Temperature in the contact point °C		Coefficient of friction
In the beginning of braking	**In the end of braking**	
20	65	0,33-0,36
45	115	0,30-0,40
175	260	0,24-0,34
310	380	0,18-0,19

In continuous braking at a constant speed of 60 km/h and braking power 26 kW temperature within the body of the disc rises exponentially up to 360°C depending on the time of braking. With increasing temperature, the friction coefficient decreased from 0,51 to 0,28. The most rapid reduction in the coefficient of friction of 0,51 to 0,32 was observed in the temperature range 260-320°C. Upon further temperature increase, the friction coefficient decreased to 0,28.

The examination of the frictional characteristics of the materials 1 and 2 in a friction disc made of cast iron A shows that the material 2 has a stable coefficient of friction. The coefficient of friction of the brake pads 2 is changed from 0,28 to 0,34 with an increase of the speed of 120 to 160 km/h and remained practically constant during the entire process of braking. The friction coefficient of material 1 in similar conditions varied from 0,35 to 0,32 and increases during braking respectively 0,43 and 0,35.

Assessing the impact of humidity on the friction coefficient is performed in pairs friction disc A – pads 6 and 2. Pads 6 are solid, and 2 – sectional. Attempts at dry friction were performed at speed 120 km/h and in the presence of moisture in the frictional contact of 90 km/h and a pressure of 0,3, 0,4, 0,6 MPa.

The analysis of the test results shows that, the friction under dry disc with an increase in pressure on the brake pad, friction coefficients reduced and in the presence of moisture at the contact point these ones increased. It should be noted that a substantial reduction of the friction coefficient with presence of moisture at the contact point was observed in the pads of molded material, and in a pair of sectional pads friction coefficients are modified slightly.

4. ASSESSMENT OF THE INFLUENCE OF THE MATERIAL OF THE PADS ON THERMAL CONDITION OF THE DISCS

These experiments were performed with two discs.

Pads are made from materials 1, 2 and 7, characterized by polymeric joints.

The temperatures occurring in the friction surface and the volume of the disc at friction with the pads 7 are of a material several times lower than in the pads 1. The temperature of the friction surface is increased to 600°C during braking with pads 2, as the body temperature did not exceed 200°C. This proves that the braking with pads 2 the temperature gradient is higher than in the pairs of materials 1 and 7. Explanation is that the material 2 with combined joints is harder than materials 1 and 7 with rubber joints and is unable to deform evenly under load. This leads to a reduction of the area of real contact, and the number of spots in the contact area, and hence the increase in the specific pressure and temperature in the contact point. Heat accumulated in the process of friction is transmitted to the disc mainly by the contact areas, thereby increasing the difference in temperature on the surface of the friction disc and in the its volume. On the friction surface of the disc after braking with pads 2 are observed dark spots, where as a rule they develop thermal cracks.

Studies of temperature modes of the brake discs C and B in braking to stop with pads 7 from different initial speeds indicate that the temperatures of the friction surface of disc C are several times lower than those of discs B. The heating in the body of the brake disc B proceeds more slowly than in disc C in the same brake mode (pressure 0,4 MPa, initial speed of 160 km/h), and the final temperature in a depth of 8 and 16 mm is 15% greater than disc C. The difference between the heating temperature of disc B at a depth of 8 and 16 mm is 50°C, and at disc B – 30°C. More rapid and uniform heating of brake disc C shows its better thermal conductivity, which improves the cooling of the friction unit in the braking process, and reduces the temperature gradient and thermal stress. The maximum temperature on the friction surface of both discs, C and B is the same, but the time for action by the friction surface of the disc B is 40% greater than in disks C.

5. BRAKE PADS WEAR

Comparative evaluation of the durability of the brake pads is performed on the size of the wear for ten braking cycles from initial speed of 160 km/h at a pressure of 0,4 MPa. Pad thickness was measured before and after braking at ten fixed points. Wear (in mm^3) is calculated as the average of ten measurements per unit braking power.

Analysis of wear of the pads (Table 1) in friction on disc C shows that the best wear resistance have the pads with rubber joints. Tests to wear a pair of drive C show that the wear resistance of the pads working with these discs is increased 8 – 8,5 times. Wear of pads 7 working with discs B is 1800 mm^3/kWh, and disc C – 220 mm^3/kWh. Wear of pads 1 is 1,5 times faster both in discs B and C. Wear of these pads are 2600 and 1800 mm^3/kWh.

Analysis of those data shows that the wear of brake pads 7 and 1 is 8 times lower in interface with discs C than with B ones. The wear resistance of the material of brake pad 7 is 1,5 times higher than that in pads 1.

6. CONCLUSION

The frictional characteristics of the friction pairs at the disc brakes depend on the temperature at the surface of friction during braking, and since the heat transfer characteristics of the friction materials. The greatest stability of the friction characteristics in both dry friction and friction in humid environments have sectional brake pads. The best friction properties and high wear resistance holds material 7.

Perspective friction pair for disc brakes in Railway rolling stock is brake disc C and brake pad 7.

REFERENCES

[1] Тонев, С., Основи на теорията, изчисленията и експлоатацията на подвижния железопътен състав, ВВТУ „Тодор Каблешков“, С., 1985.

[2] Гнездилов, Г. В., В. Ф. Титаренко, Исследование фрикцонных характеристик пар трения дисковых тормозов, ЦНИИ МПС, М. 1974.

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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ENERGY ANALYSIS OF FRACTIONAL ORDER OSCILLATIONS OF A COMPOSITION OF THE TRAIN BY A CHAIN MODEL OF FRACTIONAL ORDER PROPERTIES

Katica R. (Stevanović) HEDRIH [1]

Abstract *– A fractional order model of train composition oscillations is presented. A chain fractional order model as an abstraction of the real railway train composition oscillations in longitudinal direction is taken. By standard light fractional order, elements coupling structures between wagons of train, are presented. Fractional order differential operators express constitutive relation for force-elongation of each standard light fractional order element. New function of fractional order energy dissipation of the standard light fractional order element is introduced. Coupled ordinary fractional order differential equations of a fractional order model of the train composition oscillations, are defined. These fractional order differential equations for both cases, for the case of a train composition moving by constant or changeable velocities are considered. New method for determination of characteristic numbers as well as of eigen main fractional order modes of a chain fractional order system oscillation with finite number of degrees of freedom is presented. Analytical expressions of fractional order vibrations – real oscillatory displacements of wagons and locomotive of train composition model with fractional order properties are determined. Energy analysis of fractional order dynamics of train composition, is presented. On an example of train composition fractional order model with 11 wagons and a locomotive, an important task for next numerical experiment as well as next engineering applications, is defined.*

Keywords – Fractional order oscillations, fractional order energy dissipation, train composition fractional order model.

1. INTRODUCTION

In numerous scientific and professional literatures, simple and complex light rheological elements with elastic, visco-elatic, elasto-viscosic and plastic properties are known [1-4]. All these light simple elements with only one property are component elements in a complex, hybrid element with complex material properties. A hybrid element is built by parallel, or series or by different hybrid combinations of these simple, mass neglected elements [1-11]. Then, it is known, the numerous rheological elements named by some scientists [1]. A new property of material, no neglecting mass and mass inertia properties are introduced by new schematic presented element in Figure 1.a by a rolling element taking into account translator and rotator inertia properties [8,11]. In parallel coupling of four simple elements, presented in Figure 1: (a) rolling inertia element, (b) linear elastic element, (c) linear dissipative (damping) element and (d) fractional order dissipative element and (e) new hybrid fractional order element is obtained.

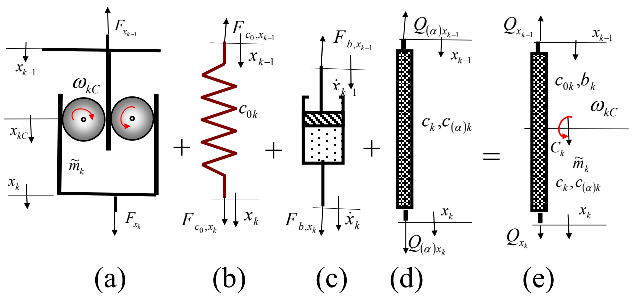

Figure 1. (e) *Hybrid fractional order viscoelastic element with translator and rotation inertia properties consisting of parallel coupled standard:* (a) *rolling inertia element*, (b) *linear elastic element*, (c) *linear dissipative element (damper) and* (d) *fractional order dissipative element*

In the basic of these elements, there are fictive models of the rods with corresponding material

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properties and axially stressed by pair of the opposite direction forces, with equal intensity for light, and different if mass inertia properties is taken into account. In addition, relations between intensity of the external active loading forces and deformation (extension or compressing) of the rods, we called constitutive stress strain relations.

Kinetic energy for a rolling element, presented in Figure 1.(a), with mass $\widetilde{m}_k$ with rotator and translator inertia properties is [11]:

$$\mathbf{E}_{K,k}^{rolling-element}=\frac{1}{8}\widetilde{m}_k\left\langle\left(\dot{x}_k+\dot{x}_{k-1}\right)^2+\frac{i_{C_k}^2}{R^2}\left(\dot{x}_k-\dot{x}_{k-1}\right)^2\right\rangle \quad (1)$$

where $\mathbf{J}_{\mathbf{C}_k}$, $i_{C_k}^2=\frac{\mathbf{J}_{\mathbf{C}_k}}{\widetilde{m}_k}$ and $\kappa_k=\frac{i_{C_k}^2}{R^2}$, respectively are axial mass inertia moment of the rolling elements, square of radius of a axial mass inertia moment and radius of disk or sphere. Coefficient for disk and sphere is not dependent of radius and is no changeable when radius increase or decrease.

Standard light fractional order element (See Figure 1. (d)) of negligible mass is in the form of axially stressed rod without bending, for which the constitutive stress-strain relation for the restitution force as the function of element elongation is given by expression containing a term in the form of fractional order derivative. This constitutive relation is in the form (see References [2-11]):

$$P_k(t)=-\left\{c_{0k}\left(x_k-x_{k-1}\right)+c_{(\alpha)k}\mathsf{D}_t^{\alpha}\left[x_k-x_{k-1}\right]\right\} \quad (2)$$

where $\mathsf{D}_t^{\alpha}[\bullet]$ is fractional order operator of the α^{th} derivative with respect to time in the following form (see References [2-12]):

$$\mathsf{D}_t^{\alpha}[x(t)]=\frac{d^{\alpha}x(t)}{dt^{\alpha}}=x^{(\alpha)}(t)=\frac{1}{\Gamma(1-\alpha)}\frac{d}{dt}\int_0^t\frac{x(\tau)}{(t-\tau)^{\alpha}}d\tau \quad (3)$$

where $c_{0k}, c_{(\alpha)k}$ are rigidity coefficients – momentary and prolonged one, is a rational number between 0 and 1, $0<\alpha<1$, determined experimentally.

In this paper we present a new element fractional order visco-elastic with translator and rotational inertia properties for describing a model of coupling hybrid elements between wagons (coaches) in a railway train composition, presented in Figure 2, fractional order chain with $n+1$ degrees of mobility and n degrees of fractional order oscillations).

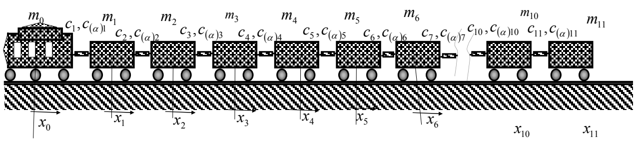

Figure 2. Abstraction of a railway composition of train with eleventh wagons and locomotive: A fractional order system in the form of fractional order chain with twelve degrees of freedom motion and eleventh degrees of freedom oscillations

Model of this hybrid element consists by a elastic spring, a damper, a fractional order dissipation element and a rolling element coupled in parallel order, and presented in Figure 1.(a-d).

Generalized forces of interactions between this hybrid fractional order element and two wagons, see Figure 2, are:

$$Q_{x_k}^{hybrid\ elem}=-\left\langle\frac{d}{dt}\frac{\partial\mathbf{E}_{K,k}^{hybrid\ elem}}{\partial\left(\dot{x}_k(t)\right)}-\frac{\partial\mathbf{E}_{K,k}^{hybrid\ elem}}{\partial x_k(t)}\right\rangle- \quad (4)$$
$$-\frac{\partial\mathbf{E}_{p,k}^{hybrid\ elem}}{\partial x_k(t)}-\frac{\partial\Phi_{linear,k}^{hybrid\ elem}}{\partial\dot{x}_k(t)}-\frac{\partial\Phi_{0\le\alpha\le1,k}^{hybrid\ elem}}{\partial\left(\mathsf{D}_t^{\alpha}\left[x_k(t)\right]\right)}=Q_{x_k(t)}^{hybrid\ elem}$$

$$Q_{x_{k-1}}^{hybrid\ elem}=-\left\langle\frac{d}{dt}\frac{\partial\mathbf{E}_{K,k}^{hybrid\ elem}}{\partial\left(\dot{x}_{k-1}\right)}-\frac{\partial\mathbf{E}_{K,k}^{hybrid\ elem}}{\partial x_{k-1}(t)}\right\rangle- \quad (5)$$
$$-\frac{\partial\mathbf{E}_{p,k}^{hybrid\ elem}}{\partial x_{k-1}(t)}-\frac{\partial\Phi_{linear,k}^{hybrid\ elem}}{\partial\dot{x}_{k-1}(t)}-\frac{\partial\Phi_{0\le\alpha\le1,k}^{hybrid\ elem}}{\partial\left(\mathsf{D}_t^{\alpha}\left[x_{k-1}(t)\right]\right)}=Q_{x_{k-1}(t)}^{hybrid\ elem}$$

$$k=1,2,3,,....,n$$

expressed by kinetic energy $\mathbf{E}_{K;k}^{hybrid\ elem}$ of component rolling element, porential energu $\mathbf{E}_{p,k}^{hybrid\ elem}$ of component linear spring element, Railigh function $\Phi_{linear,k}^{hybrid\ elem}$ of linear dissipation of energy in damper and generalized function of component fractional order energy dissipation $\Phi_{0\le\alpha\le1,k}^{hybrid\ elem}$.

Component fractional order energy dissipation is expressed by generalized function $\Phi_{0\le\alpha\le1,k}^{hybrid\ elem}$ is defined in the form [5]:

$$\Phi_{0\le\alpha\le1,k}^{hybrid\ elem}=\frac{1}{2}c_{(\alpha)k}\left\langle\mathsf{D}_t^{\alpha}\left[x_k(t)-x_{k-1}(t)\right]\right\rangle^2 \quad (6)$$

2. ENERGY EXPRESSIONS OF A RAILWAY TRAIN COMPOSITION AS A DISCRETE FRACTIONAL ORDER CHAIN SYSTEM

Taking into account generalized coordinates in a matrix column $\{x\}$ with $n+1$ elements – a known rheonomic coordinate $x_0=f(t)$, correspond to the locomotive programmed motion, and n unknown generalized coordinates x_k, $k=1,2,3,....,n$, correspond to the wagons relative motion in relation to the locomotive stationary motion as reference. This system is determined by corresponding mass inertia coefficients $a_{kj}, k,j=0,1,2,3,....,n$, $a_{kj}=a_{jk}=0$, $j\neq k$, $a_{kk}=m_k$, coefficients of linear elastic properties of springs $c_{kj}, k,j=0,1,2,3,....,n$, and coefficients of fractional order system properties $c_{\alpha,kj}$, $k,j=0,1,2,3,....,n$, and $0<\alpha\le1$, and damping coefficients $b_{kj}, k,j=0,1,2,3,....,n$. Taking into account that for $\alpha = 1$ generalized function (6) is in the form Rayleigh's functions and that is possible to take $c_{\alpha=1,kj} = b_{kj}$ for next consideration, no loosing generality we omitted these damping coefficients b_{kj}.

Expression for kinetic energy is in the form of two parts:

$$2\mathbf{E}_{K,wago+loc} = \sum_{k=0}^{k=n} m_k \left\langle \dot{x}_0 \right\rangle^2 + 2\dot{x}_0 \sum_{k=1}^{k=n} m_k \dot{x}_k + \sum_{k=1}^{k=n} m_k \left\langle \dot{x}_k \right\rangle^2 \quad (7)$$

$$\mathbf{E}_K^{rolling-element} = \frac{1}{8}\sum_{k=1}^{k=n} \widetilde{m}_k \left\langle \left(\dot{x}_k + \dot{x}_{k-1}\right)^2 + \frac{i_{C_k}^2}{R^2}\left(\dot{x}_k - \dot{x}_{k-1}\right)^2 \right\rangle \quad (8)$$

Expression for potential energy is in the form:

$$2\mathbf{E}_{p,linearelements} = c_1 \left\langle x_0 \right\rangle^2 - 2c_1 x_0 x_1 + \sum_{k=2}^{k=n} c_k \left\langle x_k - x_{k-1} \right\rangle^2 \quad (9)$$

Expression for generalized function of fractional order energy is in the form [5[:

$$2\Phi_{0\le\alpha\le1,all\ elements} = = c_{(\alpha)1}\left\langle \mathsf{D}_t^\alpha[x_0]\right\rangle^2 - 2c_{(\alpha)1}\mathsf{D}_t^\alpha[x_0]\mathsf{D}_t^\alpha[x_1] + \sum_{k=2}^{k=n} c_{(\alpha)k}\left\langle \mathsf{D}_t^\alpha[x_k - x_{k-1}]\right\rangle^2 \quad (10)$$

3. FRACTIONAL ORDER DIFFERENTIAL EQUATIONS OF A RAILWAY TRAIN COMPOSITION AS A DISCRETE FRACTIONAL ORDER CHAIN SYSTEM

Fractional order differential equations of dynamical equilibrium of the railway train composition as a discrete fractional order chain system, presented in Figure 2. are [12]:

*for locomotive

$$m_0\ddot{x}_0 + c_1 x_0 - c_1 x_1 + c_{(\alpha)1}\mathsf{D}_t^\alpha[x_0] - c_{(\alpha)1}\mathsf{D}_t^\alpha[x_1] = \sum_{k=1}^{k=n} m_k \ddot{x}_k + F_0(t)$$

* for wagons from first to ($n-1$)-th:

$$m_k(\ddot{x}_k + \ddot{x}_0) + c_k(x_k - x_{k-1}) - c_{k+1}(x_{k+1} - x_k) + + c_{(\alpha)k}\left\langle \mathsf{D}_t^\alpha[x_k] - \mathsf{D}_t^\alpha[x_{k=1}]\right\rangle - c_{(\alpha)k+1}\left\langle \mathsf{D}_t^\alpha[x_{K+1}] - \mathsf{D}_t^\alpha[x_k]\right\rangle = 0$$

$$k = 1,2,3,....,n-1 \quad (11)$$

* last wagon in composition:

$$m_n(\ddot{x}_n + \ddot{x}_0) + c_m(x_n - x_{n-1}) + c_{(\alpha)n}\left\langle \mathsf{D}_t^\alpha[x_n] - \mathsf{D}_t^\alpha[x_{n=1}]\right\rangle = 0$$

After summarizing all fractional order differential equations in the system (11) an result is obtained:

$$\ddot{x}_o\left(\sum_{k=1}^{k=n} m_k + m_0\right) = F_0(t) \quad (12)$$

which present expression for the rheonomic force $F_0(t)$ which correspond to the programed known rheonomic coordinate $x_0(t)$ corresponding displacement of locomotive. Rheonomic generalized force $F_0(t)$ for rheonomic coordinate $x_0(t)$ depending of programed acceleration of the railway train composition and total mass of all wagons including mass of locomotive. For the case that motion of the railway train composition is stationary, when velocity $\dot{x}_0(t) = v_0 = const$, is constant, them all system is moving by inertia without external excitation to the locomotive, but wagons oscillate in relation to the locomotive with corresponding number of fractional order modes, and mechanical energy of the oscillations decrease with time, followed by fractional order mechanical energy dissipations.

For precise analysis of the energy is necessary to take into acount friction forces between Railway traks and wheels of the wagons and Locomotive.

For the stationary motion $\dot{x}_0(t) = v_0 = const$ of the railway train composition, system of the fractional order differential equations, describing relative oscillations of the wagons in relation to locomotive, by n unknown generalized coordinates x_k, $k = 1,2,3,....,n$, correspond to the wagons relative motion in relation to the locomotive stationary motion as reference, is:

$$m_1\ddot{x}_1 - \sum_{k=1}^{k=n} m_k \ddot{x}_k - c_2(x_2 - x_1) - c_{(\alpha)2}\left\langle \mathsf{D}_t^\alpha[x_2] - \mathsf{D}_t^\alpha[x_1]\right\rangle = 0$$

$$m_k(\ddot{x}_k + \ddot{x}_0) + c_k(x_k - x_{k-1}) - c_{k+1}(x_{k+1} - x_k) + + c_{(\alpha)k}\left\langle \mathsf{D}_t^\alpha[x_k] - \mathsf{D}_t^\alpha[x_{k=1}]\right\rangle - c_{(\alpha)k+1}\left\langle \mathsf{D}_t^\alpha[x_{K+1}] - \mathsf{D}_t^\alpha[x_k]\right\rangle = 0$$

$$k = 2,3,....,n-1 \quad (13)$$

$$m_n(\ddot{x}_n + \ddot{x}_0) + c_m(x_n - x_{n-1}) + c_{(\alpha)n}\left\langle \mathsf{D}_t^\alpha[x_n] - \mathsf{D}_t^\alpha[x_{n=1}]\right\rangle = 0$$

4. CONCLUDING REMARKS

Then we have an autonomous fractional order differential equations along n unknown generalized coordinates, x_k, $k = 1,2,3,....,n$, correspond to the wagons relative motion in relation to the locomotive stationary motion as reference. For this system is possible to find eigen normal coordinates using formula transformation between generalized and eigen main coordinates of corresponding linear system to the fractional order using modal matrix. Previous system of fractional order differential equations (13) is possible to present in the matrix form:

$$\mathbf{A}\{\ddot{x}\} + C\{x\} + C_\alpha\left\{\mathsf{D}_t^\alpha\{x\}\right\} = \{0\} \quad (14)$$

with corresponding linear matrix form

$$\mathbf{A}\{\ddot{x}\} + C\{x\} = \{0\} \quad (15)$$

Then, we take into account that system (13) or in the form (14) have properties of special family of the fractional order system free vibrations for which matrix $\mathsf{C}_{\alpha,s\rightarrow\ s=1,2,3,...,n}^{\downarrow\ k=1,2,3,...,n}$ is diagonal and in the form:

$$\mathsf{C}_{\alpha,s} = \mathbf{R}'\mathbf{C}_\alpha\mathbf{R} = \left(c_{(\alpha)sS}\right) \quad (16)$$

where $\mathbf{R}$ is modal matrix of linear system (15) , and that by formula transformation of the generalized coordinates $\{x\} = \mathbf{R}\{\xi\}$ [12] previous system (14) can be transformed along new eigen main fractional order system coordinates ξ_s, $s = 1,2,3,...,n$, in the form of system of containing, only independent, fractional order differential equations each along one of these coordinates:

$$\ddot{\xi}_s + \omega^2_{(\alpha)s} \mathsf{D}_t^\alpha \{\xi_s\} + \omega^2_s \xi_s = 0 \text{ , } s = 1,2,3,...,n \qquad (17)$$

where:

$$\omega_s^2 = \frac{c_{ss}}{a_{ss}} \quad \omega^2_{(\alpha)s} = \frac{c_{(\alpha)ss}}{a_{ss}} \text{ , } s = 1,2,3,...,n \qquad (18)$$

characteristic number of railway train composition fractional order oscillations and eigen main fractional order independent modes are (see Refs, [2,3,13]):

$$\xi_s(t) = \xi_s(0)\sum_{k=0}^{\infty}(-1)^k \omega^{2k}_{(\alpha)s} t^{2k} \sum_{j=0}^{k} \binom{k}{j} \frac{(\mp 1)^j \omega^{-2j}_{(\alpha)s} t^{-\alpha j}}{\omega_s^{2j}\Gamma(2k+1-\alpha j)} + \qquad (19)$$

$$+ \dot{\xi}_s(0)\sum_{k=0}^{\infty}(-1)^k \omega^{2k}_{(\alpha)s} t^{2k+1} \sum_{j=0}^{k} \binom{k}{j} \frac{(\mp 1)^j \omega^{-2j}_{(\alpha)s} t^{-\alpha j}}{\omega_s^{2j}\Gamma(2k+2-\alpha j)}$$

$$s = 1,2,3,...,n$$

For each eigen main fractional order vibrations mode is possible to define a theorem of the energy rate in the form [5]:

$$\frac{d}{dt}\left\langle \mathbf{E}_{kin,s} + \mathbf{E}_{pot,s} \right\rangle = -2\Phi_s - \dot{\xi}_{ss} \frac{\partial \Phi_{\alpha,s}}{\partial\left(\mathsf{D}_t^\alpha[\xi_s]\right)}, \qquad (20)$$

On the basic author's References, we can conclude that in the system exists independent eigen main fractional order modes (19), and that between these modes no transfer energy from one mode to other (20). Also two theorems is possible to formulate of rate of mechanical energy decease with fractional order energy dissipation defined in this model of railway train composition with fractional order energy dissipation in oscillatory regimes of wagons in relation to locomotive stationary motion with constant velocity. For the case, that system of railway train composition is not in stationary motion and that locomotive motion is with periodic changes of velocity and acceleration, it is possible to identified forced fractional order vibrations of all wagons and eigen fractional forced modes appear as coupled, and complex investigation in present fractional order model. If we take into account some of simple nonlinearity is possible to wait some stochastic like and chaotic like oscillations of the wagons and no stability of composition.

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REFERENCES

[1] Goroško O.A. and K.R. Hedrih (Stevanović), (2001), *Analitička dinamika (mehanika) diskretnih naslednih sistema, (*Analytical Dynamics (Mechanics) of Discrete Hereditary Systems), University of Niš, 2001, Monograph, p. 426, YU ISBN 86-7181-054-2.

[2] Hedrih (Stevanović) K., (2008), The fractional order hybrid system vibrations, Chap in Monograph. Advances in Nonlinear Sciences, ANN, 2008, Vol. 2, pp. 226-326.

[3] Hedrih (Stevanović) K., (2011), Analytical mechanics of fractional order discrete system vibrations. Chap in Monograph. Advances in nonlinear sciences, Voл. 3, ANN, pp. 101-148.

[4] Hedrih (Stevanović) K., (213), Fractional order differential equations of dynamics of two mass particles, constrained by a fractional order element, Plenary Lecture, 8th INTERNATIONAL SYMPOSIUM ON CLASSICAL AND CELESTIAL MECHANICS (CCMECH'8), Siedlce, Poland, (The Russian Academy of Sciences, A. A. Dorodnicyn Computing Centre of RAS, Moscow State University, Moscow State Aviation Institute, Warsaw University of Life Sciences, and Collegium Mazovia in Siedlce (Poland).Book of Abstracts, **pp. 27-28. ISBN 078-83-63169-4,** @Copyright by Collegium Mazovia.

[5] Hedrih (Stevanović) K., (2013), Generalized function of fractional order dissipation of system energy and extended Lagrange differential equation in matrix form, *Dedicated to 86th Anniversary of Radu MIRON'S Birth. 30 minutes* Plenary Lecture, Abstracts of THE 13TH INTERNATIONAL CONFERENCE OF TENSOR SOCIETY ON DIFFERENTIAL GEOMETRY AND ITS APPLICATIONS, AND INFORMATICS BESIDES., ***The 86th Anniversary of Radu MIRON'S Birth.*** September 3rd (Tuesday) to September 7th (Saturday) in 2013. Faculty of Mathematics, Alexandru Ioan Cuza University and Mathematical Institute "O.Mayer" in Iaşi Romania And Tensor Society, Japan, 2013, p.3. (Full paper paper submitted for publishing in the journal Tensor of Tensor Society, Japan.).

[6] Katica R. (Stevanović) Hedrih, J. Tenreiro Machado, (2013), Discrete fractional order system vibrations, (*Preprint submitted for review-January 6, 2014).*

[7] Hedrih (Stevanović) K., (2013), Two mass particle fractional order plane system dynamics, **Dynamical Systems – Theory**, Edited by J. AWREJCEWICZ and all. 2013, **pp. 403-4012.** ISBN 978-83-7283-588-8, Printed by: Wydawnictwo Politechniki Łódzkiej,.

[8] Hedrih (Stevanović) K., (2006), Modes of the Homogeneous Chain Dynamics, Signal Processing, Elsevier, 86(2006), 2678-2702.. ISSN: 0165-1684 .

[9] Hedrih (Stevanović) K., (2005), Partial Fractional Order Differential Equations of Transversal Vibrations of Creep-connected Double Plate Systems, Chap in in Monograph - Fractional Differentiation and its Applications, Edited by Alain Le Mahaute, J. A. Tenreiro Machado, Jean Claude Trigeassou and Jocelyn Sabatier, p. 780, U-Book, Printed in Germany, pp. 289-302.

[10] Hedrih (Stevanović) K., (201`3), Fractional order hybrid system dynamics, PAMM, Proc. Appl. Math. Mech. 13, 25 – 26 (2013) / DOI 10.1002/pamm.201310008.

[11] Hedrih (Stevanović) K R. (2012), Energy and Nonlinear Dynamics of Hybrid Systems, Book Chapter, in *Dynamical Systems and Methods, Edited by Albert Luo, Tenreiro Machado and D Baleanu, , 2012, Part 1, Pages 29-83,* 2012, DOI: 10.1007/978-1-4614-0454-5_2 , ISBN 978-1-4614

[12] Rašković, D., (1965), Teorija oscilacija, (Theory of Oscillations), Nau~na knjiga, 1965, 503.(in Serbian).

[13] Bačlić, B.S., Atanacković, T., (2000), M., *Stability and creep of a fractional derivative order viscoelastic Rod*, Bulletin T, CXXI de L'Academie Serbe des Sciences st de Arts - 2000, Class des Sciences mathematques et naturelles Sciences mathematiques, No. 25, 115-131.

BAGGAGE TRANSPORT SYSTEM – NEW SOLUTION

Bernhard RÜGER [1]

Abstract *– Baggage features the highest value regarding traffic flexibility. This fact is one of the main reasons for people to choose their car instead of public transport, either regarding their daily routine or journeys. Due to the complexity of an intermodal „public luggage transport system" which ideally works simultaneously to passenger transport, as a first step an exploratory project will be launched. The project aims to survey all customer requirements as well as technical and logistical challenges and as a consequence generate a list of requirements for prospective research and development projects.*

Keywords – baggage transport, passenger needs, expectations, comfort.

1. INTRODUCTION

The carriage of baggage shows the highest flexibility value in the railroad and is one of the main reasons why the automobile is chosen instead of the train for travel. However, studies show that through the implementation of a suitable baggage logistics system, very good modal shift effects can be achieved and the train can expect up to a 20% increase in passenger numbers.

2. PROJECT IDEA

The project "BaggageLess" sponsored by the Austrian Research Promotion Agency (FFG) and the Austrian Federal Ministry of Transport (bmvit) aims to develop a suitable system for baggage transport that can be implemented for everyday traffic as well as for longer travel. This means a decisive simplification for the customer and can also change the modal-split in favor of public transport.

The demands and challenges, which will be defined in the project, orient themselves on the following scenario:

Relevant first and foremost for customers is the interface with the system, i.e. the baggage transfer and return procedure. First and foremost from the point of view of the operator are all of the phases in between, i.e. from the time the operator receives the baggage, through baggage handling and transport, up to the return to the customer.

The basic structure of what the most flexible baggage logistics system can look like is depicted in figure 1.

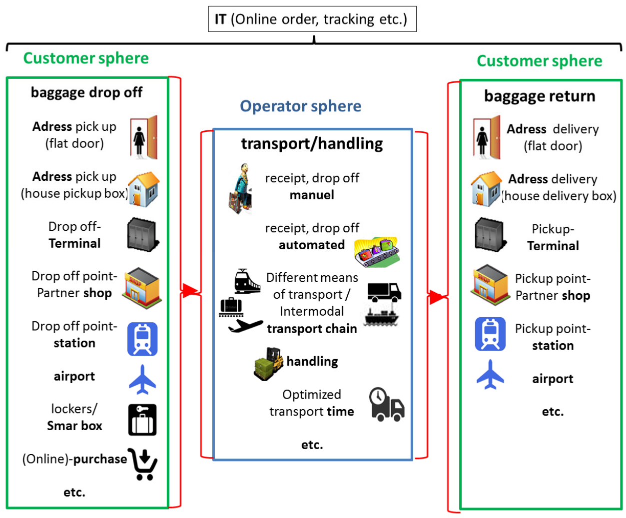

Fig. 1: Schematic depiction of a baggage logistics system

The baggage logistics system is modularly structured. For example, in the area of baggage transfer there must be different transfer possibilities from which the customer can choose. There are many conceivable scenarios which are described below:

- **Pickup/Delivery at the house door:** This service is already offered in the area of package delivery (at this time only for delivery) as well as in railroad transport house-house-baggage service. However, it must be optimized as it is at this time expensive and inflexible.
- **Pickup/Delivery at a house delivery enclosure (house-pickup/delivery box):** Analogous to house delivery enclosures (post boxes), large boxes make possible the delivery as well as

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pickup of bulk freight such as baggage; but also packages in cases where the personal presence of the customer is not possible. Due to the necessary size of the boxes, it is hardly possible to provide every housing unit with its own box.

A system must be designed which is flexibly utilisable. For example, several small boxes can be combined to achieve the required larger size. At the same time it must be ensured that only the currently authorized persons (staff of the delivery/pick up services in combination with the respective piece of baggage or the owner) have access to the contents. A house box would have the advantage that both baggage and other packages which do not fit into a conventional house delivery enclosure could be transferred even if no one is personally present to meet the delivery/pickup service. At the same time, this box can also be used for the pickup of any pieces of baggage or packages. On one hand, because recipients do not need to go at fixed opening times to the nearest post office or the nearest partner shop to pick up deposited packages; this system would be, in the area of normal package delivery, a great convenience for the customer. On the other hand, it offers the implementation of a completely new service. The house box makes it possible to send packages without having to go to a post office.

The desired pickup of pieces of baggage or packages can be ordered over the internet; whereby, the box automatically informs the delivery service as soon as it is filled.

- **Central Drop Off Terminals:** At central points (hot spots) analogous to baggage lockers, innovative baggage deposit systems can be set up as short-term interim storage of baggage (e.g. while shopping) but the same time, as reception or retrieval points for baggage transport. These central drop off terminals can for example, include smart-boxes (see below) for the storage of diverse pieces of baggage.
- **Smart Boxes:** A key research question describes the necessary standardization of packaging and transport units. In particular it must be examined whether by baggage transport, transport containers such as for example the above mentioned SmartBox can be used system-wide or what additional requirements for style and (re) design of the pieces of baggage are needed. Baggage can be stored in the SmartBox. The SmartBox contains a chip and a small display. It is at any time possible to configure the SmartBox (e.g. using a smart phone or terminal) so that at a desired time it can be set to a defined goal. This system can then handle many small pieces of baggage (e.g. while shopping) as well as travel baggage.
- **Special challenges in the logistics chain:** People travel independently using available systems of public transport and make travel breaks. Along the way they do things which are not directly connected to their travel purposes, make detours and are not time bound to the transportation offered.

  The baggage being transported parallel to the traveler must be taken over by the transport service provider, collected, stored, transported, sorted and once again separated for the individual traveler. This requires not only appropriate systems but also minimization of processing time. Therefore, in general the baggage arrives at its destination at a different time than the traveler; and that implies the need for storage at the destination and the design of a pickup system by delivery service or individual.

3. OPERATOR MODEL

The innovation with respect to a future baggage logistics system is: that similar to multimodal personal mobility, a corresponding and accompanying freight mobility will be created. Thus there will be a complete decoupling of personal mobility from freight transport.

Similarly, as currently flexible systems are used in the framework of direct personal mobility, be it classical public transport or multi-purpose rental systems such as Car2Go or City Bike, in which at almost any time a vehicle can used and then parked; it should also be possible in the future to drop off baggage at an adequately available transfer point and have it transported to the desired destination. This system will allow in the future a significant increase in the flexibility of personal mobility; since the choice of transport as to whether or how much baggage is conveyed must not be considered, but limiting baggage can be dropped off at any time.

In the field of energy supply as well as telecommunication and public transport it is increasingly common for infrastructure and operations to act separately. This means for example, that a telecommunications provider does not have its own infrastructure but makes use of alternative infrastructure and only offers service "telephony". An operator model specializing in baggage services can look similar.

There are a variety of companies that specialize in the field of freight mobility. These are both shippers who transport freight using various means of transport, as well as traditional mail and package delivery. Also, other service facilities such as baggage deposit systems at train stations etc. should be considered. Because the requirements for baggage transport are very diverse, it is not useful to create a completely new system. On the contrary, existing service providers including their infrastructure must be integrated into the system and their systems optimized to ensure the best possible efficiency. For example, it can be a separate operator who is responsible for all matters relating to the transportation of baggage. The booking of service takes place through this operator; the operator takes care of the smooth flow of transport and is also the sole point of contact in all matters. The operator itself has no available infrastructure in the true sense but accepts the intermediary and coordinator role and depending on the specific requirements uses various service providers and service facilities (see Fig. 2).

This system also gives rise to a better utilization of existing systems; as free capacity can be used in a more targeted way.

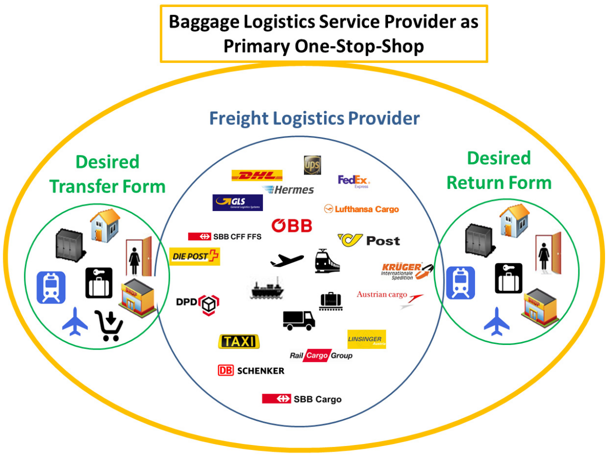

Fig. 2: Possible Operator Model

Those accumulated measurements can be used in order to design adequate storage between the seat backs or baggage racks.

Analysis show that there are two main issues regarding baggage room. First passengers do not want to lift their luggage, and especially not to the height of overhead storage. This attitude is more common amongst women and increases with age.

Second and due to security reasons, passengers wish to have their luggage in visual range. If these requirements are not met, passengers are very willing to store their luggage in not-intended place, like seats or corridors. This behaviour leads to a lower quality level and to a loss in capacity due to occupied seats.

4. CONCLUSION

The actual innovation, which is discernible from the outside, is that a fully adequate replacement for the trunk of the private automobile will be created. Only when the same flexibility can be created that one's own automobile trunk provides, is it possible to leverage sustainable mobility forms such as public transport to make the required breakthrough!

REFERENCES

[1] Rüger Bernhard, Reisegepäck im Eisenbahnverkehr, Dissertation TU Wien, 2004

[2] Chiambaretto, Paul; Baudelaire, Claude; Lavril, Thibault: Measuring the willingness-to-pay of air-rail intermodal passengers, in: Journal of Air Transport Management, Volume 26, 2013, S. 50-54.

[3] Plank Viktor, Dimensionierung von Gepäckablagen in Reisezügen, Diplomarbeit TU-Wien, 2009

[4] Rüger Bernhard, "Bereitschaftselastizität - Empirische Ermittlung zum Verkehrsmittel-wahlverhalten"; 20. Verkehrswissenschaftliche Tage in Dresden, Dresden; 19.09.2005 - 20.09.2005; in: "Grenzenloser Verkehr in einem grenzenlosen Europa", (2005), 31 S.

[5] KOWARCZ, Sascha; VOSPERNIK, Stefan: GBÖ Kurzreisen Winter 2000/01, (Gästebefragung Österreich Winter 2000/01) Info Research International, Wien

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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PESA 122NASF SWING - THE NEW TRAMS IN SOFIA

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Abstract *– At the end of 2013 began the delivery of 20 trams for the city of Sofia - type PESA 122NaSF Swing, production of Pojazdy Szynove PESA Bydgoszcz SA. The trams are with 6-axes and 1009 mm wheel gauge. With low-floor along the entire vehicle, designed for one-way traffic. They use a entirely new composition for the city of Sofia – three bogies supporting five sections, connected by four floating joints. The new trams have systems for management, monitoring, passenger information. They are suitable for transporting elderly, disabled and people in wheelchairs. This paper will give a description of trams PESA 122NaSF Swing, indicate the differences with the currently operated trams in Sofia and analyse the problems arising in the beggining of their service.*

Keywords – trams, Sofia, PESA, chassis, traction equipment.

1. INTRODUCTION

The *PESA 122NaSF Swing* trams were delivered to „Sofia Public Electrical Transport Company" JSC[1] in the period from December 2013 – May 2014. They were manufactured in Poland by the Polish company Pojazdy Szynove PESA Bydgoszcz SA[2].

These trams have a composition that is used for the first time in the city of Sofia - five complete low-floor sections, interconnected via four floating joints, which allows better negotiation of tight railroad curves.

The delivery of the new trams is part of an integrated city transport project, financed by Operational Programme "Environment". The total value of the delivery contract for the 20 trams, diagnostic equipment, spare parts and personnel training is 33 784 726,65 euro. The price of a single vehicle is 1 660 000 euro.

These trams are the first non second-hand ones introduced into the transport network of Sofia since year 2000.

2. BRIEF DESCRIPTION OF THE *PESA 122NASF* TRAM

2.1. General overview

The *PESA 122NaSF Swing* tram (fig. 1) is a continuation of the *120Na Swing* model and is a specially modified version to suit the specific usage requirements of Sofia city. The trams has six axles, matching the wheel gauge of 1009 mm that is used in the city. It is designed for one-way traffic, and is not a Multiple Unit (MU) type.

The tram has the following dimensions: length– 30,120 m, width – 2,3 m, body height – 3,4 m, height with a current collector in operational position – 5,8m. The designed speed of *PESA 122NaSF Swing* is 70km/h, but is limited by the onboard computer to 55km/h to comply with city traffic regulations. When this speed is exceeded, the traction units are turned off. The maximum slope grade that can be climbed is 60 ‰. The minimum curve radius is 18 m. The tram has capacity to transport 201 passengers, from which 41 sitting, and the rest 160 are standing, at a density of 5 passengers per m^2.

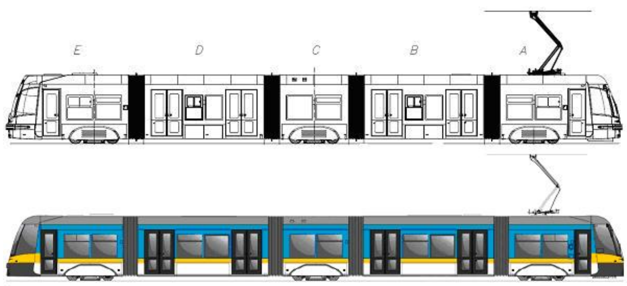

Fig.1. PESA 122NaSF Swing tram

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2.2. Technical specifications

Tab. 1. Technical specifications

Wheelset formula	$B_0' \, 2' \, B_0'$
Wheel gauge	1 009 mm
Kinematic gauge	PN-K-92008
Length of tramcar	30 120 mm
Width of tramcar	2 300 mm
Body height	3 400 mm
Height of tramcar with retracted current collector	3 850 mm
Height of tramcar with maximum extended current collector (in operational mode)	5 800 mm 6 380 mm
Floor height from top of rail	330 mm
Weight Empty (Tare) Loaded – 5 passengers/m^2	 40 858 kg 54 756 kg
Wheelbase between bogies	10 750 mm
Wheelbase of bogies	1 800 mm
Design speed	70 km/h
Maximum slope grade	60 ‰
Minimum curve radius in operational conditions	18 m
Passenger capacity at 5 passengers/m^2	201 passengers
Sitting places	41
Operation ambient tempeature	- 30 ÷ + 40
Traction motors	4

2.3. Chassis

The chassis is comprised of three bogies – two traction (type 03PND) and one support (type 03PTD), fixed to sections A, C e E.

The bogies have two axles, with two-stage suspension. The bushing suspension stage has two cylindrical metal-rubber bushes, and the central stage has two pairs of two cylindrical coil springs on each side. In the two suspension stages of each bogie there are altogether eight hydraulic shock absorbers with vertical and horizontal action.

The wheels are elastic, and the elastic elements are arranged in rings between the hubs and the wheel bandage.

2.4. Traction equipment

The traction equipment of the trams comprises 4 traction electrical motors of type *DKCBZ 0211-4SA*. The motor is 3-phase asynchronous, the rotor is a squirrel-cage design, the stator is connected in a star (WYE) arrangement. The motor provides both traction and dynamic braking. The motors are mounted on both sides outside the frame of the bogie and transfer torque to the axles via two-stage cylindrical-conical reduction gearboxes and elastic clutches. The housings of the traction motor and gearbox are rigidly connected in one single block.

Each traction motor is powered individually by a power inverter converting the DC from the overhead power line into 3-phase 400V / 50Hz AC. The power (throttle) control is performed via Pulse Width Modulation (PWM), by IGBT power transistors.

2.5. Body

The body of the tram has a complete low floor and is composed of five sections, connected by four floating joints. The body has a fully supporting structure, and complies to the requirements of the standards EN 15227:2008 cat. IV and A1:2010.

The passenger compartment (fig. 2) is equipped with 41 seats, and the area for 201 standing passengers is 32,21 m^2.

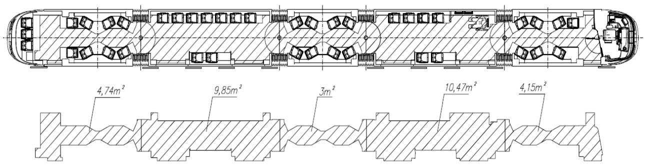

Fig.2. Arrangement of the seats and the standing passenger area

The doors are situated on the right. The second door is equipped with a ramp for wheelchair and baby stroller roll-on/roll-off access. Opposite to the door there is a place for securing a wheelchair or baby stroller.

2.6. Brakes

Braking of the *PESA 122NaSF* tram is performed by three independent braking systems: electrodynamic brake, hydromechanic brake; electromagnetic track brake. The collective work of the different brake systems is controlled by the onboard computer, which optimizes braking efficiency in the different braking regimes.

Main braking is performed by the electrodynamic brake. After the speed reaches 3 km/h, until complete stop of the tramcar, braking is performed by the hydromechanical brake. The energy recovered by regenerative electrodynamic braking is recuperated to the overhead power line.

In case of extreme brake action, the hydromechanic and electromagnetic track brake are collectively applied.

3. MAIN DIFFERENCES FROM ALL OTHER TRAMCARS IN SOFIA

The *PESA 122NaSF Swing* tram is different from the currently operational articulated railcars, produced in the Sofia Tramcar Factory, in the following aspects:

- Fully low body floor;

- Fully computerized control by an onboard computer;
- Different arrangement of the seats in the passenger compartment;
- Bogies are fixed to the sections, and the joints are floating type;
- Fully air conditioned passenger compartment;
- Excellent noise insulation of the passenger compartment.

PESA 122NaSF Swing trams offer more passenger conveniences and superior ride comfort.

The higher safety level of the machines leads to more safety shutdowns than the older tram types. The procedure to reset the system back in operational mode takes more time than with the currently used trams. There are two emergency modes that minimize the necessity of using another vehicle for towing.

There are considerable structural differences between the new and the currently used trams. These differences require changes both in the tram depot repair shop and in Emergency Service procedures.

Due to the lower floor of these trams, all equipment containers are mounted on the roof. This required building of new service and repair equipment (Fig. 3). Changes were made to the operation of the underfloor grinding machine. A procedure is in progress for purchasing an underfloor wheel lathe.

Fig 3. The new roof access service equipment

Considerable changes are required in equipment and workflow in case of emergencies, especially when partial hoisting of the tram is necessary - in cases or derailment of chassis malfunction. The manufacturer-provided technology is complex and requires more preparation time.

Fig.4 compares *PESA 122NaSF Swing* trams (top) and similar in length and passenger capacity *T8M 700 M* trams (bottom). The main differences in the composition are the floating joints and the fixed bogies of the Polish trams.

While the bogies of the currently used trams can rotate up to 11 degrees related to the body, around a central pivot, the *PESA 122NaSF Swing* bogies are fixed to the body sections. The Bulgarian trams have the support bogies under the joints, unlike the Polish ones, which have two floating joints between each two bogies. This leads to twisting of the body in case of derailment. Because of this, before partial hoisting of the tram in case of emergency and repair, one or two joints have to be blocked.

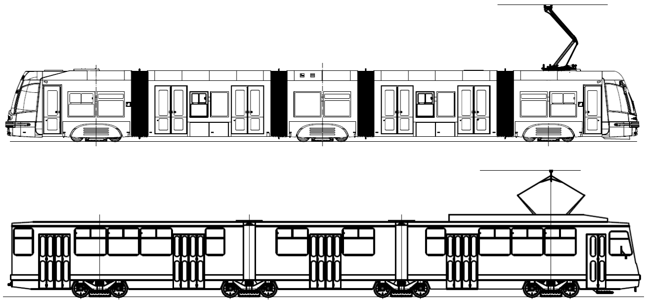

Fig.4. Comparison between the composition of PESA and TM, manufactured in the tram factory in Sofia.

These specifics of the new trams do not allow the use of the currently employed techniques for rerailment.

4. IMPROVEMENT OF THE ACOUSTIC ENVIRONMENT

The noise levels measured in the city of Sofia during the last years are constantly increasing. According to a report from the Regional Health Inspection Service[4], the noise levels measured in 2013 reach 77 dB. This is above the 65 dB level allowed by the current regulations № 6 / 2006 for ambient noise levels [5]. The high noise levels have negative psychological and physiological impact on the quality of life. The main noise pollution source is transportation. For this reason, various measures are taken to lower noise emissions. One of these measures is the purchase of the new *PESA 122NaSF Swing* trams and the start of a new public procurement procedure for commissioning more new trams for the city.

The new trams completely meet the current European noise level regulations. These trams are considerably quieter than the rest in the fleet of „Sofia Public Electrical Transport Company” JSC. Their introduction will contribute to the improvement of the acoustic environment of the Bulgarian capital.

5. EXPLOITATION-RELATED PROBLEMS

In the first months after the introduction of *PESA 122NaSF Swing* in Sofia, the usual new equipment adoption problems appeared.

The drivers had to adapt to the different way of operation of the new tramcars. In the cases of failures and emergencies, the drivers are frustrated with the procedures for restarting the machine in emergency mode.

The technical problems that occurred are related to the fact that the prescribed functional tests were not carried out in the manufacturing factory, because it lacks a track with a 1009 mm wheel gauge. The test runs were carried out in Sofia, before their acceptance according to the commission contract.

Together with the tramcars, in accordance with the warranty clauses in the contract, a team of Polish experts was sent to Bulgaria. Together with their Bulgaria colleagues, in the period of 3 years, they will be in charge of the technical condition of the tramcars.

Meanwhile, lecturers from the manufacturing company are training Bulgarian personnel in the depot's workshop and at the Emergency Service.

Consulting with colleagues from the city of Warsaw, where a significant number of tramcars of the base model are in service, shows that the problems observed in Bulgaria are identical to the ones observed in Warsaw. Experience was exchanged.

6. CONCLUSIONS

After about one year of service of the *PESA 122NaSF Swing* tramcars, it can be concluded that they show excellent operational characteristic and are well accepted both by the personnel working in them and by the passengers.

REFERENCES

[1] http://www.elektrotransportsf.com/ - Sofia Public Electrical Transport Company JSC
[2] www.pesa.pl/en/ - PESA Bydgoszcz SA
[3] Pojazdy Szynove PESA Bydgoszcz SA, Dokumentacja techniczna, 2013.
[4] www.srzi.bg – Regional Health Inspection Service – „Report of noise levels observed in the city of Sofia in 2013", Sofia 2013.
[5] Regulation № 6 / 2006 for ambient noise characteristics, describing the level of discomfort at different time of the day, ambient noise limits, noise parameter and noise health impact evaluation methods.

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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HYBRID INTELLIGENT VIBRATION CONTROL OF RAIL CAR BODY WITH PIEZO ACTUATORS

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Abstaract–*The softer, more compliant structure with piezo actuators of railcar bodies with low eigenfrequencies that significantly affect perceived passenger ride comfort is become important issue in design of modern rail vehicles. Recent years various approaches have been taken to reduce comfort-relevant vibrations of the car body. In this paper, for control of railcar structure we are suggesting hybrid intelligent control concept that combine fuzzy logic with particle swarm optimization of fuzzy control parameters for stabilization and active vibration control*

Key words – Intelligent control, particle swarm, piezo actuators, railcar structure.

1. INTRODUCTION

Recently, ride comfort becomes an increasingly important issue of modern railway vehicles. The ride quality of a modern railway vehicle is mainly determined by forces of inertia acting on the car body and therefore on the passenger. These accelerations result from the vibrations of rigid body modes as well as elastic modes of the car body. A common criterion to evaluate the ride quality of a railway vehicle is to measure or to simulate the system response to a real excitation (track irregularities, etc.) in order to obtain time histories of the accelerations on certain points of the car body. Then the weighted root mean square value of the acceleration in the horizontal and vertical direction of the car body is an appropriate measure for the ride quality [1].

$$a_{ISO,rms} = \sqrt{\frac{1}{T}\int_0^T a_{ISO}^2(t)dt} \tag{1}$$

where $a_{ISO}(t)$ is the frequency weighted acceleration. Weighting filters for vertical and horizontal accelerations are defined in UIC 513 [2].

Whole-body vibrations are transmitted to the human body of the passengers in a bus, train or when driving a car. The ISO 2631 standard gives an average, empirically verified objective quantification of the level of perceived discomfort due to vibrations for human passengers. The accelerations in vertical and horizontal directions are filtered and these signals' root mean squares (RMS) are combined into a scalar comfort quantity. Fig. 1 shows the ISO 2631 filter magnitude for vertical accelerations which are considered. The highest sensitivity of a human, for the heavy metro car, eventuates in the frequency range of f ≈ 4 − 10 Hz. [3].

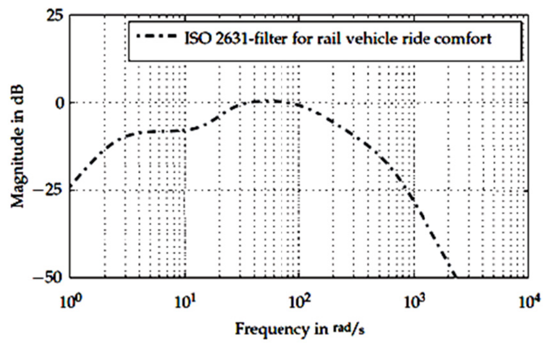

Fig. 1. Filter function according to ISO 2631

The other words, a good ride quality meaning the reduction of the vibration amplitudes of the car body, because the softer, more compliant structure exhibits low eigenfrequencies that significantly affect perceived passenger ride comfort.

Various approaches have been taken to reduce comfort-relevant vibrations of the car body that can be grouped into vibration isolation and vibration

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damping approaches.

The isolation approaches include passive, semi-active, and active concepts to decouple the car body from the bogeys and wheel sets (see [4] and [5]).

The vibration damping approach for vibration reduction is the application of an active control system to alleviate the elastic vibrations of the railway car body. Both passive (Hansson et al. [6]) and active control schemes (Kamada et al. [7], Schandl et al. [8]) have already been proposed.

The purpose of this paper is to illustrate the design steps of such an active vibration control system and to focus attention on the performance of this concept. Also for control of railcar structure we are suggesting hybrid intelligent control concept that combine fuzzy logic with particle swarm optimization of fuzzy control parameters for stabilization and active vibration control. This work is based on the results of Popprath et all [1], Schirrer et all [3] and Schirrer & Kozek [10].

2. FLEXIBLE RAIL CAR BODY ANALYTICAL MODEL

For controller design procedure a mathematical model of the flexible rail car body is necessary. More precisely a model of the elastic modes of the car body is needed for this purpose because the elastic modes of the car body can be influenced only by actuator forces. The equations of motions are expressed by a first-order state-space representation obtained by a finite element analysis within the frequency range of interest.

The metro car body structure is directly actuated via locally mounted Piezo stack actuators. Using strain measurement signals, the control law actuates the structure in order to minimize ride comfort-relevant acceleration signals across the car body inner part. Because this system is subject to variations in damping and frequency of the flexible modes is a challenging for control design. The mathematical model of the rail car body, obtained by an FE model and subsequent order reduction steps, considers 17 elastic modes and 12 frequency-response-modes (FRM), as demonstrated in [11].

Figure 2 shows positioning of the actuators and sensors (one of several criteria for optimal actuator/sensor placement) and the principle of how the actuators work is shown in Fig. 3.[9]

The equations of motion are given by the following system of differential equations of order n [9]:

$$\boldsymbol{M}\ddot{\omega} + \boldsymbol{L}\dot{\omega} + \boldsymbol{K}\omega = \boldsymbol{f}(t) \tag{2}$$

Here **M** is the (n × n) mass matrix, **L** is the (n × n) damping matrix, **K** is the (n × n) stiffness matrix, and **f**(t) is the (n× 1) vector of generalized excitation forces containing excitation as well as control forces.

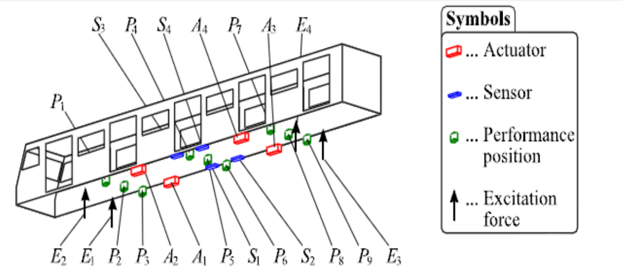

Fig. 2. Flexible rail car body: positions of input and output variables

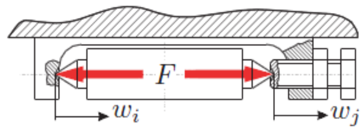

Fig. 3.Piezo-stack actuator mounted in console

A transformation is defined by replacing the (n × 1) vector of generalized coordinates $\boldsymbol{\omega}(t)$ with

$$\boldsymbol{\omega}(t) = \boldsymbol{\Phi}\boldsymbol{q}(t) = \sum_{j=1}^{n} \phi_j q_j(t) \tag{3}$$

where

$$\boldsymbol{\Phi} = [\phi_1, \phi_2, \ldots, \phi_n]^T$$

is the matrix of eigenvectors of (2). Inserting (3) into (2) and left-multiplying by$\boldsymbol{\Phi^T}$, one obtains a diagonal systemin modal coordinates:

$$\ddot{\boldsymbol{q}} + 2\boldsymbol{\zeta\Omega}\dot{\boldsymbol{q}} + \boldsymbol{\Omega}^2\boldsymbol{q} = \boldsymbol{\mu}^{-1}\boldsymbol{\Phi}^T\boldsymbol{f}(t) \tag{4}$$

where **μ** is the (n × n) matrix of modal masses, ***ζ*** is the (n × n) matrix of modal damping's and **Ω** is the (n × n) matrix of undamped eigenfrequencies. Definition of

$$\boldsymbol{x} = [\boldsymbol{q}, \dot{\boldsymbol{q}}]^T \tag{5}$$

leads to the state space system equation

$$\dot{\boldsymbol{x}} = \boldsymbol{Ax} + \boldsymbol{B_1 d} + \boldsymbol{B_2 u} \tag{6}$$

and the output equation

$$\boldsymbol{y} = \boldsymbol{C_2 x} \tag{7}$$

which together form the state space description of (4). In (6) and (7) **A** is the (2n × 2n) system matrix, $\mathbf{B_1}$ is the (2n×l) disturbance input matrix, $\mathbf{B_2}$ is the (2n×m) input matrix, $\mathbf{C_2}$ is the (p × 2n) measurement output matrix, **x** is the (2n × 1) state vector, ***u*** is the (m × 1) vector of control signals, ***d*** is the (l × 1) vector of disturbances (excitation of the car body from secondary suspension) and **y** is the (p × 1) vector of controlled variables. The controlled variables may consist of measured outputs as well as of performance variables.

If one actuator is used, forces are acting in the directions w_i and w_j according to Fig. 4, and if only one excitation force is acting on the structure in the direction w_l, the disturbance input matrix $\mathbf{B_1}$ and the input matrix $\mathbf{B_2}$ are

$$B_1 = \begin{bmatrix} 0 \\ \vdots \\ 0 \\ \phi_1(w_l) \\ \vdots \\ \phi_n(w_l) \end{bmatrix}, B_2 = \begin{bmatrix} 0 \\ \vdots \\ 0 \\ \phi_1(w_j) - \phi_1(w_i) \\ \vdots \\ \phi_n(w_j) - \phi_n(w_i) \end{bmatrix} \quad (8)$$

In (8) $\phi_m(w_j)$is the component of ϕ_m in direction of w_j. When the sensors are collocated with the actuators the output matrix $\mathbf{C_2}$ is proportional to the input matrix $\mathbf{B}_2$ [12],

$$\boldsymbol{C}_2 = \frac{1}{l_s}\boldsymbol{B}_2^T \quad (9)$$

where l_s is the distance between the nodes w_i and w_j in the unstrained state.

Equivalent transfer function descriptions for (6) and (7) are given by

$$\boldsymbol{G}_{su} = \boldsymbol{C}_2(\boldsymbol{sI} - \boldsymbol{A})^{-1}\boldsymbol{B}_2 \quad (10)$$

for the open loop transfer function from actuator action to the outputs and

$$\boldsymbol{G}_{sd} = \boldsymbol{C}_2(\boldsymbol{sI} - \boldsymbol{A})^{-1}\boldsymbol{B}_1 \quad (11)$$

for the open loop action of the disturbances on the outputs.

Augmenting the output equation (7) with a q × 1 performance vector $\mathbf{z}$ (typically vertical accelerations at various positions), the overall representation becomes

$$\begin{bmatrix} \dot{\boldsymbol{x}} \\ \boldsymbol{z} \\ \boldsymbol{y} \end{bmatrix} = \begin{bmatrix} \boldsymbol{A} & \boldsymbol{B}_1 & \boldsymbol{B}_2 \\ \boldsymbol{C}_1 & \boldsymbol{D}_{11} & \boldsymbol{D}_{12} \\ \boldsymbol{C}_2 & \boldsymbol{D}_{21} & \boldsymbol{D}_{22} \end{bmatrix} \begin{bmatrix} \boldsymbol{x} \\ \boldsymbol{d} \\ \boldsymbol{u} \end{bmatrix} \quad (12)$$

Here $\mathbf{C}_1$ is the q×n performance output matrix and $\mathbf{D}_{11}$,$\mathbf{D}_{12}$, $\mathbf{D}_{21}$, and $\mathbf{D}_{22}$ are the feed-through matrices. The explicit notation of performance variables $\mathbf{z}$ is reasonable since only strains are measured but the accelerations are used to quantify performance. Furthermore, this system structure is well suited for a robust controller design.

3. FUZZY CONTROLLER DESIGN

In addition to the conventional controller design approach [13], the fuzzy controller design of flexible rail car body was considered in this paper.

Rule based fuzzy logic controllers are useful when the system dynamics are not well known or when they contain significant nonlinearities. Fuzzy logic controllers apply reasoning, similar to how human beings make decisions, and thus the controller rules contain expert knowledge of the system. The big advantages of fuzzy logic control when applied to a flexible rail car body are that the system neither needs to be accurately described nor does it need to be linear. The design process for a fuzzy logic controller consists of determining the inputs, setting up the rules and designing a method to convert the fuzzy result of the rules into output signal, known as defuzzification.

Takagi-Sugeno fuzzy logic controller suggested in this paper is defined as a list of fuzzy control rules, where each rule is defined as:

$$R_c^{\,i}\text{: if } \mathbf{x}=\mathbf{LX}^{i} \text{ then } \mathbf{u} = g_i(\mathbf{x}),$$

where $\mathbf{LX}^{i}$m is fuzzy region. Nonlinear formulaton of global fuzzy logic controller is:

$$\mathbf{u} = \sum_i \omega^i(\mathbf{x}) \cdot g_i(\mathbf{x}) \quad (13)$$

where $\omega^i(\mathbf{x})\in[0,1]$ is normalized membership value of some crisp state space vector $\mathbf{x}$ to fuzzy region $\mathbf{LX}^{i}$ (i=1,2,...m).

The strain measurement signals drove the fuzzy controller of the actuator forces, in order to keep the magnitude and frequencies of rail car body within the proposed bounds. The measured input signal and its derivate are controller inputs and were normalized and divided in three regions each: low, middle and high. The output MFs of the controllers were constants, namely actuator forces. The first controller output was generated as a result of an interpolation of 3 constant gains based on fuzzy rules.

Tuning of the parameters for the *low*, *average* and *high* input and output values can be done by expert knowledge or after many simulation trials. However, optimal fuzzy controller gain values when there is no adequate expert knowledge can be determined as the result of some heuristic optimization method.

The closed loop system with optimally adjusted fuzzy controller should have a quick response and small overshoot. Such response is of great importance having in mind passenger ride comfort.

4. PARTICLE SWARM OPTIMIZATION OF PARAMETARS OF FUZZY CONTROLER

In this paper Particle swarm optimization was used for numerical calculation of optimal fuzzy controller gains. Using this algorithm is simple, easy to implement and there are just fewer parameters need to be adapted.

It was first introduced by Kennedy and Eberhart in 1995 [14], as new heuristic method inspired by the social behavior exhibited by flocks of birds flying across an area looking for food.

Mathematically, for a given function $f: S\square R$, where $S\subseteq R^D$, find a point $\boldsymbol{x}^*$ such that

$$\min_{x\varepsilon S} f(\boldsymbol{x}) = f(\boldsymbol{x}^*) \quad (14)$$

In the basic particle swarm optimization, particle swarm consists of $n$particles, and the coordinates of each particle represent a possible solution called particles associated with position and velocity vector in D-dimensional space [14].

At each iteration particle move towards a optimum solution, through its present velocity, personal best solution obtained by themselves so far and global best solution obtained by all particles.

The position of ith particle of the swarm can be represented by a D-dimensional vector $\mathbf{x}_\mathrm{i} = (\mathrm{x}_1, \mathrm{x}_2, \ldots, \mathrm{x}_\mathrm{D})$. The velocity (position change per generation) of the particle $\mathbf{x}_\mathrm{i}$ can be represented by another D-dimensional vector $\mathbf{v}_\mathrm{i} = (\mathrm{v}_1, \mathrm{v}_2, \ldots, \mathrm{v}_\mathrm{D})$. The best position previously visited by the ith particle is denoted as $\mathbf{p}_\mathrm{i} = (\mathrm{p}_1, \mathrm{p}_2, \ldots, \mathrm{p}_\mathrm{D})$. If the topology is defined such that all particles are assumed to be neighbors and g as the index of the particle visited the best position in the swarm, then p_g becomes the best solution found so far, and the velocity of the particle and its new position will be determined according to the following two equations:

$$\boldsymbol{v}_i^{t+1} = \boldsymbol{v}_i^t + c_1 r_1 \left(\boldsymbol{p}_i^t - \boldsymbol{x}_i^t\right) + c_2 r_2 \left(\boldsymbol{p}_g^t - \boldsymbol{x}_i^t\right) \quad (15)$$

$$\boldsymbol{x}_i^{t+1} = \boldsymbol{x}_i^t + \boldsymbol{v}_i^{t+1} \quad (16)$$

r_1 and r_2 are random variables in the range [0,1]; c_1 and c_2 are acceleration coefficients regulating the relative velocity toward global and local best [15].

5. CONCLUSION

In this paper, for control of railcar structure we are suggesting hybrid intelligent control concept that combine fuzzy logic with particle swarm optimization of fuzzy control parameters for stabilization and active vibration control.The main advantages of suggested hybrid fuzzy control algorithm are relative simplicity, universal control algorithm and fast response.

The design, manufacturing and experimental modal analysis of the railway vehicle modeldescribed in this contribution sets up many possibilities for the future research on this field.

The designed model and the knowledge about its dynamical behavior makes it nowpossible to develop different control strategies for improved structural damping of the elasticcar body to achieve a high ride quality.

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REFERENCES

[1] S. Popprath, C. Benatzky, C. Bilik, M. Kozek, A. Stribersky, J. Wassermann, "Experimental modal analyisis of a scaled car body for metro vehicles ",(2006),The Thirteenth International Congress on Sound and Vibration, Vienna, Austria, July 2-6,2006.

[2] UIC 513, "Guidelines for evaluating passenger comfort in relation to vibration in railway vehicles",UIC, 1994.

[3] Schirrer A., Kozek M., and Schöftner J., "MIMO Vibration Control for a Flexible Rail Car Body: Design and Experimental Validation." Vibration Analysis and Control–New Trends and Developments (2011).

[4] E. Foo and R. M. Goodall, "Active suspension control of flexible-bodied railway vehicles usingelectro-hydraulic and electro-magnetic actuators," *Control Engineering Practice*, vol. 8, no. 5, pp.507–518, 2000.

[5] Stribersky, A., Müller, H. & Rath, B. (1998). The development of an integrated suspension control technology for passenger trains, Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, Vol. 212, pp. 33–42.

[6] Hansson, J., Takano, M., Takigami, T., Tomioka, T. & Suzuki, Y. (2004). Vibration Suppressionof Railway Car Body with Piezoelectric Elements, JSME International Journal Series C 47(2): 451–456.

[7] T. Kamada, T. Tohtake, T. Aiba, and M. Nagai, "Active vibration control of the railway vehicle bysmart structure concept," in *19th IAVSD Symposium - Poster Papers*, S. Bruni and G.Mastinu, Eds.,2005.

[8] Schandl, G., Lugner, P., Benatzky, C., Kozek,M. & Stribersky, A. (2007). Comfort enhancementby an active vibration reduction systemfor a flexible railway car body, Vehicle System Dynamics 45(9): 835–847.

[9] M. Kozek, C. Benatzky, A. Schirrer , A. Stribersky, (2008), "Vibration Damping of a Flexible Car Body Structure Using Piezo-Stack Actuators", Proceedings of the 17th World Congress The International Federation of Automatic Control Seoul, Korea, July 6-11, 2008.

[10] Schirrer, A. & Kozek, M. (2008). Co-simulation as effective method for flexible structure vibration control design validation and optimization, Control and Automation, 2008 16th Mediterranean Conference on, pp. 481 –486.

[11] Schandl, G. (2005). Methodenuntersuchung zur aktiven Schwingungsreduktion eines Schienenfahrzeugwagenkastens, PhD thesis, Vienna University of Technology, Vienna.

[12] A. Preumont. Vibration control of active structures: an introduction. Kluwer, 1997.

[13] Ćirić I., Ćojbašić Ž., Nikolić V., Petrović E., "Hybrid Fuzzy Control Strategies for Variable Speed Wind Turbines", Facta Universitatis, Series: Automatic Control and Robotics, Vol. 10, No 2, (2011), pp. 205 – 217.

[14] Kennedy and Eberhart., Particle swarm optimization. IEEE International Conference on Neural Network,(1995), 1942-1948

[15] Qinghai Bai., Analysis of Particle Swarm Optimization Algorithm. *Computer and Information Science, Volume,*3 (2010), No.1.

30 YEARS OF THE EXPLOITATION OF LOCOMOTIVES TYPE DVM12

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Abstract *– In 2014 it will be 30 years from the beginning of the exploitation of diesel-electric locomotives type DVM12. This type of locomotives was developed in the 1980s in the Ganz-MAVAG factory based on the concept of the DVM2 locomotives for the needs of former Yugoslav railways, that is ŽTP "Beograd" (JŽ 641.3) and several industrial companies in former Yugoslavia and Hungary. The paper shows a brief history of supply, the introduction into traffic and exploitation of locomotives type DVM12.*

Keywords – Diesel locomotive, exploitation, history.

1. INTRODUCTION

The locomotives type DVM12 (hun. *Dízel-Villamos Mozdony 12*) were manufactured in the *Ganz-MÁVAG* factory from Budapest for the needs of Yugoslav railways and several industrial companies in former Yugoslavia and Hungary. They were designed for shunting service although they could be used both for traction of light freight and passenger trains on plain lines without train heating. The first locomotive was manufactured in 1984 and up until 1988 which was the year the last one was made a total of 40 locomotives were manufactured (table 1.).

Table 1. List of delivered locomotives type DVM12

Purchaser	Year of manufacture	Number of locomotives	Locomotive numbering
Yugoslavia-JŽ	1984	15	641.301-315
	1986-1988	16	641.316-320, 323-332, 335
Yugoslavia-industry	1986-1987	4	641.321, 322, 333, 334
Hungary-industry	1986-1987	5	A25.101, 102, 103, 104, 106
	Total:	**40**	

2. THE DEVELOPMENT OF LOCOMOTIVES TYPE DVM12

The locomotives type DVM12 were developed during the 1980s in the *Ganz-MAVAG* factory based on the concept of locomotives type DVM2 (926 locomotives type DVM2 were manufactured between 1954 and 1977 for the industrial companies and railways in Hungary, mostly for export – table 2.), using a well known mechanical part with certain modifications and modern electrical equipment. A new type of *SEMT Pielstick* 8PA4V-185VG diesel engine was built (manufactured in the *Ganz-MÁVAG* factory, with the license of the French company), main generator, power control system, compressor, electrical equipment, etc.

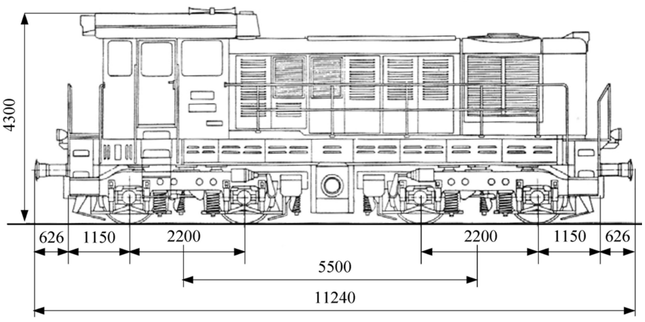

Fig.1. Locomotive type DVM12

The power of *SEMT Pielstick* 8PA4V-185VG diesel engine is 982 kW, but it was limited to 660 kW because of the compatibility with the characteristics of the main generator. Having in mind that the power of *Ganz-Jendrassik* XVI Jv 170/240 diesel engine, that was built in the locomotives type DVM2, is 441 kW, the traction characteristics of locomotives type DVM12 and DVM2 differed significantly. The maximum speed of 80 km/h remained the same.

The locomotives type DVM12 were delivered in two subtypes: DVM12-1 (manufactured in 1984) and DVM12-2 (manufactured from 1986 to 1988) with the same traction characteristics, but with slightly different equipment.

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Table 2. List of delivered locomotives type DVM2

Purchaser	Year of manufacture	Number of locomotives	Locomotive numbering
Prototype	1954	2	M424.5001, 5002
Hungary-MÁV	1957-1969	166	M44.001-166
	1969	5	M44.201-205
	1970	24	M44.501-524
Hungary-GySEV	1969-1971	5	M44.303-307
Hungary-industry	1963-1977	89	A25.004-013, 017-020, 022-040, 042-085, 088-099
Czechoslovakia-ČSD	1957	5	T455.001-005
China-CR	1957-1959	17	ND15.101-117
	1965	8	unknown
China-industry	1959	1	unknown
Albania-HSH	1959	1	unknown
Poland-PKP	1958	10	Lwe58.01-10
	1961-1968	263	SM41.01-263
Poland-industry	1961-1968	31	S101-131
	1963-1968	11	SM41.A-I, K-L
	1966	2	SL-3, 4
	1966-1971	64	SM41.979, 1016-1020, 1154-1160, 1164-1169, 1263, 1274-1276, 1325-1334, 1380-1383, 1422-1434, 1577-1586, 1602-1605
	1963	1	unknown
Yugoslavia-JŽ	1960-1961	15	641.001-015
	1971-1972	45	641.101-145
	1970	20	641.201-220
Bulgaria-BDŽ	1965-1968	65	51.02-66
Bulgaria-industry	1962-1970	41	DE60.01-41
	1965	1	DE60.01
	1971-1973	29	51.108-136
Turkey-industry	1976	5	TCDF 9-13
	Total:	**926**	

The manufacturing of locomotives type DVM12 lasted a relatively short time. Having in mind that in December, 1987 the *Ganz-MAVAG* factory disbanded into several independent companies the further research of the development of the locomotives of this type was not done.

3. THE LOCOMOTIVES DELIVERED TO YUGOSLAV RAILWAYS

The former Yugoslav Railways (JŽ) acquired 80 locomotives type DVM2 (table 2.) for the then ŽTP "Beograd", now Serbian Railways (ŽS). The locomotives were classified into 3 subclasses: JŽ 641.0, 641.1 and 641.2 which were each slightly different. Because of the positive experience with the locomotives type DVM2 in the beginning of the 1980s ŽTP "Beograd" decided to purchase more modern locomotives type DVM12 of which the subclass JŽ 641.3 was formed. It should be mentioned that before that there was the remotorization of locomotive JŽ 641.012 that was done in 1982 in the *Ganz-MAVAG* factory by building in the *SEMT Pielstick* 8PA4V-185VG diesel engine manufactured in the above Hungarian factory.

With the withdrawal of the locomotives type DVM2 in the late 1980s and during the 1990s the locomotives type DVM12 became the leading type of ŽTP "Beograd" shunting locomotives, although they were often used both for the traction of light freight and passenger trains on lines with lower axle load.

On May 1^{st}, 2014 the active fleet of ŽS consisted of 29 locomotives 641.3. Their arrangement by depots is shown in table 3. The locomotives with the valid revision are typed in bold.

Table 3. The arrangement of locomotives ŽS 641.3 by depots

Depot	Locomotive number
Beograd	**305**, **306**, 309, **310**, **312**, 313, 317, 319, 323, 326, **327**, 328, 329, 332
Zaječar	302, 303, 304, **318**, 320
Lapovo	308
Kraljevo	**330**
Niš	307, 311, 316, **325**, 331, **335**
Ruma	**314**
Zrenjanin	**324**

The locomotive 641.301 is in *Šinvoz* factory in Zrenjanin waiting to be scrapped while the 641.315 has already been scrapped.

Fig. 2. ŽS 641.332 (Photo: Marko Djukić)

Within the regular repair, which was realized in factory *Šinvoz,* the modification of locomotives 641.305 and 641.306 (in 2006) and 641.310 (in 2007) was done by introducing the microprocessor control. According to the same program the locomotives 641.314, 641.327 and 641.335 were modified in 2011 in factory *MIN* from Niš.

Fig. 3. ŽS 641.305 (Photo: Marko Djukić)

4. THE LOCOMOTIVES DELIVERED TO THE INDUSTRIAL COMPANIES IN FORMER YUGOSLAVIA

The industrial companies in former Yugoslavia were delivered 4 locomotives for the needs of:

- *Đuro Salaj* paper factory in Krško - 641.321 and 641.333;
- *UNIS* metal industry in Vogošća - 641.322;
- *Feronikl* factory in Glogovac - 641.334.

During the first decade of the 2000s the locomotives 641.321 and 641.333 were sold to the Italian construction company *Salcef* where they were renumbered into 2041.321 and 2041.333, and later into 2045.321 and 2045.333, respectively. During the last years these locomotives were engaged in the repair of tracks in Croatia.

Fig. 4. Salcef 2041.321 (Photo: Marko Djukić)

The locomotive 641.334 is in factory *Šinvoz* in Zrenjanin awaiting the regular repair.

5. THE LOCOMOTIVES DELIVERED TO THE INDUSTRIAL COMPANIES IN HUNGARY

The industrial companies in Hungary were delivered 5 locomotives for the needs of:

- Chemical industry *Borsodi Vegyi Kombinát* (BVK) - A25.101;
- Oil industry *Nagyalföldi Kőolajipari Vállalat* - A25.102 and A25.103;
- Chemical industry *Tiszai Vegyi Kombinát Rt.* (TVK) - A25.104;
- Oil industry *Dunai Kőolajipari Vállalat* - A25.106.

All locomotives that were delivered to the industrial companies in Hungary are in exploitation. The locomotive A25.101 operates in factory *Borsod Chem Rt.* (former *BVK*) in Kazincbarcika; A25.102 and A25.103 in company *MOL Rt.* in Algyő; A25.104 in factory *TVK* in Tiszaújváros; A25.106 in company *MOL Rt.* in Nyírbogdány.

Fig. 5. MOL A25.102 (taken from www.benbe.hu)

6. CONCLUSION

The locomotives type DVM12 were developed in the early 1980s in order to create a more modern type of DVM2 locomotives. Unfortunately, the manufacturing of the locomotives type DVM12 didn't last long and thus couldn't reach the amount of the original type DVM2.

In its period of exploitation the locomotives type DVM12 had a significant role in carrying out shunting operations and traffic on non-electrified lines of Serbian railways. In the last ten years or so an increase in the degree of immobilization and the reduction of reliability and economy of the service of these locomotives is seen as a result of inadequate maintenance and the problem of obtaining the suitable spare parts.

It is realistic to expect that the locomotives are in exploitation for another 10 to 15 years. The possibility of the locomotive remotorization should be considered in order to extend their operating life.

REFERENCES

[1] Gábor, C., Gombos, I., Meszár, A., Szabó, J., *50 éves a magyar vasút M44 sorozatú mozdonya 1957-2007*, MÁV Szolnoki Járműjavító Kft., 2007.

[2] Dallos, F., *A magyar szénhidrogénipar gazdálkodó és irányító szervezetei a MOL Rt. megalakulása elôtti idôszakban: 1933. VI. 8. és 1991. X. 1. között*, Kôolaj és Földgáz, Vol 34 (134), No. 8, Budapest, 2001.

[3] Djukić, M., *55 Years of Type DVM2 Locomotives Exploitation*, XV International Scientific-Expert Conference on Railway, Niš, 2012.

[4] Lánczos, P., Süveges, L., Szóródi, E., Villányi, G., *Fél évszázados a MÁV M44 sorozatú dízel-villamos tolatómozdonya és a Bah négytengelyes elővárosi személykocsi*, Magyar Vasúttörténeti Park Alapítvány, Budapest, 2008.

[5] Milićević, Z., Perović, N., *Dizel-električne lokomotive 641-300*, Zavod za novinsko-izdavačku i propagandnu delatnost JŽ, Beograd, 1993.

[6] *Author's personal archive.*

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THE INFLUENCE OF THE RAILWAY FLEET MODERNIZATION ON THE ENERGY EFFICIENCY

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Abstract – *The modernization of the fleet has a significant impact on the improvement of the energy efficiency of the railway system. The modernization of all types of rolling stock in different ways contribute to improved performance, but the biggest impact on energy efficiency has the modernization of traction vehicles which are direct consumers of energy. In this paper through a "case study" has been presented the modernization of DMU Series 712, produced by the Spanish manufacturer MACOSA, the impact on energy consumption and therefore energy efficiency and the improvement of the safety and quality of services in passenger transport will be presented.*

Keywords – Modernisation, energy efficiency, energy consumption, DMU.

1. INTRODUCTION

Macedonian Railways Transport JSC in its passenger fleet has several Diesel Multiple Units MACOSA Series 712 produced between 1975 and 1979. They are used in Macedonian passenger rail traffic. Their long-term exploitation necessitated the modernization. During the regular general overhaul of the DMUs, several changes are made and new systems where introduced. These interventions significantly have changed the basic design of the train and increased the level of safety and comfort for passengers. The following work operations where made:

- Completely new interior lighting (replaced the old internal neon lighting with the new LED lighting);
- New sound system;
- Installation of LCD TVs in every car with the steering command in the driver cabin of the train;
- Installing CCTV for security with continuous monitoring and surveillance monitor in the driver cabin;
- Installing an alarm system against theft and damage;
- Installing fire alarm system.

2. STRUCTURE OF THE ROLLING STOCK FLEET OF MACEDONIAN RAILWAYS TRANSPORT JSC

Macedonian Railways Transport JSC is a railway operator in Republic of Macedonia, which provides services for carriage of passengers and goods on the national and international level. In order to perform the basic services for the carriage of passengers and goods different types of traction vehicles are used. Those vehicles are presented in the following tables:

Tab. 1. Macedonian Railway Transport Company – Rolling Stock Fleet

	Locomotives				Other vehicles			
Year	Total	Electric	Diesel	Shunters	Coaches	EMU/DMU	Freight wagons	Passenger wagons
2012	43	16	14	13	48[1]	10	1011	68

The series and main features of electric locomotives are reported in the following Table.

Tab. 2. Electric Locomotives Features

Class	Use	Units (Total)	Units (Operational)	Factory Year	Revamping Year	Power (kW)	Max. Speed (km/h)
441	Service	8	4	1968-1987	2001-2011	3400-3860	160
442	Service	3	2	2001	2002-2011	3860	160
461	Service	3	3	1978	2006-2008	5100	150
462	Service	2	2	2009	-	5100	120

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The series and main features of diesel locomotives are reported in the following Table.

Tab. 3: Diesel Locomotives Features

Class	Use	Units (Total)	Units (Operational)	Factory Year	Revamping Year	Power (kW)	Max Speed (km/h)
661	Service	14	9	1961-1972	1998-2011	1454	120
667	Shunting	2	1	1981	1988-2003	882	
621	Shunting	2	1	1962	-	205	
642	Shunting	7	7	1962-2010	2001-2006	606	
643	Shunting	1	-	1967	2009	680	
734	Shunting	1	1	1957	2002	478	

The series and main features of EMUs/DMUs are reported in the following Table.

Tab. 4: Electric/Diesel Multiple Units Features

Class	Units (Total)	Units (Operational)	Factory Year	Revamping Year	Engine	Power (kW)	Max Speed (km/h)
412	4	2	1985-1986	1991-2006	Electric	1360	130
712	6	4	1977-2005	1988-2012	Diesel	412-522	120

The average age of the fleet is relatively high compared to the EU railways. According the UIC statistics the rolling stock over 35 years of age is belonging to one statistical group. However, it is worth nothing when the fleet often is more than 25-30 years, especially if we take in mind that the general overhauls extends the life span of vehicles for one to two decades. Old vehicles, particularly those which are not modernised often show lower energy performance (have high specific consumption for traction etc.), high emissions of gasses and higher costs for operation. The following tables are presenting the age structures of the fleet of the railways in EU and the Balkan's railways according to statistics presented by the UIC in 2012. If we analyse the use of the fleet is worth noting if the most of the diesel locomotives are used for passenger traffic, while the vice versa situation applies to the use of electric locomotives. This is justified by the incomplete electrification of the Macedonian railway network. The railway network is electrified along Corridor X, where the freight traffic on the north-south axis of the Balkan region is most common. Passenger trains, instead, often are pulled by diesel locomotives, to ensure proper and consistent service between major destinations, sometimes also on electrified sections. This happens when a train must operate through mixed sections (electrified / not electrified) to provide service for the transport of passengers, and this is the most effective way of execution of this transport through the use of diesel fleet, although not particularly convenient in cost and emissions. This kind of use has a negative impact on the type of diesel fleet, actually the large diesel locomotives are equipped with engines with large installed power suitable for traction of heavy (freight) trains and definitely over-dimensioned for passenger trains. The situation could be improved by extending the electrification of the Macedonian railway network or by using diesel traction with less installed power that adequate traction for passenger trains, such as DMU (Diesel Multiple Units) or four-axle and less power diesel locomotives. The following table shows a specific energy consumption / cost for each type of rolling stock. The strong side of the DMU and EMU compared with locomotives is pretty clear. Less weight, smaller engines with lower installed power leads to lower energy consumption. With the increase of their use in transportation of passengers and putting the focus on the use of large diesel and electric locomotives for freight traffic, where most freight demand more power for traction leads to a significant improvement in energy efficiency of the fleet. Also an coherent investment strategy for renewal and purchase of fleet in that direction is welcome, it would provide further impetus to improve performance.

2.1 Comparison with the EU countries

Different railways in Europe operate on networks of different sizes and performances, showing different results in terms of efficiency in energy use. However, power consumption can be compared between different countries just assuming uniformity, consistency and methodology of measures for comparison. The project Railenergy by UIC shows uniform data on consumption of railways respectively while presenting a set of key indicators. The effectiveness of the operation, including the technical characteristics of the railway system and the attractiveness of the services are represented by:

- Traction energy consumption per run - kWh / gross tkm or L / gross tkm for freight and passenger traffic;
- Executed transport energy consumption - kWh / road-km or L / road-km for passenger traffic and kWh or L / net ton km for freight.

In specific cases because of the absence of these data there is a need to use the general data. They can be calculated as the total traction energy (kWh/gross ton km), and compared with similar European cases.

The value of Macedonia is calculated by taking into account the prediction that in the passenger transport the average passenger weights 80 kg.

3. MODERNISATION OF DIESEL MULTIPLE UNIT MACOSA SERIES 712

Given that the use of EMU and DMU for passenger transport is far more efficient way to utilize the fleet and the use would mean a considerable saving of energy that makes this way of operation of the passenger transport energy efficient. Although the use of EMU and DMU itself is energy efficiency but considering that the fleet of Macedonian Railways Transport JSC consist of relatively old rolling stock, then the improving of the energy efficiency would contribute to an even better performance. Besides improving energy efficiency, modernization of DMU and EMU contributes to improved interior comfort, ambiance and performance. This can be a reason for greater attractiveness and appeal to passengers in same time resulting with more passengers and better utilization of the units in final case resulting in greater energy efficiency. In this context below is presented the modernization of DMU owned by MRTJSC which will be analysed as a practical example to improve energy efficiency. With the general overhaul the DMU is completely reconditioned all systems of the train, as the diesel engines, compressors, transmission, electrical installation, braking system and other sub-systems. The general overhaul and modernization of the DMU was made in MR Transport JSC Skopje.

3.1. LED lightening

The basic method of interior lighting of the train Series 712 is with use of neon lights. The poor lighting effect, the short use life, especially the energy inefficiency caused the need for replacement of the existing lighting system with modern LED lighting. The current electrical installation is used where electrical converters are installed for converting of the power from 24 VDC to 12 VDC. The LED lights are installed in the form of rods in three carriages, interspace and toilets. A 110 LED lights rods of 1 m length are installed. According the control measurements that where performed the reduced electrical consumption of energy is by 50% compared to the previous system. This shows that this measure achieved the goal of energy efficiency, and the effect of light is far better than neon.

3.2. Sound system

The basic model of DMU Series 712 possessed sound system, but over the exploitation that system was damaged and removed. In this modernization of the attic of the train a new cable network RR 2 x 0.75 was installed. The transition between the carriages was made with connectors and distribution boxes. In the two driver cabins the control system is situated (CD player, amplifier). The command is independent from the both driver cabins depending in which direction the train moves. Throughout in the train are installed 23 speakers in total with a total power of 250 W at maximum load.

3.3. LCD TV

In the space where the existing main electrical closet on the train is, a set of the main distribution board is installed. With the installation of the inverter the existing electric voltage of 24 VDC is converted to 220 VAC. Through the circuit breakers a network created which leads to more outlets of power. A signal cable network connecting the TV series is installed as same as seven LCD televisions, two in each car and at the section dedicated to first class. TV signals comes from driver cabins where CD player and amplifier are. The signal comes from the splitter which splits the TV receivers.The TVs through the connectors are supplied with a voltage of 220 VAC directly from the main switchboard. The video can be played from both driver cabins through the USB disk in the amplifier or CD.

3.4. CCTV

Throughout the train in the attic a signal cable network is installed and serves to transfer information from video cameras to the DVR. Eight cameras are installed, two in each car, in the section dedicated to first class and one in the cargo. In both driver cabins two monitors are set which allow to driver in real time to monitor the situation in the passenger compartment of the train. The entire content of the video surveillance 24 hours are recorded and stored in the DVR. The CCTV through the cable PP 2 x 0,75мм² is powered with 12 VDC. The power comes directly from the main switchboard.

3.5. Anti-theft and fire protection alarm system

The Diesel Multiple Unit is secured from theft and damage by fire. Throughout the train by the signalling network seven Motion sensors are installed, by two in each car and one in the section dedicated to first class. Also seven sensors against fire are installed. The connection of the sensors is through cable RR 12 x 0.22 mm² and 6 x 0.22 mm². The alarm unit is located in the main junction box. Above the door in the three carriages three sirens that signal when the sensor emit loud sound are installed too.

4. THE EFFECTS OF THE MODERNISATION OF THE DMU TOWARDS ENERGY EFFICIENCY

The effects of the modernization of the DMU towards the energy efficiency are high. From the November 2012 MZ Transport for passenger transport used to use two DMU and the remaining transportation of passengers was served by diesel locomotives series 661. With the modernisation and putting in to service the two overhauled DMU the energy efficiency was significantly improved. Table 11 shows a significant reduction in consumption of oil and grease. During the period of one year (from 01.08.2012 to 01.08.2013) the lubricants consumption is reduced by about 50%. While for the same time period the oil consumption is reduced by about 30%. This data shows that at the time of putting in to service of the two reconditioned and modernized DMU's a great energy efficiency and cost savings are made for the company.

5. CONCLUSION

Taken in consideration that in fact Macedonian Railways Transport JSC owns old traction and towed vehicles, the procedure for modernization of existing rolling stock it is of particular importance for the company. The financial savings are huge as same as the benefits felt by passengers themselves as users of railway passenger traffic. It can be concluded that the investment needed to modernize the DMU returns very soon and only as a result of savings in consumption of oil and lubricants, and not to neglect the fact that maintaining the DMU is considerably cheaper and simpler unlike diesel locomotives series 661 which are used for traction in the passenger rail traffic.

The introduction of the new systems in the DMU is to increase the level of safety, comforts and security of the DMV.

REFERENCES

[1] M. Steiner, R. Manser: "Energy Storage in Railway applications ", 2nd BOOSTCAP Meeting 2001

[2] Fribourg (CH) Kilibrada M., Zecević S., Upravljanje kvalitetom u logistici, Saobraćajni fakultet, Beograd, 2008

[3] MACOSA series 712, original manufacturer technical documentation, 1979

[4] F. Hentschel, K. Mueller, M. Steiner, "Energy Storage on Urban Railway Vehicles",UIC Railway Efficiency Conference May 2000

MEASURING ACCELERATIONS FRAME TRAM BOGIES T81 IN ORDER TO ESTABLISH THE REASONS FOR THE EMERGENCE AND DEVELOPMENT OF CRACKS

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Abstract *– This paper refers to the frames of tram bogies T81, fitted on operating trams types T6M 700 and T8M 700M in Sofia. In the material are described the measurements of the accelerations in the bogie frame. A method for processing the received data is described and analyzed. Based on this analysis, it is found that one of the reasons for appearance and development of cracks in the bogie frame are the large values of the accelerations and the resulting deformation and material fatigue.*

Keywords **– Tram, bogies, wheelset, wheels, acceleration, accelerometer.**

1. INTRODUCTION

In recent years an increasing number of cracks are found in the crossbar of the frame at the tram bogies T81. About 80 % of all bogies undergoing major repair have cracks. The cracks are concentrated in two sections - at each end of the crossbar below the weld.

In this material are published the results from a research on the impact of bumps in the railroad on the undercarriage of the trams and particularly to the bogie frame. Accelerations are measured in the frame and based on that are made calculations on the generated by them internal stresses using the finite element method and the program Autodesk Inventor Pro 2012.

2. PROBLEM

The frame of the tram bogie T81 is open type, it has an H-shaped spatial form. At both ends of the longitudinal beams are shaped the upper cups of the spring sets of the axle spring rate (ASR). In the middle of the longitudinal beams along the crossbar are formed the bottom cups of the springs from the CSR (*Fig. 1.a.*).

In the modified design the cups are with a closed top, and the new cups, of the already shorter springs lie on the upper sheet of the longitudinal beams (Fig. 1.b.).

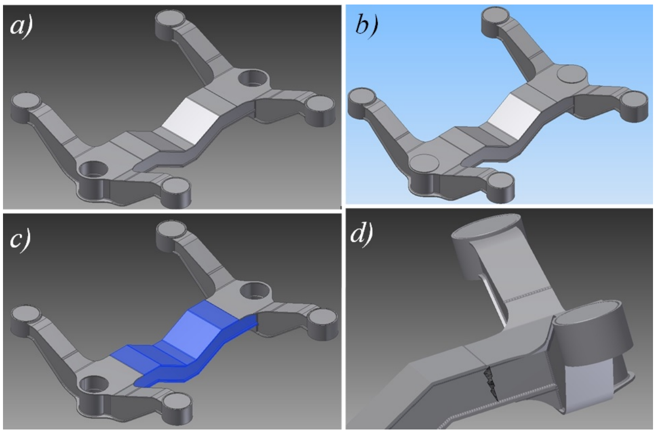

Fig.1. Tram bogie frame T 81

In Figure 1.c. in blue is shown the crossbar of the frame, and in Figure 1.d. is shown the location of the occurrence of cracks - along the weld between the upper sheet of the transverse and longitudinal beams.

According to the observations a crack first appears in the weld between the upper sheets of the transverse and longitudinal beams, then the crack starts developing randomly on the vertical sheets. In picture 1.a. is shown a crack in the weld and on picture 1.b. - The development of cracks in the vertical wall of the bar.

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Picture 1. Occurrence of crack on the weld and developments in the vertical sheets.

3. MEASURING THE ACCELURATIONS IN THE FRAME

For registering of the accelerations in the frame were used two measuring systems. The location of their installation on to the bogie frame is shown in Figure 2. Position 1. is the system for measuring accelerations in the cup above the spring of the ASR at the right wheel of the first wheelset. With position 2. is marked the system of measuring accelerations above the endangered section.

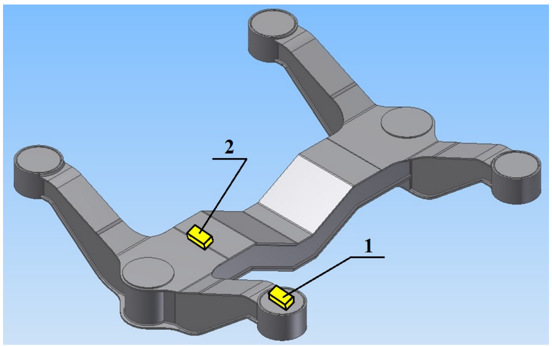

Fig.2. Locations of the measuring instruments.

The accelerometer (1) is shown in picture 2. a sensor from the company Analog Devices - ADIS16405 was used, which provides an opportunity to measure three axes of linear acceleration, angular velocity and magnetic induction of the Earth's magnetic field. The measurement range of the accelerations is ± 18g, at angular speed ± 300 ° / sec, magnetometer ± 2,5 g. The maximum operating frequency is 819,2 Hz. To locate the position and speed of the vehicle in the system is built-in a receiver of signals from the two global navigation systems - GPS and GNSS. Its type is LEA 6S, manufactured by the company *ublox*. To the inertial data is added the location data from the GPS / GNSS and both are simultaneously recorded on a SD card. Simultaneously, the navigation data is transmitted over a GPRS channel to a remote server.

Picture 2. Accelerometer placed on the cup of the spring from the ASR..

The second system (2) is made of a personal computer and a system for development by the company ST [1]. It is able to measure accelerations in three axes in the range ± 2g, ± 6g, with a frequency from 40 to 2560 Hz.

4. RESULTS FROM THE MEASUREMENTS

The route (Fig. 3.a.) includes sections with different track condition.

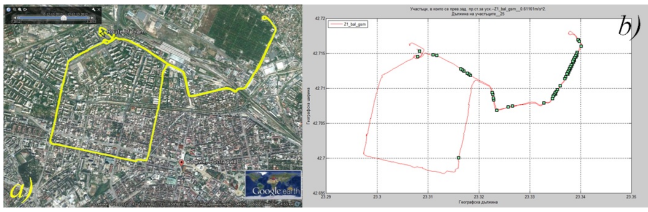

Fig.3. Route of the measurement.

The first part of the route the railroad is in good condition and the second part are the areas with poor railroad conditions.

In Figure 3.b. are shown the locations where the effective values of the accelerations are above a certain threshold value determined by the algorithm described in [2]. Cluster of sites which exceed the threshold value are observed in the second part of the route where the railroad is made of low channel rails embedded in panels. The values the accelerations in the cup of the ASR were recorded at a frequency of 240 Hz, and the accelerations in the longitudinal beam with a frequency of 160 Hz. Afterwards, the received signals are processed with programs developed in the programming environment Matlab. The peak and the effective value of the accelerations are determined, their spectral density is also determined.

The peak value of the acceleration is determined by looking for the difference between the maximum and minimum values of the acceleration in a window with a length of one second. The resulting peak values of the acceleration of the cup of the spring from the ASR are shown in Figure 4. And in Figure 5.are shown the effective values of the acceleration.

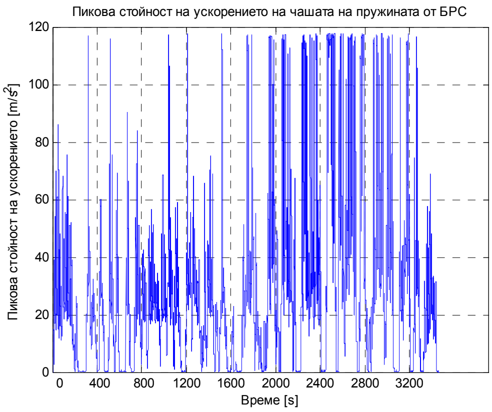

Fig.4. Peak value of the accelerations on the cup of the spring from the ASR.

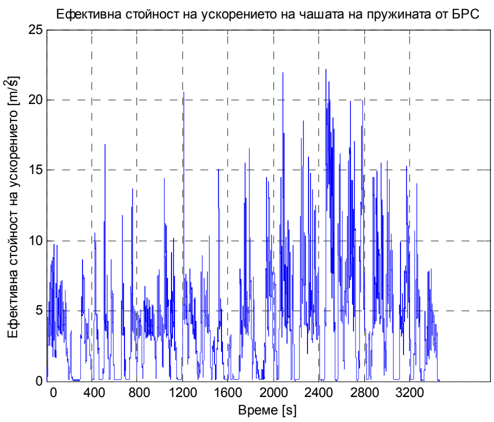

Fig.5. Effective value of the accelerations on the cup of the spring from the ASR.

The effective value of the accelerations are determined by the equation:

$$RMS\{A(n)\} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} A^2(n)} \qquad (1)$$

Where N - number of readings in the window, A - acceleration value for the n-th report. The window used for determining the the effective value is also with a 1 second duration.

The results obtained after processing the signals indicate that the second part of the route (after 1800th second) the values of the accelerations are much higher. There appear the more dangerous low-frequency vibrations.

5. INFLUENCE OF THE FORCES CAUSED BY THE ACCELERATIONS ON THE FRAME OF THE BOGIE

In Figure 6. is a diagram to the static forces acting on to the bogie frame. Where Q is the static load of the car body transmitted to the over-spring beam via the central bearing, Q / 2 is distributed static load by CSR and Q / 4 is the static load on each of the sockets.

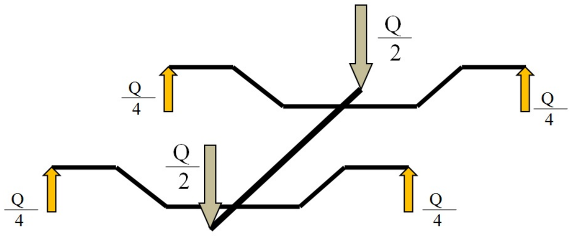

Fig.6. Scheme of the static load of the bogie frame.

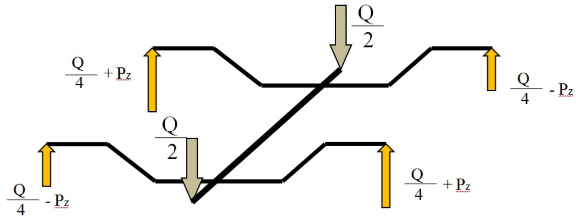

Fig.7. Scheme of the forces whenthe front right wheel is crossing a bump in the road.

When one of the wheels passes through a random bump in the road (Fig. 7.) depending on its shape (rising or sinking of the ground), emerge forces which get summed up with the existing static forces. Torsional tensions that have emerged in the frame are transmitted in the structure diagonally symmetric [3], and tend to deform the bogie frame in the scheme shown in Figure 8. Possible deformations of the frame of the bogie under the effect of the forces of static load and the forces caused by the unevenness of the road are shown Figure 9.

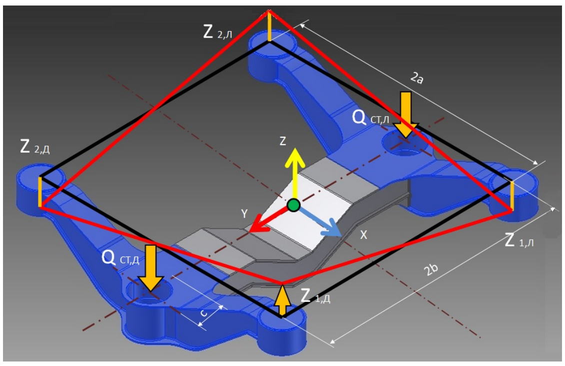

Fig.8. Scheme of the twisting of the frame.

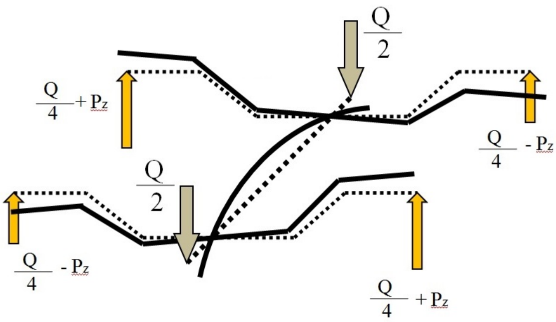

Fig.9. Deformation of the frame under the action of the forces caused by unevenness of the road.

After the passing of the first wheel through the bump in the road immediately after that the rear wheel also passes through it. Then follows a new twist to the bogie frame according to Figure 8. then the forces all have the same value but with opposite signs, i.e., follows a new twist on the beam in the opposite direction. The intensity of the process of successively twisting in opposite directions depends on the speed. The period is the time need for the two right wheels to pass over the same bump. At a speed of 3 m/s the time for the two right wheels of the bogie to pass over the same bump is about one second.

The crossbar beam of the bogie frame is subjected to a large number of cycles with loads the block at various levels, which leads to a strong reduction of the fatigue strength of the material.[4]

The values obtained for the stresses in the beam calculated with maximum values of accelerations exceed the stress values for the material and its border of drag out.

P_z values obtained after calculation are used to analyze the internal stresses in the finite element method using Autodesk Inventor Pro 2012. Analysis was made with the values obtained from the average and maximum acceleration under load.

In Figure 10. are shown the results of the calculations of the internal stresses in the bogie frame from the average values of the accelerations in scale with a maximum value of 200 MPa.

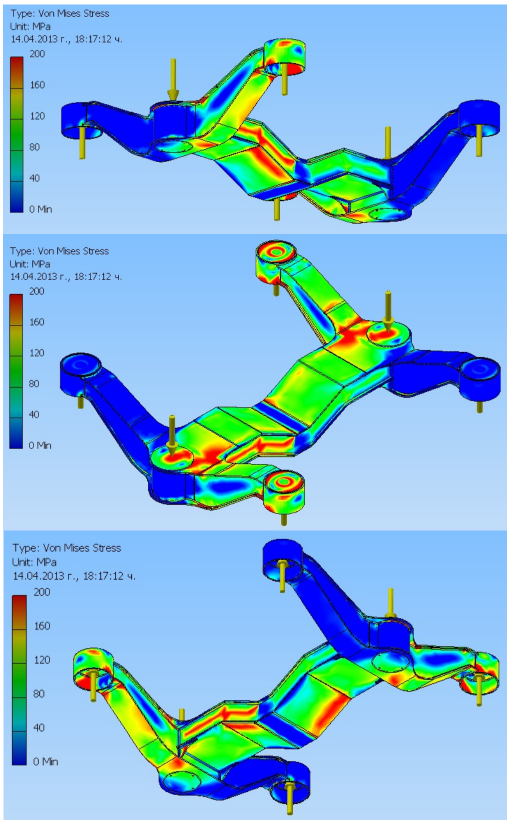

Fig.10. Tensions in the bogie frame, with an average values of acceleration.

Figure 11. Shows the results of the internal stresses in the frame at maximum acceleration, on a scale with a maximum value of 1400 MPa.

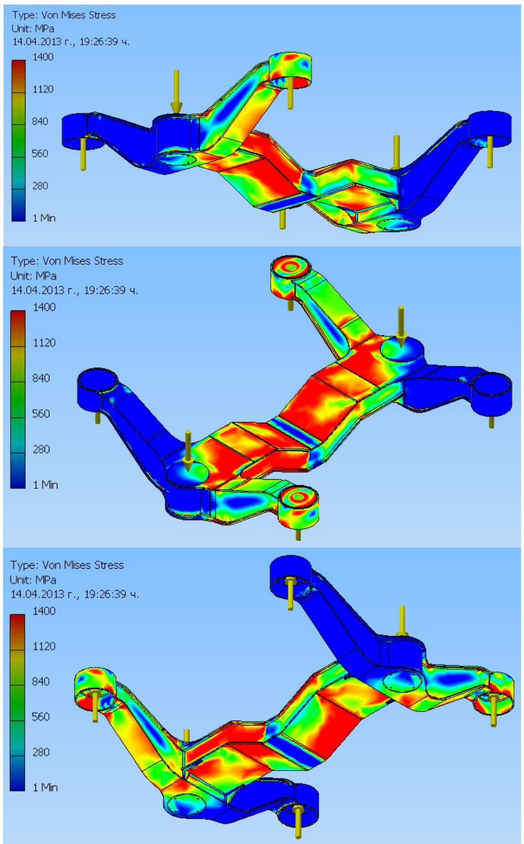

Fig.11. Tensions in the bogie frame at maximum acceleration.

Figure 10. And 11. clearly shows that the highest levels of internal stress in the crossbar are in the area of the occurrence and development of cracks.

6. CONCLUSION

The data published in this paper confirm that the track condition is one of the reasons for the emergence and intensive development of cracks in the crossbar of the bogie frame.

REFERENCES

[1] www.st.com, UM0285, User guide, EK3LV02DL Evaluation Kit, September 2006

[2] Iontchev E., Simeonov Iv., Miletiev R., *GSM/GPS/INS system for urban railway monitoring based on MEMS inertial sensors*, Proceedings of the 22nd Micromechanics and Microsystems Technology Europe Workshop, Tonsberg, Norway, 19-22 June 2011, pp. D81

[3] Ружеков Т., Пенчев Ц., Димитров Е., „*Теория и конструиране на железопътна техника*", ВТУ, София, 2011 г.

[4] Пенчев Ц., Атмаджова Д., „*Якост и дълготрайност на автомобилна и железопътна техника*", ВТУ, София, 2007 г.

THE BULGARIAN STATE RAILWAYS EXPERIENCE IN DETERMINING FATIGUE STRENGTH OF ROLLING STOCK STRUCTURES

Dobrinka ATMADZHOVA [1]

Abstract *– The mandatory tests of newly built railway cars have been implemented in the Bulgarian state Railways (BDZ) since 1966. The application of UIC/ORE B12/RP17 began in R-modification method (diagram Moore - Commerce - Jasper) in 1978. The UIC method of Goodman diagram became applicable in 1980, as determination of extreme values of the dynamic stress was performed as follows: by actual manifestation until 1982; 1982 - 1988 years – by "three Sigma" rule in the period 1982-1988 and by the method of SNCF since 1988. Although the UIC method is primarily intended for testing, it can also serve for calculations at the design stage. The paper examines the BDZ experience to determine fatigue strength at the stages of design and testing of rolling stock structures.*

Keywords – Railway vehicles, strength, fatigue, durability, testing and design.

1. INTRODUCTION

Determining the fatigue strength is achieved in stages of design and testing of rail vehicles.

The main factors (or variables), we operate are classified into two groups - resistivity and load as:

- the group of factors "resistivity" R is determined by the boundaries of: fatigue σ_{-1}, τ_{-1}, destruction σ_B, τ_B, yield stress σ_s, τ_s ... of material, i.e. R (σ_{-1}, τ_{-1}, σ_B, τ_B, σ_s, τ_s …);

- the group of factors "load" T is determined by the stresses: equivalent σ_{eq}, σ_{max}, τ_{max} and amplitude σ_a, τ_a, the asymmetry of the cycle r, etc., i.e. T (σ_{eq}, σ_{max}, τ_{max}, σ_a, τ_a, r …).

2. COMPUTATIONAL METHODS

Although all of the aforementioned factors that are probabilistic in nature (because they manifest themselves as "not being completely determined" but with some dispersion), the computation methods, which are involved, are usually based on deterministic but not on probabilistic approach, nevertheless that it is able to provide higher accuracy. It is because at the stages of design (construction) and feasibility studies, due to the extremely limited amount of information, the traditional deterministic approach is not only preferable to the probability one but in most cases it is the only approach possible to implement.

Based on the hypothesis of Palmgren-Miner related to linear summation of faults

$$\Sigma n_i/N_i = a \tag{1}$$

and Wöhler's law

$$N_i \sigma_i^m = N_Б \sigma_{-1D}^m \tag{2}$$

The formula obtained

$$\sigma_{-1D} = \sqrt[m]{\frac{1}{a.N_Б} \sum_{\sigma_i \geq 0,5\sigma_{-1D}}^{\sigma_m} n_i \sigma_i^m} \tag{3}$$

is an output one both for manufacturing and wagons and rolling stock in general. The main indications are: σ_{-1D} – fatigue limit of the piece; $N_Б$ – basic number of cycles (10^7); a – coefficient of accumulation ($a_{средно}$ = 1); m – power factor; σ_i and n_i – stress and number of cycles of the i-th degree.

Formula (3) adapted for application to transport objects with limited amount of information and a specified value of the safety factor λ is usually applied in the form:

$$\sigma_{-1D} = \lambda \sqrt[m]{\frac{L}{a.N_Б.\ell} . \sum_{\sigma_i \geq 0,5\sigma_{-1D}}^{\sigma_m} \left| n_i \sigma_i^m \right|_{\ell}} , \tag{4}$$

where: L is the distance traveled by the vehicle in km for the specified period of service (job), for example the whole amortization period, the period to overhaul, etc.; ℓ - length in km of a representative section (ℓ << L) characterized by a spectrum of load, which is in the real section L for the entire period of operation.

Formula (4) is applied most often after tests carried out in order to check for the satisfaction of the conditions of fatigue strength based on information

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gathered from them. In rare cases, it is applied at the stage of design to perform fatigue-strength calculations based on virtual representative section. This formula and the method based on it, in fact are principally not different from the method of British Railways (BR) to predict the service life of rail rolling stock in the part of "analysis of the effect of damaging by loads". Indeed, (4) where λ =1 and a = 1 can be represented by the ratio:

$$\frac{\ell}{L} = \frac{\sum_{\sigma_i \geq 0{,}5\sigma_{-1D}}^{\sigma_m} \left| n_i \sigma_i{}^m \right|_\ell}{a.N_Б.\sigma_{-1D}{}^m}, \qquad (5)$$

known by the name "relative damage" or "relative resource", which, related to 1 km mileage (i.e. with $\frac{\ell}{L}/\ell$) according to the given one in the method of BR definition, represents the reciprocal value of the distance, i.e. 1/L, where the very mileage L with the identical expression resulting from (4) is determined from:

$$L = \frac{\ell.N_Б.\sigma_{-1D}{}^m}{\sum_{\sigma_i \geq 0{,}5\sigma_{-1D}}^{\sigma_m} \left| n_i \sigma_i{}^m \right|_\ell} \qquad (6)$$

3. MANDATORY TYPE TESTS INCLUDING ASSESSMENT OF FATIGUE STRENGTH BY EXPERIMENTAL AND THEORETICAL NON-DESTRUCTIVE APPROACH

The mandatory tests of newly built wagons in Bulgaria have been introduced since 1965-1966, when the equipment of Wagon Lab with devices supplied from the USSR was finished and the testing device for stationary tests on wagon structures was built up. In this initial stage (until 1978) the strength assessment of static bench tests was performed by the standards of UIC while for the train (road) tests the USSR standards of wagon manufacturing were used to assess, even though indirectly and not so strictly, not only the classical strength but also the fatigue strength (or durability) of structures. Internal (created in NRIT-BDZ) regulations, standards, etc. based on own examinations were also applied.

The implementation of the uniform UIC/ORE method in modification R-method (diagram Moore-Commerce-Jasper) based on bulletin ERRI (ORE) B12/RP17 from 1977 began in 1978 [1]. It provides theoretical and experimentally verifiable complete assessment of fatigue strength (durability) in a form convenient for direct application, taking into account production, technological and other factors in real conditions of production and operation of wagons. In 1980, based on the bulletin published, this method began to be applied using the diagram of Goodman-Smith (or Goodman) and later, in accordance with the official regulations of ERRI (ORE), several clarifications and changes were brought in it, e.g.:

1. The definition of the minimum and maximum value of the total stress as well as the dynamic stress determining them based on the mandatory mathematical statistical processing with the rule of "three Sigmas", i.e. $\sigma_{dmax} = m(\sigma_d) + 3S_{\sigma d}$; $\sigma_{dmin} = m(\sigma_d)-3S_{\sigma d}$. Later, in 1989, this rule was substituted with the condition to determine σ_{dmax} and σ_{dmin} with a probability level P = 99,865%, 0,135% respectively.

2. The graphical determination of $\sigma_{d\,max} \equiv \sigma_{d|99{,}865\%|}$ and $\sigma_{d\,min} \equiv \sigma_{d|0{,}135\%|}$ with scales of construction especially selected by the method of SNCF: only for authoritative strains.

The so-called experimental-theoretical non-destructive approach is briefly characterized by well-established methods and programs, which are used to carry out defining[1] tests on a test sample[2] made to work under operating conditions in characteristic modes (train, shunting, Loading and Unloading Operations - LUO, etc.). At that strains and dynamic wheeled indices as well as the factors of "load" (strength, speed, acceleration, ...), which caused them are measured (or registered, reported, observed); the information collected from the tests is processed and the results obtained for different features (strain, acceleration, etc.) are compared with the admissible values of established criteria that are theoretically grounded and tested in practice.

It is the experimental and theoretical non-destructive approaches that all required (by government and departmental regulations) type tests have been performed through, including: strength, general dynamic and braking tests.

The main test facilities at the institute NRIT are:

a) Wagon laboratory for strength and dynamic tests, which has equipment with a capacity of not less than 48 channels, of which 36 amplifying; after 1979 it was reequipped with new apparatuses having greater capabilities, including automatic information processing.

b) Wagon laboratory for brake tests of train sets, locomotives and separate wagons also equipped with multi-devices capable of parallel registration of forces, pressure, acceleration, etc. in train and stationary mode.

c) The testing device for static testing of wagons that performs only some supporting functions with other types of testing is not examined here.

d) Other (supporting):

- facilities for turning "bogie-body" to measure the

[1] Defining studies are those which determine the basic characteristics of waggons: fatigue-strength, dynamic, braking, without destruction.

[2] The samply tested is most often a prototype but in some cases it is one of regular production, operation, etc.

stiffness and torsion and "wheel-rail" loading of rail vehicles;

- stationary laboratories for strength and dynamic tests, brake tests, etc.

Finally, regarding the mandatory type tests of wagons carried out until now using experimental and theoretical non-destructive approach it can be concluded that all (over 30) structures subjected to these tests and being in series production for the BDZ and export (from 1965 until the cease of this activity after the democratic changes) showed no mass defects in long-term operation. These tests, undoubtedly, contributed not only to ensuring regular production of wagons and increasing their reliability in operation, but also to creating developments of scientific and technological achievements, e.g.:

- identification, study and creation of theory of torsion vibrations of wagon structures;
- reducing the intensity of wear-out of flanges and rails and producing a bogie with radial entry into curves;
- a system of rapid unloading (stripping) oil from rail tankers, etc.

The test facilities created by the staff of the National Research Institute for Transport Ltd. (NRIT) in Sofia with the BDZ as well as the corresponding research methods and approaches, are mostly unique and many of them were patented as inventions.

4. BENCH TESTS ON FATIGUE STRENGTH

The bench tests on fatigue strength are held mainly by destructive approach as depending on the quality "durability" of the tested sample their duration is limited by the destruction[3] of the sample or by reaching a specified number of cycles.

The first bench tests of wagons in Bulgaria were conducted in 1970. Then, due to the transition to a new brand of steel for wagon manufacturing, it was decided to test its durability in a real (natural) structure of wagon (particularly of a tank) with longitudinal impact loads of a large number of cycles (500 000). It was possible due to the extremely high productivity of the device and its ability to operate in an automatic mode with relatively low energy consumption. A brief explanation of its structure and the main principle of operation will be given below.

The device of impact tests of wagons (Fig. 1) built in NRIT with the BDZ in 1969 is characterized by a flat and straight track section where there is a rope 1 stretched longitudinally on both sides guided by rollers 2, which in turn are mounted on the energy absorbing devices 3 in pillars 4 located at the four corners. Prior to each impact test the active wagon A, which is initially attached (bonded) to the rope, is accelerated to a specified speed and at the moment immediately before impact contact with buffers, it is automatically disconnected (released) and then after the impact the start position of wagons is restored (also automatically!).

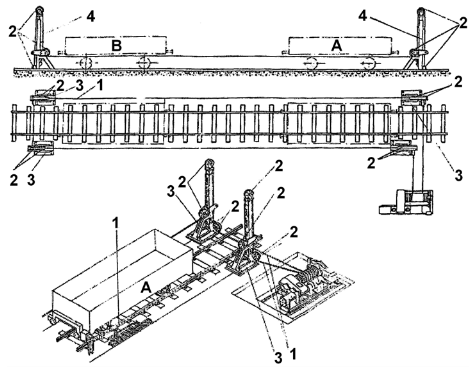


Fig.1 Device of impact tests of wagons.

The testing device is able to work with both with hand control and in automatic and semi-automatic mode according to three different programs (or schemes):

- by a traditional programme characterized with one active (accelerated) wagon and one passive wagon (Fig.1);
- by a programme with two active wagons accelerated into oncoming traffic;
- by "shuttle" programme characterized with two passive wagons and one active wagon between them, which is accelerating now in one, then in another direction.

The bench tests of wagon bogies under the requirements of UIC code 510 and code 515 in regard to fatigue strength with destruction were carried out first in the period 1986-1988. It was then when a model bogie of passenger carriage of type T73AD and a freight wagon Y25Cs were tested. Subsequently, in different periods several models of bogies family Y25, including also modifications "R" and "L", were tested.

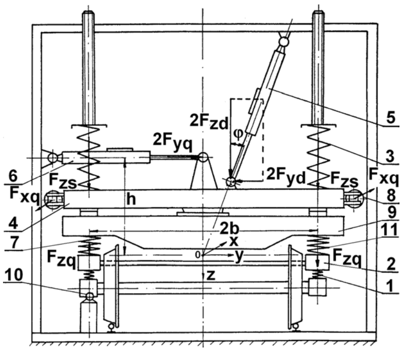
As it is known, according to the UIC requirements [2], the bench tests of bogies are performed at two stages:

- first stage – static tests;
- second stage – tests of fatigue strength,

as the obligatory condition is: the second stage is performed if the requirements at the first stage are met. Here we will put the accent on the second stage.

The tests of fatigue strength were conducted using two different devices: for bogies of freight and passenger wagons. The tests of freight wagon bogies corresponded exactly to the requirements of UIC code 510 for applying power of five components on each side of the frame beam: vertical static F_{zs}, vertical quasi F_{zq}, vertical dynamic F_{zs}, quasi horizontal (transverse) F_{yq} and horizontal dynamic (transverse) F_{yd}, as the structure of the testing device meets those requirements.

[3] The destruction may be up to a specific, predetermined level or to such a state that does not allow the continuation of testing.



1 – spring first degree; 2 – frame-side; 3 loading springs for static load; 4 – loading bar; 5 – inclined service cylinder; 6 and 8 – horizontal service cylinders; 7 and 11 – springs second degree; 9 – over-spring beam; 10 - support.

Fig. 2 Scheme of a device of testing the fatigue strength of a frame and over-spring beam of T73AD bogie

Regarding the methodology and the device (Fig. 2) for testing a passenger carriage bogie, taking into account the results of previously performed train (track) tests, it was considered necessary that [3]:

1) Over-spring beam (9) (Fig. 2) of the bogie should be included in the bench tests together (in parallel) with the frame without breaking the requirements of UIC related to the frame tests.

2) An extra pair of forces F_{xq} should be applied by service cylinders (8) (Fig. 2) with a quasi-static effect in longitudinal direction in order to simulate the friction "wheel-rail" forces in the same direction where the torque is seeking to obliquely deform the frame seen in plan.

According to the scheme of bench testing a passenger bogie in NRIT (Fig. 2), by service cylinder (5) (120kN) mounted at an angle, (4) vertical and horizontal dynamic components horizontal and quasi-static forces F_{zd} and F_{yd}, are exercised by means of the loading beam. The service cylinders (6) and (8) (40kN) are used to exercise the horizontal quasi-forces $2F_{yq}$ and F_{xq}; as by the action of $2F_{yq}$ vertical quasi-static forces F_{zq} are created. The vertical static load is implemented by coil springs (3) and the bogie springs, of the axle-box spring degree (1) and of the central one (11), are blocked in order to save energy and increase the frequency of loading.

The devices for testing passenger and freight bogies are given in Fig. 3 and Fig. 4.

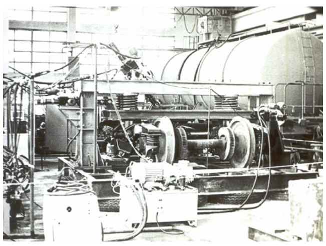


Fig. 3. General type of a device for testing dynamic fatigue of passenger bogies.

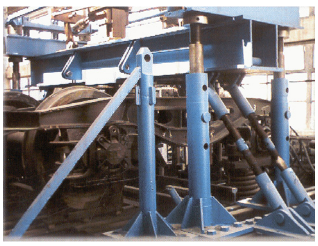


Fig. 4. General type of a device for testing dynamic fatigue of freight bogies.

The section modulus of turning "carbody-bogie" is measured by the stand (Fig. 5), which is a rotating platform 2 with rails 1 (maximum angle of 12°), building on the thrust bearing 4-driven system hydraulic power cylinders 3, which powered by hydraulic station. During rotation measured torque M and angle-ψ, forming diagram "ψ-M." The stand is used for testing the durability of a large number of cycles.

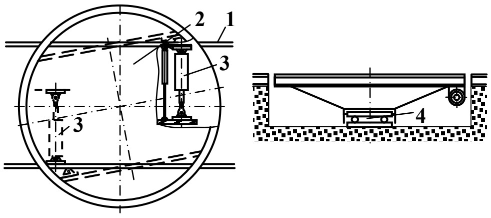


Fig. 5. Stand for measuring section modulus of turning "carbody-bogie".

In 1980-1991, using the improvised testing facilities in NRIT, fatigue tests on models (samples) were implemented for:

- side walls (particularly for their bearing pillars) and doors of wagon Eas;
- doors and windows of a passenger carriage;
- the "body-bogie" connection of a passenger wagon using own methodologies of this istitute.

5. CONCLUSION

1. The mandatory tests (strength, general dynamic and braking) for the newly built rail structures with indirect assessment of fatigue strength by the non-destructive approach have been introduced in Bulgaria since 1965.

2. The direct assessment of fatigue strength (based on tests as in the preceding point) has been applied since 1978 in compliance with UIC / ERRI B12RP17-1977.

3. The bench tests of fatigue strength by destructive approach on bogies of freight and passenger cars according to the requirements of UIC code 510 and 515 has been applied since 1986.

4. All newly constructed structures of wagons in Bulgaria, which have undergone mandatory tests, have shown no mass defects in long-term operation.

REFERENCES

[1] ERRI(ORE) QUESTION B12 Standardisation des Wagons Rapport №17, Utrecht 1977-1980.

[2] UIC – 510, 515.

[3] Petrovic D., M. Bizic, M. Djelosevic, Determination of dynamic sizes during the process of impact of railway wagons, Archive of Applied Mechanics, DOI: 10.1007/s00419-011-0549-5, (2011).

[4] Petrovic D., M. Bizic, Improvement of suspension system of Fbd wagons for coal transportation, Engineering Failure Analysis 25 (2012) doi:10.1016/j.engfailanal. 2012.05.001.

[5] Bizic M., D. Petrovic, Z. Djinovic, M. Tomic, Experimental Testing of Impact of Railway Wagons, Experimental Techniques, July 2012, doi:10.1111/j.1747-1567.2012.00850.

[6] Penchev T. Atmadzhova D. Strength and durability of automobile and railway equipment, S. 2007

Traffic and Transport

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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ASSESSING ACCIDENT SEVERITY RISK AT RAILWAY CROSSINGS IN SERBIA BY USING A MULTINOMIAL LOGIT MODEL

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Abstract – *This study used a multinomial logit model for modelling the accident severity on railway crossings in Serbia. The road sign warning device, exposure to traffic and maximum train speed at a given crossing were significantly associated with probability of accident frequency and significantly influenced the expected total number of fatalities or injuries caused by traffic accidents. Sensitivity analyisis is conducted to evaluate the effect of an explanatory variables changes on different accident severities.*

Keywords – Railway traffic safety, Railway crossing, Accident severity, Multinomial logit model.

1. INTRODUCTION

In the last few years, more collisions and severe crashes with a considerable material damage at railway crossings have been reported by the Serbian Rail Administration. For example, from 2007 through 2011, 312 accidents occurred at 2,138 railway crossings in Serbia. These accidents resulted in 59 fatalities and 130 injuries [1]. Currently more than 74% of the 2,138 railway crossings in Serbia are of passive control type (St. Andrew's cross and Stop sign). Therefore, investigations of the risk factors that may be associated with accident at railway crossings are vital in order to identify the crossings for future safety improvement.

The generalized logit model was used to explore the key factors that may be responsible for different degrees of accident severity at railway crossings [2]. A zero inflated Poisson regression model is used to describe the relationship between the extra zero count fatality or injury data and explanatory variables on railway crossings in Taiwan [3]. In this paper the analysis of accident severity is performed using a multinomial logit model.

2. DATA DESCRIPTION

The data supporting this research came from two sources; (1) Accident database of Serbian railway crossings (2007-2011) [4] and (2) the Serbian railway crossing inventory database (2007-2011) [5]. The available historical accident data set for modelling accidents at railway crossings were collected from 2007-2011 (5 years of accident information) [4] and provides the information about the time, location and conditions of accident for 2,138 railway crossings, but we observed 745 crossings.

Dependent variable accident severity is defined as an average impact per accident. The average impact is a weighted average of deaths and injuries in each accident. In this paper the accident severity is characterized as equivalent fatality. We equalized three injuries as an equivalent of one death according to Regulation on personal compensation (Official Gazette of the Republic of Serbia no. 34/2010) [6].

The accident frequency is the number of accidents that took place at a given time period. It is a countable variable that in our observations takes values from 0 to 5. The frequency of these values is given in Tab. 1. It represents the number of accidents that took place at observed 745 crossings in the period from 2007 through 2011. In this period of time, at 514 (69%) crossings there were no accidents, and at the remaining 231 (31%) crossings there were 312 accidents in total. This dependent variable accident severity is further categorized into three levels: Y=0 (i.e., accident severity of 0), Y=1 (i.e., accident

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severity of 1) and Y=2 (i.e., accident severity of 2). In other words, accident severity is 0 if there were no injuries or fatalities, it takes value 1 if there were less than 3 injuries per accident, and it takes value 2 if there were 3 or more injuries (or 1 fatality) per accident. The frequency of these values is given in Tab. 1.

Tab. 1. Observed accident frequency and accident severity frequency of Y=y

Accident frequency level	Observed frequency	Accident severity level	Observed frequency
$y = 0$	514	$y = 0$	633
$y = 1$	180	$y = 1$	72
$y = 2$	35	$y = 2$	40
$y = 3$	6		
$y = 4$	6		
$y \geq 5$	4		

The Serbian railway crossing inventory database (2007-2011) [5] contains the characteristics of each railway crossing and its traffic conditions. Let $\mathbf{x} = (x_1, x_2, x_3, \ldots, x_{17})$ be a 17–variable vector corresponding to a railway crossing. Here, x_1 denotes railway category which is 1 for main lines, and 0 for other lines. x_2 (EXPO) denotes geometric mean of number of trains per day and average annual daily traffic volume (AADT). x_3 denotes maximal train speed at a given crossing. x_4 is a binary variable for number of tracks, which is 1 for single track and 0 for multiple track. x_5 denotes crossing surface type, which is 1 for asphalt, concrete panels and rubber panels and 0 for cobblestone, wood planks and gravel. $(x_6, x_7, x_8, x_9, x_{10})$ is used to denote road type, which is $(1,0,0,0,0)$ for main road; $(0,1,0,0,0)$ for regional road; $(0,0,1,0,0)$ for rural and local; $(0,0,0,1,0)$ for farm and non-categorised and $(0,0,0,0,1)$ for street. x_{11} is a binary variable for crossing width, which is 1 for 6m or less and 0 for more than 6m. x_{12} is binary variable for sight triangle, which is 1 if exists and 0 if it doesn’t exists. x_{13} is binary variable for crossing angle, which is 1 for angle from 60° to 90° and 0 for less than 60°. $(x_{14}, x_{15}, x_{16}, x_{17})$ is used for warning devices which is (1,0,0,0) for road signs; (0,1,0,0) for flashing lights; (0,0,1,0) for full gates and (0,0,0,1) for half-gates.

3. MULTINOMIAL LOGIT MODEL

The analysis of accident severity is performed using a multinomial logit model. Multinomial logit models have gained popularity for this type of data mainly because they can account for the dependent variable’s ordinal nature.

Let $\pi_j(\mathbf{x}) = P(Y = j; \mathbf{x})$ be the probability of $Y = j, j = 0, 1, 2$. The multinomial logit model is given as follows [2]:

$$\operatorname{logit}[\pi_j(\mathbf{x})] = \log\frac{\pi_j(\mathbf{x})}{\pi_0(\mathbf{x})} = \alpha_j + \mathbf{x}\beta_j, \quad j = 1,2. \quad (1)$$

Here α_j is the intercept parameter, and $\boldsymbol{\beta}_j = (\beta_{j\alpha_j 1}, \beta_{j2}, \ldots, \beta_{j17})^T$ is 17- dimensional vector of regression parameters for j – the value of dependent variable. From Eq. (1) taking $\alpha_0 = 0$ and $\beta_0 = \mathbf{0}$ we obtain:

$$\pi_j(\mathbf{x}) = \frac{\exp(\alpha_j + \mathbf{x}\boldsymbol{\beta}_j)}{\sum_{k=0}^{2}\exp(\alpha_k + \mathbf{x}\boldsymbol{\beta}_k)}, j = 0, 1, 2 \quad (2)$$

The analyses have been done using the Rfunction *multinom* [7]. Here we also used the Akaike information criterion (AIC) stepwise procedure. The parameters were estimated using the maximum likelihood estimate (MLE) method. The results were presented using the function *mlogic.display* [8]. The coefficients for the final model accident severity are presented in Tab. 2.

4. MODEL APPLICATIONS

The predicted probability of accident severity, given a set of values in the explanatory variables, can be calculated by plugging MLEs $(\hat{\alpha}_j, \hat{\beta}_j)$, $j = 1, 2$ (Tab. 2.) and $(\hat{\alpha}_0, \hat{\boldsymbol{\beta}}_0) = (0, \mathbf{0})$ into Eq. (2) as follows:

$$\hat{\pi}_j(\mathbf{x}) = \hat{P}(Y = j;\ \mathbf{x}) = \frac{\exp(\hat{\alpha}_j + \mathbf{x}\hat{\boldsymbol{\beta}}_j)}{\sum_{k=0}^{2}\exp(\hat{\alpha}_k + \mathbf{x}\hat{\boldsymbol{\beta}}_k)}, \quad j = 0,1,2. \quad (3)$$

Sensitivity analyisis is conducted by using Eq. (3). We can evaluate the effect of the change of an explanatory variable on interest on the probability of severity of accidents, given that the other variables are held at their sample means or at certain levels.

4.1 Sensitivity analysis

By using Eq. (3) here we obtain the predicted probabilities of different accident severities at the different numbers of daily trains and different maximal train speed at a given crossing for two level of traffic control, road sign and half-gate.

Fig. 1 shows the plots of predicted probabilities of accident severity level $Y = j, j = 0$ vs. the number of daily trains in the range of 10 to 80 trains, Fig. 2 of $Y = j, j = 1$ and respectively Fig. 3 of $Y = j, j = 2$, for two level of traffic control, road sign and half-gate. For plots of predicted probabilities of different accident severity level vs. the number of daily trains in Figs. 1, 2 and 3. we hold the train speed on 71.5 km/h, anualy daily traffic on 1,540 at their sample mean in data set, road tipe as mainline, crossing width is 1 (6 m or less) and crossing angle is 1 (from 60° to 90°).

Fig. 1. shows that the probability of Y = 0, decreases with the increase in the number of daily trains. Moreover, the probability of Y = 1 increases slowly as the number of trains increases (Fig. 2.).

Tab. 2. Multinomial logit model result for accident severity

Independent variable	Severity level (y = 1)		Confidence interval	Severity level (y = 2)		Confidence interval
	Coefficients/SE		RRR (95% CI)	Coefficients/SE		RRR (95% CI)
Intercept	-5.76	0.694***	-	-5.55	0.826***	-
VOSIG(x_{14})	1.33	0.385***	3.78(1.78,8.04)	0.65	0.428	1.92(0.83,4.44)
VOBR(x_{16})	-1.28	0.667	0.28(0.08,1.03)	-1.93	1.051	0.15(0.02,1.14)
SIRPPB(x_{11})	1.26	0.297***	3.53(1.97,6.31)	1.20	0.378**	3.33(1.58,6.98)
MBRZ(x_3)	0.22	0.068**	1.24(1.09,1.42)	0.12	0.083	1.12(0.95,1.32)
EXPO(x_2)	0.08	0.015***	1.08(1.05,1.11)	0.05	0.017**	1.05(1.02,1.09)
BRKOLB(x_4)	-0.87	0.427*	0.42(0.18,0.97)	-0.36	0.463	0.70(0.28,1.73)
KATPRM(x_1)	-0.39	0.311	0.67(0.37,1.24)	0.74	0.430	2.09(0.90,4.87)
Residual Deviance: 668.53						
AIC = 700.53						

Level of significance: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

However, the probability of Y = 2 increases quickly with the increase in the number of daily trains (Fig. 3.). The predicted probability result on different accident severity levels indicate that more severe accidents are observed as the number of daily trains increases. It suggests that if warning devices are upgraded from road signs to half gates on railway lines on which train frequencies are or will be increased, signifficant reduction in less severe accidensts would occur. However, efects of such upgrade will not affect more severe accidents.

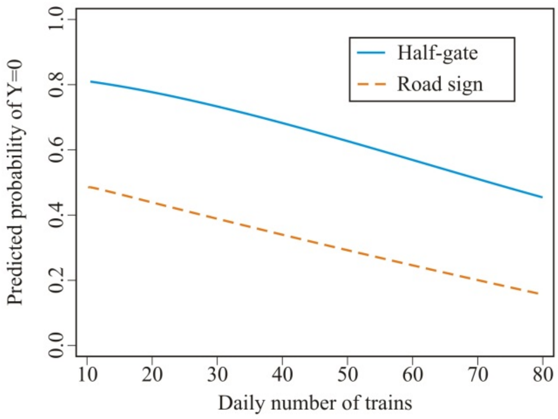

Fig.1. Predicred probabilities of accident severity $Y = 0$ as the number of trains increases (in range from 10 to 80) comparing two different protection systems

Fig. 4. shows the plots of predicted probabilities of accident severity level $Y = j, j = 0$, vs. the maximal train speed which is in range from 20 to 120 km/h, Fig. 5. of $Y = j, j = 1$ and respectively Fig. 6. of $Y = j, j = 2$, for two level of traffic control, road sign and half-gate. For plots of predicted probabilities of different accident severity level vs. the maximal train speed in Figs. 4, 5 and 6, we hold the number of daily trains on 26, anualy daily traffic on 1,540 at their sample mean in data set, road tipe as mainline, crossing width is 1 (6m or less) and crossing angle is 1 (from 60° to 90°).

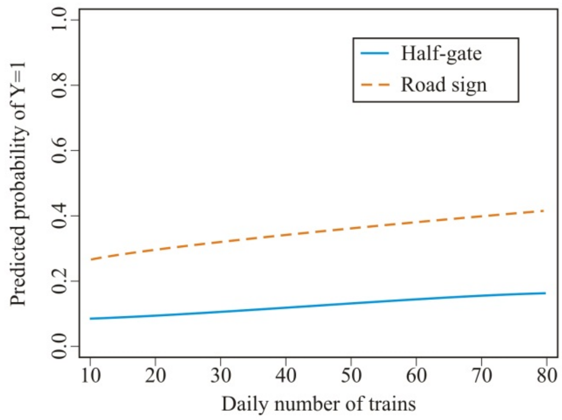

Fig.2. Predicred probabilities of accident severity $Y = 1$ as the number of trains increases (in range from 10 to 80) comparing two different protection sistems

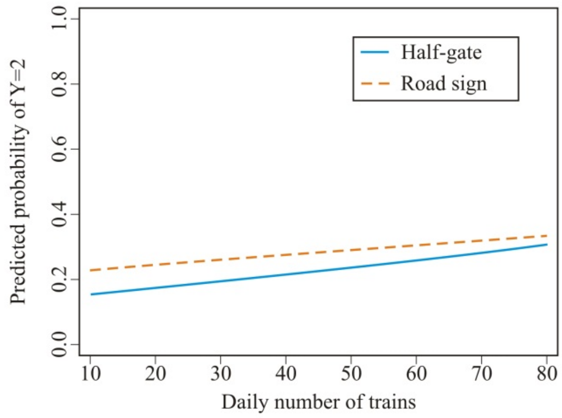

Fig.3. Predicred probabilities of accident severity $Y = 2$ as the number of trains increases (in range from 10 to 80) comparing two different protection sistems

Fig. 4. shows that the probability of Y = 0, decreases with the increase the maximal train speed. Moreover,

the probability of Y = 1 increases slowly as the maximal train speed increases (Fig. 5.). However, the probability of Y = 2 increases quickly with the increase in the maximal train speed (Fig. 6.). The predicted probability result on different accident severity levels indicate that more severe accidents are observed as the maximal train speed increases. It suggests that if warning devices are upgraded from road signs to half gates on railway lines on which train speeds are or will be increased, signifficant reduction in less severe accidensts would occur. However, efects of such upgrade will not affect more severe accidents.

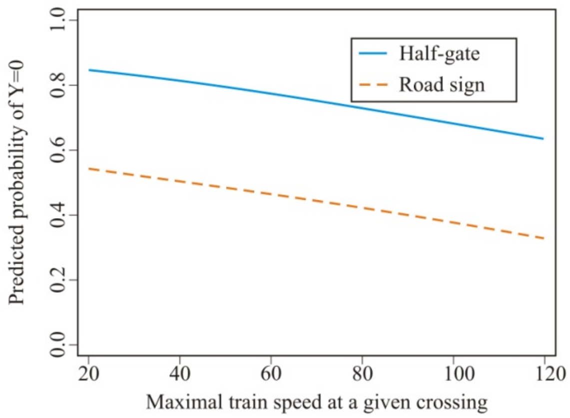

Fig.4. Predicred probabilities of accident severity $Y = 0$ as the maximal train speed at a given crossing increases (in range from 20 to 120 km/h) comparing two different protection systems

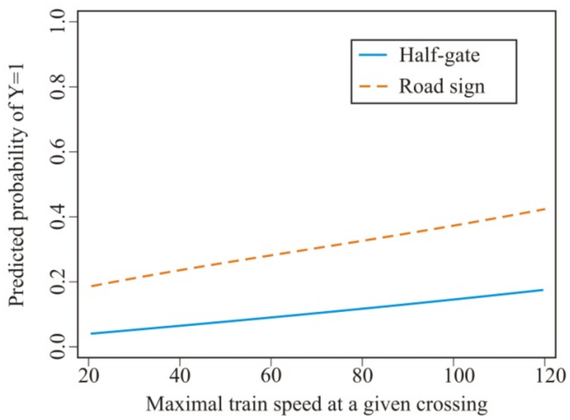

Fig.5. Predicred probabilities of accident severity $Y = 1$ as the maximal train speed at a given crossing increases (in range from 20 to 120 km/h) comparing two different protection systems

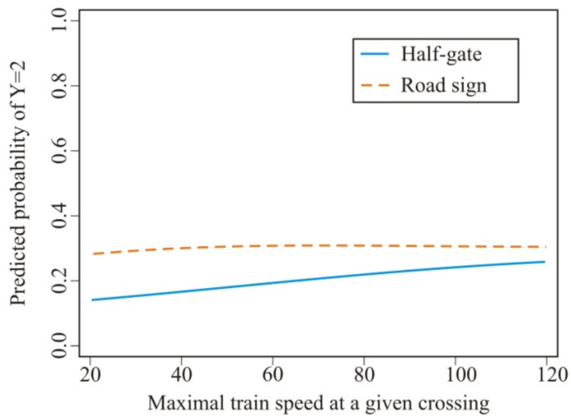

Fig.6. Predicred probabilities of accident severity $Y = 2$ as the maximal train speed at a given crossing increases (in range from 20 to 120 km/h) comparing two different protection systems

5. CONCLUSION

Data points used in this study i.e. accident reports and railway crossing's characteristics were extracted from two official data-bases containing actual events and site descriptions. Multinomial logit model were used for the assessment of accident severity. We also conduced sensitivity analysis to evaluate the effect of the number of daily trains and maximal train speed on accident severity.

REFERENCES

[1] Serbian Rail Administration. Statistics on accidents on Serbian railways 2011; in Serbian.

[2] Hu, Shou-Ren., Li, Chin-Shang., and Lee, Chi-Kang. (2010). "Investigation of key factors for accident severity at railroad grade crossings by using a logit model." *Safety Science,* 48(2), 186-194.

[3] Hu, Shou-Ren., Li, Chin-Shang., and Lee, Chi-Kang. (2011). "Assessing Casualty Risk of Railroad-Grade Crossing Crashes Using Zero-Inflated Poisson Models." *Journal of Transp. Engineering,* 137(8), 527–536.

[4] Serbian Rail Administration. Accident database of Serbian railway crossings (2007-2011), Serbian Railways; in Serbian.

[5] Serbian Rail Administration. The Serbian railway crossing inventory database (2007- 2011), Serbian Railways; in Serbian.

[6] Official Gazette of the Republic of Serbia no. 34/2010; in Serbian. Regulation on personal compensation.

[7] Venables, W. N., and Ripley, B. D. (2002). *Modern applied statistics with S*. Fourth Edition. Springer, New York. ISBN 0-387-95457-0.

[8] Chongsuvivatwong, V. (2012). *epicalc: Epidemiological calculator. R package version 2.14.1.6*. http://CRAN.R-project.org/package=epicalc.

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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ANALYSIS OF RAIL AND ROAD INFRASTRUCTURE FOR POSSIBLE USE OF CAR HANDLING SYSTEMS

Vladimir REDŽOVIĆ [1]

Abstract *– This paper presents an analysis of the current state of use of the car handling systems or car shuttle trains in Switzerland and in Germany. Due to the differences between the performances of these car handling systems conclusions and factors that are important for the future of those transport systems will be drawn and defined. On this basis the guidance for the consideration of the possible use of available capacity of the railway and optimization of the expansion of road networks will be given. The goal is to optimize and to reduce the constructional costs for both the road network and the railway as much as possible. Optimizing the combined use of road and rail infrastructure could provide a big contribution to environmental protection at the same time.*

Keywords – car handling systems, rail infrastructure, environmental protection, constructional costs.

1. INTRODUCTION

The Swiss are successfully applying car handling systems for passenger and vehicle transport since 1926, for example in Kandersteg a place near the capital of Switzerland 40 million vehicles have been taken care of by the car shuttle train.

Fig.1: Car shuttle train (Switzerland)
(source: BLS Switzerland)

In Germany similar car handling systems are to be abolished for economic reasons after many years of operation and the offer of the rail system is gradually reduced.

Car trains are driving through Germany since 1930. The first train drove 33 hours from Hamburg to Base. At the time a freight train was used to transport the vehicles. Passengers travelled with a separate train. The first proper car trains ran from 1956 on. During that year 930 vehicles were transported. The increase of vehicles being transported was steady until the beginning of the seventies. In 1973 185 thousand vehicles were transported on the 114 international routes and the 49 German routes.

Fig.2: Car train (Germany)
(source: photo: Frank May (dpa))

When the Deutsche Bahn found that this type of traffic was not profitable for them in 1978 40% of the offered routes were reduced. Through these reductions in offers and through the booming deals in air traffic this type of travel and vehicle transport have become less attractive and therefore difficult to maintain. In addition, roads and highways are expanded to a further and better standard which leads to a greater comfort in travel. It has become rather problematic for the Deutsche Bahn to find solutions that represent a competitive alternative to traveling by car. This

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situation has led to a situation where the few customers requesting a car train are handled by car transporting trucks instead of car trains.

Fig.3:car-truck transport / Deutsche Bahn AG (source:"obs/Jörg Gläscher / Deutsche Bahn AG")

2. TRANSPORT SYSTEM THE AND ITS FEATURES

A comparison of the two transport systems the car train in Germany and the car shuttle train in Switzerland shows significant differences. What are the systems features that enable economic operation of Swiss car shuttle trains and why does it not work with the German car train? In comparison to the German car train the Swiss car shuttle train has got one feature which significantly improves acceptance on behalf of car drivers. The car shuttle train is based on a direct integration of the car transportation by rail within the travel route. The train ride is part of the journey between the place of departure and the destination. It is not required to take a additional ride to the rail station as it is required for German car train a relatively complex process of the train ride.

The most important and decisive difference is the duration of the travel. Whereas the journeys of the systems in Switzerland are relatively short with a duration of less than 30 minutes and have a relatively high clocking of trains and therefore have short waiting times the journeys with the German car train take a few hours mostly during night. This means that the complexity of the journey with a car train leads to less attraction and less acceptance of this type of mobility and might as well come to an end.

3. ACCEPTANCE AND INFLUENCING FACTORS

The features of the transport system in Germany and in Switzerland and the analysis of their achievements and performance figures in transported vehicles let us define a set of important influencing factors. The most important factors are:

- travel time / driving duration
- price
- traffic safety
- comfort.

The above-mentioned four factors directly influence the decision of a car driver on the use of this transport option. These factors can, if they are taken into account, provide the opportunity to adapt the transport system and develop in a way that their function, acceptance and efficiency can be increased followed by a rise in the number of vehicles transported.

The driving duration and travel time can be reduced by optimizing the loading processes and faster trains.

By increasing the number of transported vehicles and the optimization of journeys, prices can be kept low at the same time.

Traffic safety is great in these transport systems and even greater if compared with the traffic safety of regular road traffic.

The comfort is greater or at least equal. The passengers remain in their own vehicles during the train ride and therefore do not have to control the vehicle. So the comfort can be estimated even greater.

4. BENEFITS

The car handling systems have a couple of benefits and should be offered as much as possible. As it was previously mentioned this transport system offers the following benefits:

- greater traffic safety
- reduction of road traffic
- economic effects
- train economy
- environment sparing

The interruption of a journey through the loading of the vehicle to the wagons and the combined journey by train provides a certain dynamics and provides the driver with a recovery period. This increases traffic safety.

The more vehicles are transported by rail, the more the road traffic is reduced. This is followed by many positive economic effects. The rail company benefits of the usage of existing capacity and infrastructure. The roads do not have to be further developed nor broadened, which can save both costs and area for road construction. This in turn has positive effects on the environment in terms of both exhaust emissions and in terms of noise and the use of the free space.

5. USE POTENTIAL

These transport systems are used where ever they are beneficial to car passengers in comparison to the use of a road. It becomes beneficial if the alternative is not much better with respect to the travel time (speed) the prices and other factors. The following conditions must be fulfilled similar to the car shuttle system in Switzerland:

- high frequency of trains (low latency)
- short travel time
- uncomplicated loading and continuing of the travel
- reasonable pricing (value for money)
- less attractive alternatives (length, time fuel and costs)

6. STATE ANALYSIS

Starting point for all solutions in traffic is the analysis of the current traffic situation regardless of whether it is motivated by the search for solutions to current traffic problems or part of a future-oriented planning of traffic. In both cases, the solution is depending on the one hand on the existing traffic infrastructure and on the other hand on the objective a solution is searched for. If a current traffic analysis shows that it would be necessary in an area to build new road or to broaden and or expand an already existing road, it is useful to analyze all possible alternative types of traffic solutions and possibilities and to take the existing infrastructure into consideration within the search of a final solution. Even in cases where the roads have sufficient capacity, it is prudent and advisable to consider other transport options for environmental reasons. Car shuttle services could be a potential solution to big cities for larger distances. The city of Belgrade as an example could use a rail connection with a car transport between "Topcider" and "Novi Beograd" or might even lead to "Karaburma" to ease congestion in the city center and also shorten the travel time through the city. In addition of the positive effects are possible to the environment because exhaust emission and traffic noise are reduced.

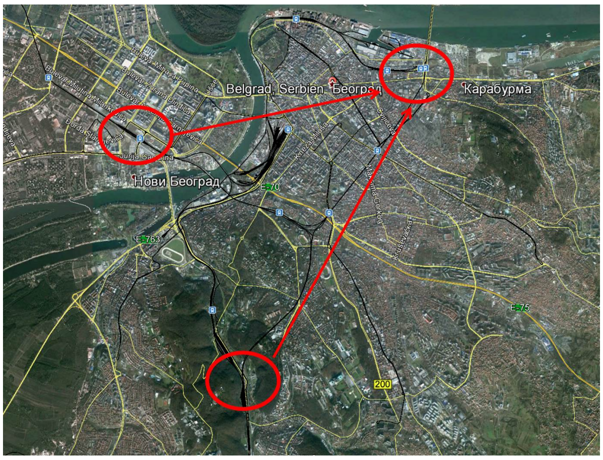

Fig.4: possible connection for car shuttle service (source: Google-Earth)

For a decision on the introduction of a car-train system many different potential analyzes have to be carried out. Primarily, the existing infrastructure of the railway is to be analyzed if potential routes that are eligible for car-train operation are given. After finding and defining the potential routes with respect of space and track systems as well as the length of the route between the potential car-train stations, the traffic analysis has to follow. It will show whether the new car transport option could be integrated successfully into the overall transport network. This test is based on the current traffic numbers, congestion analysis, waiting in traffic, possible bypasses the congestion endangered points or nodes and escape traffic. In the next step, the transport developments should - forecasts are analyzed to determine whether a car-train or a road version with extension of the road space is the better option for the future.

In this evaluation of the variants other already mentioned factors have to be co-analyzed for the assessment. This includes the environmental side of the two variants as well as the profitability and future significance in relation of the road and rail transport. With an existing rail infrastructure a car shuttle service is relatively inexpensive compared to a road renovation and expansion.

Car transport is particularly interesting to big cities with existing rail infrastructure and little free areas and spaces for street extension (such as Belgrade). In these cases, a road extension is always rather problematic and an ease of congestion by offering car shuttle service on the rail represents the best alternative.

Often industrial tracks with existing unloading ramps which are not in use anymore offer the opportunity to create a car handling system with relatively little effort.

7. DECISION

The decision for car shuttle service has to be taken on the basis of an accurate analysis and evaluation of traffic and economic conditions as well as environmental reason. Necessity and life potential (profitability) of the car handling system need to be scrutinized and carefully examined before an the decision for the creation of the system can be made. A relevant addition to the construction costs are operating costs. The revenue must cover the operation and maintenance.

8. SUMMARY AND RECOMMENDATIONS

Car train or transport of vehicles by train has been used for decades. In various versions they showed up in the past as both viable and non-viable. Despite many positive aspects and benefits in particular for the environmental protection, these traffic variations are integrated poorly into traffic. Both road construction and vehicle development have had a influence to this development. Both allow the achievement of driving at higher speed including high travel comfort which makes competition for car handling systems harder and more difficult. Nevertheless, there are still places which justify the use of these systems. Places like nature conservation parks are especially suitable. Urban areas are where the strain through traffic is very high and an alternative is required are another example. The important factors for the acceptance of these systems by car driving individuals are the loading processes (complexity and duration), speed (duration) and price. The targeted use of these systems and possible network expansion and further development and optimization of the loading processes could become a kind of combined public MIV (motorized individual traffic). The car shuttle trains in Switzerland show that these systems are functioning and development potential particularly in cooperation with politics is certainly there.

REFERENCES

[1] BLS Schweiz / Homepage
[2] Deutsche Bahn AG / Homepage

MODELING AND DESIGN FACILITIES FOR DEALING WITH DANGEROUS GOODS ON RAILWAY

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***Abstract** – The aim of this research is implementation of decision making methods and risk analysis in the process of planning of layout and working technology in railways. In the paper, these methods are applied in layout planning for dangerous goods handling facilities. We proposed methodology for determination of criteria and their weights relevant for adequate selection and ranking of alternative solutions. Three alternatives and their simulation models with technologies for dangerous goods handling at private sidings are developed. Delphi method is used for defining relative weights of criteria and AHP method is used for ranking of alternatives. The final result is the selection of optimal alternative in the sense of defining necessary capacities and optimal layout and working technology.*

Keywords – risk analysis, planning, railway facilities, dangerous goods, decision.

1. INTRODUCTION

A number of substances used in everyday life, categorized as dangerous goods are increasing. Their transport is inevitable and in the transportation process, handling points as initial-end points are of great importance. As regulations in the field of ecology and environmental security are becoming more stringent, the layout and technology planning of handling points becomes more up-to-date.

Contemporary trends are to focus dangerous goods transport on railway. In Europe, 8% of the total freight transported are dangerous goods, and about 25 % are transported by railways[1]. In order for railways to successfully deal with this, certain conditions are required - safety and transportation procedures for reducing risks of accidents during the transport, and adequate track capacity.

This problem has been approached differently. The comparison of transport means for dangerous goods is given in the paper [1]. In the papers [2] the accent is put on routing and scheduling problems in transport network. Risk accidents analysis of technologies for dangerous goods handling in marshalling yards is given in papers [3].

The subject of this paper is modelling of layout and working technology of handling points for manipulation with dangerous goods in railways.

2. METODOLOGY

Planning of railway facilities for dangerous goods is based on an integrated decision and risk methodology for selecting the most suitable layout and working technology alternative. The general integration process includes steps as stated below:

Initial step forms admissible set of layout and technology alternatives.
Step 1 defines set of criteria for decision making.
Step 2 identifies the initial weights of relevant criteria.
Step 3 performs AHP as one of technique for Multi Criteria Decision Making (MCDM).
Step 4 forms rank list of alternatives.
Final step selects the most suitable alternative.

[1] Inland transport of dangerous goods, Institute for European Environmental Policy, 2011

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2.1. Layout and technology alternatives

Designing of multiple alternatives of private sidings is necessary in order to perceive different technical-technological sides of the problem and perform their comparison. Alternatives' generation is performed by designer's creativity. For this reason, admissible set of layout and technology alternatives is initially formed in order to select an optimal alternative in the following steps. The simulation modelling is recommended for better comparison of the admissible alternatives. Simulation models give opportunity to show certain system behaviour in real conditions relatively easily and enable comparison of different system solutions. Such analysis is easy to perform changing conditions as system surrounding, service rate or arrival rate.

2.2. Relevant criteria

There is a great number of criteria that can be studied regarding selecting or ranking alternatives. For the purpose of defining the relevant criteria hierarchical structure is established, with criterion groups on top level and criteria at lower level. Hierarchical criterion structure used in this paper for layout and technology planning of handling points with dangerous goods consist of 5 criterion groups and 14 criteria (Table 1. - detailed are given in [4]).

Risk management in hazardous goods transport comprises a group of preventive measures, the state of preparedness to react, reactions to accidents and all this in order to decrease the possibility of an accident and possible consequences that can be potential ecological catastrophes.

In scientific literature, there are different opinions on what risk is actually and how it can be quantified [5]. Some authors think that risk is multidimensional and that it relates to situations that can be followed by a certain undesired event. While quantifying risk of dangerous goods influence on people, analysts are focused on one or two factors - accident probability and number of people that are affected by dangerous goods in the case of an accident. Two factors combination product and can be considered as expected accident consequence. In dangerous goods transport, risk is defined as expected accident consequence connected with two factors (p_i - accident probability and expected consequence C_{ij}). So, the risk *TR* on the private sidings (*P*), with the sidings segments (i) for dangerous goods (j) is defined as the sum of partial risks per siding segments (4).

$$TR(P) = \sum p_i \cdot C_{ij,} \ (\mathrm{i} \in \mathrm{P}) \tag{1}$$

The accident probability (p_i) is calculated as the product of shunting accident rate (per shunting movement) and wagons handling performance. This performance is in function of number of movements and number of wagons in shunting composition. Values of shunting accident rate are usually determined on the basis of accidents surveys from the previous period. The expected consequence (C_{ij}) is calculated from the exact number of employees and facilities within a buffer distance.

Tab. 1. Hierarchical structure of relevant criteria

Criterion group level	Criterion level	Expression
Transportation criteria	Technological functionality	Numerical units
	Utilization of certain facilities	
	Possibility of functioning in the case of an accident	Ling. description
Cost criteria	Infrastructure investments	Monetary units
	Exploitation costs	
	Infrastructure maintenance costs	
Spatial criteria	Handling point location in regard to residential zones	Ling. description
	Handling point location in regard to protected natural zones	
	Handling point location in regard to big economic entities	
Environment criteria	Ground pollution	Ling. description
	Influence on air pollution	
	Noise level	
	Vibration level	
Safety criterion	Risk of accidents	Numerical units

Due to the great number of the criteria, they should be grouped into influence groups according to what they represent. A great problem is criterion quantification within the groups according to possibilities of numeric defining. Certain criteria can be expressed in numbers which is the most favourable way for multi criteria decision making. However, for some criteria it is not possible to be expressed in numbers. Assessment of these criteria is possible on the basis of subjective factors expressed by linguistic descriptions: absolutely important, important, necessary, usual, unimportant and undesirable

2.3. Initial weights of relevant criteria

One of the main characteristics of multi criteria decision making is that the criteria may not have equal importance. Although subjectivity is expressed in the process of determining the relative weight of criteria there is a need for standardization. For the purpose of this paper, a Delphi method [6] is used to identify initial weights of relevant criteria. Procedure for determining the initial weight was carried out in three phases according to defined hierarchical criterion structure:

1. Determining the relative weight of every group of criteria (g_k, $k=1..5$)
2. Determining the relative weight of every relevant criterion (c_i, $i=1..14$).
3. Corrections of relative weight of criterion with its group weight (w^i_i, $i=1..14$).

The survey covered traffic and civil engineers, spatial planners and environmental experts. Two models were used in this process: *Expert for a field* and *All experts for all fields*. The case Expert for a field is simpler and experts assess criteria from their expert fields. Another model is more complex because the group of experts is heterogeneous. Here the determining of the criteria values is performed taking into the consideration conflicted interests, and this more closely corresponds to real-life conditions.

Determining the relative weights of criteria is very important for the final decision making process result. In this paper, initial values of criteria weights will be corrected by eigenvalues of the criteria resulted from the multi criteria decision making by AHP method.

3. CASE STUDY

3.1. Application on private sidings for dangerous goods

This paper considers the possibility of private sidings construction for the needs of "Batteries Factory Sombor". Main scope of work of this factory is production of starter batteries for passenger and freight vehicles. The factory needs certain amounts of raw materials in order to realize continuous production. It is, primarily, sulfuric acid, raw refined lead, lead-calcium-aluminium alloy, liquefied petroleum gas (LPG), coke polypropylene boxes and separators. Bearing in mind daily amounts of raw materials that are brought to the factory and number of single output batteries, certain capacity calculations have been made.

3.2. Layout and technology alternatives

This paper considers three alternatives of private sidings (Fig. 1). In the description of alternatives, emphasis will be on the technical characteristics, technological process and the position of facilities to handle dangerous goods.

In the first alternative, private sidings directly comes to the handling points in the factory area. Other two alternatives consider that the private sidings are located directly by the railroad. Because of that, additional pipelines are necessary for liquefied petroleum gas transport from the track to factory facilities, as well as lorries with reloading mechanization that would perform reload process from the wagons and transport to factory facilities. This isolation reduces the risk of accidents but it affects the shunting duration

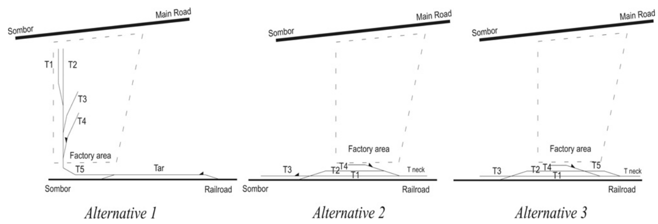

Fig.1. Proposed alternatives

Technology of private sidings servicing is modelled by the Queuing Theory. The model contains several simple consecutive servicing systems. In these simple systems shunting composition is considered as client, and consecutive servers are Sombor station, railroad and private sidings with handling points. Servicing durations are shown in the form of variable distributions obtained from statistical surveys (Tab.2).

Tab. 2. Exponentially distributed shunting durations

	Alt. 1	*Alt. 2*	*Alt. 3*
Server	λ	λ	λ
station (departure)	0.09	0.09	0.09
railroad	0.04	0.04	*0.04*
T_{ar} (arrival)	*0.06*	*0.1*	*0.1*
T_1	*0.2*	*0.25*	*0.25*
T_2	*0.25*	*0.17*	*0.17*
T_3	*0.33*	*0.33*	*0.33*
T_4	*0.33*	*0.14*	*0.33*
T_5	*0.2*	*0.25*	*0.14*
T_{ar} *(return)*	*0.2*	*0.2*	*0.2*
station (arrival)	*0.11*	*0.11*	*0.11*

Simulation models are performed in Simevents program, MATLAB 7.6.0 (R2008a) subprogram. From the simulation outputs we extract arithmetical mean ($\overline{X(n)}$) of private sidings occupations and total delivery durations as key technological indicators (Table 3). The usual way to assess the precision of $\overline{X(n)}$ is to construct a confidence interval for μ based on sufficient large number of independent experiments (n) [7]. For this reason we create 95 percent confidence intervals based on 80 observations (n=80). Also, Table 3 shows total number of wagons handling (WHP) with dangerous goods for alternatives 1. This performance directly influence on risk of accident during the switching at private sidings

Figure 2 presents arithmetical means of total delivery durations obeying the Low of large numbers. For performance of more then 40 observations it may be deducted that $\overline{X}(n)$ is not a random variable anymore, but it becomes arbitrary close to mathematical expectation μ

Tab. 3. Simulation model outputs

Server purposes		*Alternative 1*	
		$\overline{X}(n)$	Confidence interval
Arrival track	T_{ar}	17.9	17.9 ± 3.1
Track for *Habis* wagons	T_2	4.3	4.3 ± 1.0
Track for *Eas* wagons	T_1	4.4	4.4 ± 0.8
Track for tank with sulf. acid	T_3	2.7	2.7 ± 0.5
Track for tank with LPG	T_4	3.4	3.4 ± 1.1
Total duration		114.6	114.6 ± 8.6
WHP		30	

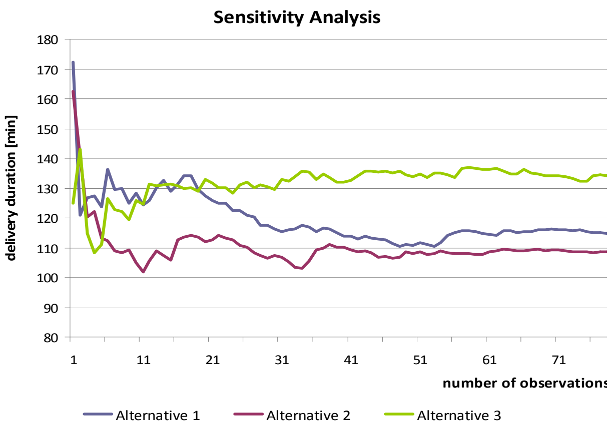

Fig.2. Expectation of total delivery durations

3.3. Evaluation of private sidings alternatives

In this methodology, pairwise comparison matrix obtained using the transformation of linguistic descriptions in numeric values has a central place. For evaluation of private sidings alternatives we form pairwise comparison matrix of dimension 14x14 for criteria in higher level and 14 matrix of dimension 3x3 for alternatives in lower level for each criterion.The final weights of the alternatives are evaluated as composite weights $U_j = \sum w_i^{\,f} E_j^{\,i}$. The best alternative is the one with *max* U_j.

Pairwise comparison matrix of alternatives:

for 1st criterion for 14th criterion

	A_1	A_2	A_3		A_1	A_2	A_3
A_1	1	0.5	0.33	A_1			
A_2	2	1	0.5	A_2			
A_3	3	2	1	A_3			

Vector priority for alternatives:

	U_j	rank
A_1	0.410	1
A_2	0.305	2
A_3	0.286	3

4. CONCLUSION

This paper contributes to the transport of dangerous goods through the formulation of a methodology for the ranking of layout and working technology for handling points with dangerous goods. In this methodology defining the relevant criteria and their weights has important place. Risk of accidents is indicated as the most important criterion, followed by criteria from the group of environmental (ground and air pollution). Cost criteria, especially maintenance and exploitation costs, are determined for the least relevant factors. In order to make realistic weight determination, Combination of Delphi and AHP methods is used in order to realistically determinate criteria weights. The procedure of multi decision making is performed using the AHP method.

The proposed methodology is used to evaluate alternatives in the case of private sidings with sulfuric acid and liquid petroleum gas handling points for the Battery Factory Sombor. For this purpose three alternatives with their simulation models were designed. Applying the methodology, it is found that the alternative with private sidings inside the factory area is the most suitable. The final result is the selection of optimal alternative in the sense of defining necessary capacities and optimal layout and working technology.

ACKNOWLEDGEMENT

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REFERENCES

[1] Rongrong, L., Yee, L.: *Multi-objective route planning for dangerous goods using compromise programming*, Journal of Geographical Systems, 13(2011)3, 249-271.

[2] Erkut, E., Gzara, F.: *Solving the hazmat transport network design problem*, Computers and Operations Research, 35(2008)7, 2234-2247.

[3] Bagheri, M., Saccomanno, F., Fu, L.: *Effective placement of dangerous goods cars in rail yard marshaling operation*, Canadian Journal of Civil Engineering, 37(2010)5, 753-762.

[4] Maksić, G., et al.: *Choice of infuential parameters of manipulation spot for the purpose of handling dangerous materials,* Ecologioca, 16(2009), 249-255.

[5] Cozzani, V., et al.: *Hazmat transport: A methodological framework for the risk analysis of marshalling yards,* Journal of Hazardous Materials, 147 (2007), 412-423.

[6] Linstone, H., Turoff, M.: *Delphi Method: Techniques and Applications,* Addison-Wesley, Reading (Massachusetts), 1975.

[7] Law, A.: *Simulation Modeling and Analysis,* McGraw-Hill Inc, New York, 2007.

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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RAILWAY TRAFFIC IN SUSTAINABLE ENVIRONMENTAL DEVELOPMENT AND ENERGY EFFICIENCY

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Abstract *– Increase the frequency of all types of traffic, causing an increase in emissions of air pollutants and impacts on global climate change and warming the Earth. The United Nations and the European Union is taking a series of legislative measures aimed at reducing emissions of greenhouse gases. Regarding rail transport, it is in terms of air pollution and energy efficiency and rational when it comes to diesel and electrified railway traction. In this paper, we give some guidelines on sustainable environmental development, given a short overview of regulations to reduce the impact of greenhouse gas emissions, as well as guidelines for the rational use of energy in transport, methods, processes and procedures for risk management and impacts due to climate change. Such an approach to the analysis of strategies and policies for sustainable development and energy efficiency is Execute by the Community of European Railways (CER) and the International Union of Railways (UIC).*

Keywords – Railways, Environment, Energy Efficiency, Risk Management, Climate.

1. INTRODUCTION

Rail transport is one of the most energy efficient and environmentally suitable ways to transport people and transport of goods, with the real possibility of further reducing the impact on air pollution and environmental accidents as possible. Electrically powered locomotives are no direct air pollution, a new diesel engines and their systems for the treatment of exhaust gases significantly reduce their negative impact, which is the ecological aspect is very important for the initiation of the negative consequences of the appearance of the greenhouse effect and thus environmental pollution and labor environment.

When it comes to the energy system, the state of Serbia, must in the future, to provide conditions for open, efficient, sustainable and secure energy market, which would establish a business climate conducive to the intensification of international trade. To achieve these conditions, it is the fulfillment of numerous factors, some of which are very important, as they increase energy capacity, higher production efficiency, cost-effective energy transfer, ie. with minimal losses, rational consumption, greater orientation to rail transport and others.

Improving energy efficiency, increasing competition, can actually reduce the overall need for investment in energy infrastructure and fuel costs, while striving to produce electricity from alternative renewable sources, as well as the substitution of fossil fuels.

2. EUROPEAN POLICY AND LEGISLATIVE MEASURES IN THE TRANSPORT

Far back as in 1990. adopted a draft plan of the overall consequences of successive reduction of greenhouse gases, and to about 20%, and in the case of having favorable circumstances, this reduction can be expected in about 30%, by 2020. and even 50%, in 2050.

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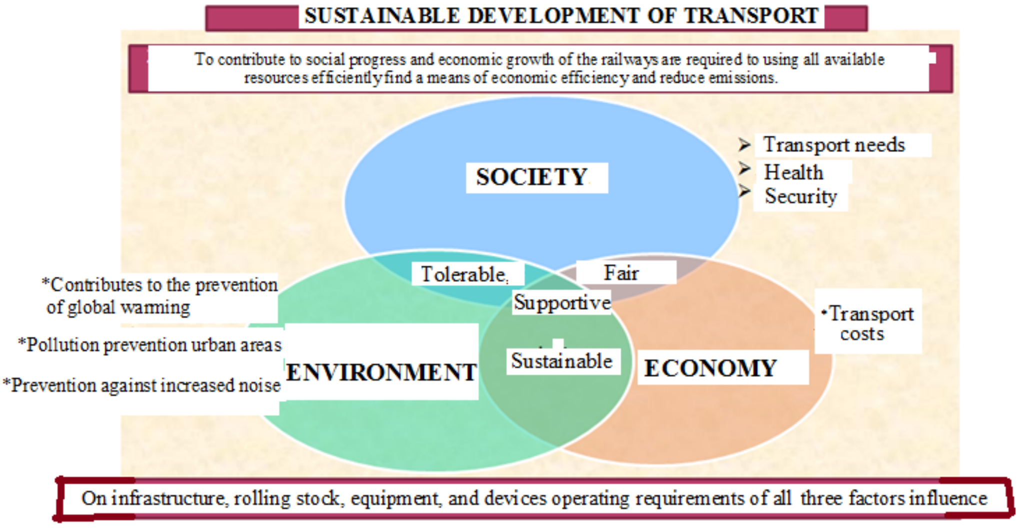

Fig.1. The effect of some factors on the sustainable development of railway transport

Surveys conducted in the EU in the field of nature conservation and environmental pollution have found that traffic directly cause about one quarter of the overall CO2 emissions, according to statistics from the period in 1990., And 2005th, only transport within the EU influenced the growth of CO2 emissions to 26%, of which more than 90% compared to road transport. Railways is the cause of only 0.6% of emissions from diesel consumption and less than 2%, by issuing plant to produce electricity. Some general factors that influence the sustainable development of railway transport, shown in Fig. 1.

One of the most important tasks in the field of sustainable development to protect the environment and achieve cost-effective energy efficiency, with a view to 2030 extention cable. Energy consumption in rail transport by 30%, compared to the baseline in 1990., A vision that by 2050., this value is halved. The function of the energy efficiency and the achievement of the objectives of the EU, the 2020th, the use of so-called "smart grid" will significantly contribute to reducing carbon dioxide emissions and reduce energy consumption, as well as the introduction of energy efficient technologies in the production of energy from renewable sources by 20%.

3. SMART GRIDS FUTURE STEPS

As mentioned, today's world is increasingly propagated so. intelligent products, or so. "Smart" devices that are used in many industries. All of this will be feasible by introducing intelligent power grid (Smart Grid), which is the so-called. energy future, which will households, industry, transport agents and other users to be connected to each other, so that the electricity spending as needed, with switched on and off.

Such possibilities become more interesting when one takes into account the combination of individual installations, components and devices, such as smartmeter, flexible electricity production in different types of plant automation and control home appliances. Although these are indications of the future, the EU is working intensively on the development and implementation of an integrated power grid (Smart Grid), which will represent the future of the network in many areas and in railway transport.

Intelligent electricity networks are better suited to compensate for fluctuations in power generation, particularly renewable energy. Such networks have special sensors and other communication systems to identify errors in the system and implement appropriate corrective measures. Smart grids will enable private users and companies to sell excess electricity (from household solar and wind plants, electric vehicles and energy and thermal systems), diverted to the public network.

4. MANAGEMENT RAILWAY SYSTEM IN ENVIRONMENTAL

Transport sector is one of the pillars of modern economy, although that, to a large extent influence the sustainable development of the environment. Potential role of the railway sector in terms of improving energy efficiency and reducing greenhouse gas emissions from fossil fuel and the use of alternative fuels with continuous improvement of efficiency of working capacity, comfort, and overall quality of transport services. To reinforce this position, the railway companies were forced to as part of its business conduct ambitious environmental policy with a special program of sustainable development, which implies a constant search for adequate solutions to issues that arise in this area.

One of the methodologies implemented by the railroad company's environmental certification in accordance with European regulations, which should allow the creation of environmentally friendly products transportation services, but also economically viable, with the smallest possible cost of raw materials and energy. Effects of acquisitions can control the flow of costs in the short term, but a growing wave of price, but indicates that only greater energy efficiency can bring long-term success. Some companies according to the protocol developed by ISO EN 14064 certification system, grading six gradations of CO2 in the process of making the product, in order to oblige and encourage all companies in the supply chain environmental management in their overall operations.

Energy management must have a clear policy, strategy and plan of concrete actions to improve the established time limits, numerical and practical goals. Special attention must be given to the rational use of energy, increase business productivity, purchasing power in terms of economic cost, investing in energy-efficient trains, stations and facilities, the use of energy from renewable sources and constantly monitoring the consumption of energy used.

The program for energy management are included in the standards ISO 9001 quality management and ISO 14001 accreditation for environmental management.

One aspect of energy management on the railway, is shown in Fig. 2.

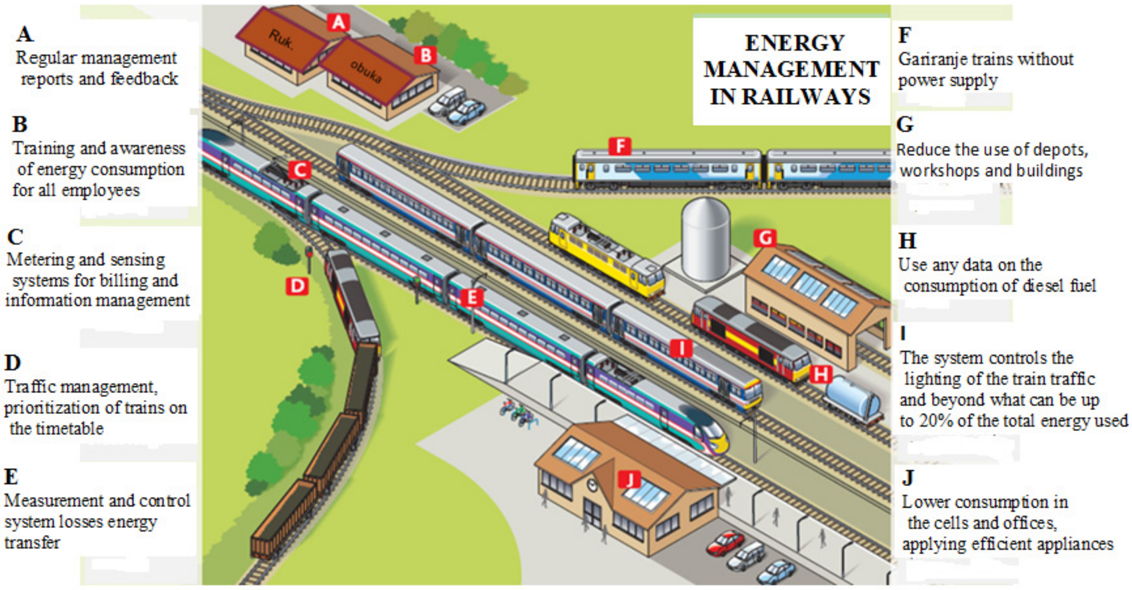

Fig. 2. Energy Management in Railways

This allows the recording of documents, in terms of: records of energy consumption, maintenance manuals, operating manuals, operating procedures and training manuals, audit operations, check management arrangements, the review process of policies, implementation of projects to encourage regular and formal review program effectiveness formed and others.

Power management on the railway is a systemic problem that requires regular reports and management information, training and awareness of energy consumption for all employees, metering and sensing systems for billing and information management, organizational measures to achieve energy savings in regular operation, measurement and management losses in the system of power transmission etc.

The so-called. smart and efficient energy solutions railways, means finding the right solutions for the measurement and analysis of energy consumption in railway systems through a common methodology for simulation comparison and prioritization, the "cost-benefit" analysis of the efficiency and also the necessary tools to support decision making in the market conditions. Search and formation energy database has the following objectives: an analysis in terms of life cycle cost of services, cost of energy, the ranking of the main technological performance for strategic planning, procurement of new vehicles, the modernization of the existing fleet and other.

All the factors involved in the use of energy are part of operational control, the optimization limits for reliable and energy-efficient operation. A significant contribution to the collection and analysis of data metering and control of all aspects of the business, achieved only in areas where there is no impact on the competitiveness of transport services, the contradictions between the achieved energy savings and time inefficiencies. Control and analysis of energy consumption affects the normalization of energy sorting at the source according to sections, regions, number of trains, to the driver in order to determine performance and efficiency.

Electricity for traction, is basically used to accelerate the train up to a certain speed, overcoming the resistance movement, supply management and supply of electricity for lighting, heating, cooling and ventilation wagons and the like. Technical solutions indicate that in addition to the investment in a modern fleet, the savings can be through the optimization of movement ("smart drive"), in order to efficiently use the degrees of handling and braking, with a measure of active traffic management and efficient layout of traction units.

Electric energy for cells, workshops, warehouses, stores and other business premises, must not be neglected, because these costs represent up to 30% of total electricity costs. Some aspects of energy saving rail traffic, according to field of application and applied technology can be:

1) Management (ecological "smart"-driving, managing and determining the capacity of trains).
2) Infrastructure (reversible substations for power transmission, power management in real-time asymmetric system, 2X1, 5 DC traction system, sub-parallel, reduced line redundancy, increase of voltage at 4kV, railway units to save energy).
3) Components of the vehicle (unit for depositing energy in vehicles, the reuse of heat loss).
4) Gear towing vehicle (super conductive transformers and inductors for towing, medium frequency distribution of energy, innovative hybrid diesel-powered).
5) Optimisation (new control technologies to reduce energy converters in inertial motion, active filtering technology to reduce losses of passive filter (reactor), the re-use of energy efficiency converters, control mean value of voltage).

Modern innovations for rationalization of electricity is the possibility of using technology to deposit on the vehicle, which in addition to its modularity and system complexity caused by multiple risk parameters related to sizing the influencing factors for energy savings, all of which are characteristic: size, weight and the ability of the system to deposit energy control concept, the necessary power supply vehicles, power and control of the diesel drive, driving systemic loss of power, vehicle information, schedule, profile stripes, etc..

Operating mode for energy savings in the case of diesel traction, based on equipment that has a range of power diesel engine in the optimum mode of deposition of energy, which can provide additional power in the absence of the required power at a time when there is a difficulty in the mining developments.

5. CONCLUSION

The aim of this paper is to initiate a future concrete cooperation between the railways and the Power Industry of Serbia aimed at a framework of rational energy use, protection and conservation of the environment, promotion and stimulation of all types of clean technologies in accordance with the fundamental principles of state policy. Serbian Railways should be included in the project of intelligent electricity grids, in order to efficiently balance the supply and demand of energy. To off-load periods of greatest demand and reduce wastage of electricity that occurs in long transmission networks.

REFERENCES

[1] "Railways and Environment, Building on the Railways, Environmental strengths", UIC, CER, Brussel, 2009.
[2] „Rail Transport and Environment, Facts and Figures", UIC, CER, Brussel, 2008.
[3] Mads Bergendorf, „Rail Energy-Intermidia Results", ECO Rails Workshop, Brussels, 2010.
[4] Enno Wiebe, „UIC/UNIFE Technical Recommendations", 11th UIC Sustainabillity Conference, Madrid, 2010.
[5] "Process, Power, People", Energy Efficiency for Railway Managers, UIC, Paris, 2008.
[6] Consultation on the Transposition of Directive 2008/50 of the EU Parliament and of the Council of 2008 on ambient air Quality and Cleaner air for Europe, 2009, DEFRA, London,
[7] Petrovic P., Vukmirović S., Jevtic M.: "The Importance of Interoperability of Railway systems in Serbia of the Trans-bonuses", Scientific-expert Conference on Railways, "XIV RAILCON '10", Niš, p. 239-242.
[8] Petrovic P., "Environment Serbia: a Review of the situation, Demography, Development of policy, Planning, education, Finance and Implementation," (Symposium "Research and Design for Economy-IIPP", University of Belgrade, 2007.
[9] Directiva 2009/29, Official Journal L 140, 05/06/2009 P. 0063 – 0087.
[10] Directiva 2009/31, Official Journal L 140, 05/06/2009 P. 0114 – 0135.
[11] Petrovic P., "Trends in Emission Control of Diesel Engines in terms of Global Environmental Pollution" (The Scientific Journal "Ecologica", No.13, 2007.. Belgrade, Faculty of "Futura", p.169-176).
[12] Petrovic P., "International Conference of Environment and Sustainable Development" (The Scientific Journal "Research and design for Economy-IIPP, University of Belgrade, No. 17-2007, V, p. 57
[13] Petrovic P., Popovic P., Lučanin V.: "Interoperability as a Strategy of Operational Excellence in the International Competitiveness of Rail Transport Serbia ", (12-th International Conference" Quality and reliability ICDQM-2009 ", Belgrade, Serbia, str.703-711th

SELECTION OF RAILWAY LEVEL CROSSINGS FOR INVESTING IN SECURITY EQUIPMENT USING HYBRID DEMATEL-MARIC MODEL

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***Abstract** – According to the European Railway Agency in the European Union every year on railway level crossings (RLC) occurs over 1200 traffic accident in which life loses more than 400 people. In addition to the tunnel and specific locations that are identified as black spots on the roads, RLC have been identified as potential weak points in road infrastructure that significantly jeopardize traffic safety. In Serbia exists about 2350 RLC, one of which is part the secured by systems of active and passive safety (traffic signs, light signals, sound signals, barriers, etc..). Insurance RLC is a material expenditure. The RLC selection process for installation of security equipment accompanied by a greater or lesser degree of criteria vagueness that are necessary for making the relevant decisions. For exploitation these uncertainties and vagueness in this paper was used fuzzy logic. This paper presents the application of a new method of multi-criteria decision-making (Multi-Attributive Real-Ideal Comparative Analysis - MARICA), which represents support in the selection process for RLC to invest in safety equipment. Identified are eight criteria that influence the investment decision. MARICA method was tested on the example of choice of eight RLC for investing in safety equipment.*

Keywords – Railway level crossings, Railway accidents, Multicriteria decision making, MARICA, DEMATEL.

1. INTRODUCTION

Railway level crossings represent the intersections of road and rail transport, and potentially are dangerous points for road users. In general terms level crossings may be provided with automatic or mechanical insurance. In addition, RLC may be and unsecured, where ramps for drivers do not exist and where they placed only traffic signs and other equipment. Ensuring a level crossing with automatic insurance (AO) requires a great investment because the devices to ensure the RLC are expensive and because there are a large number of RLC who are unsecured.

At the RLC a large number of accidents that accompany major material damage and loss of lifes happens. It is estimated that in road accidents an average of 1,308 people lose their lives daily in the world [5]. Of the approximately 54 million people who die each year in the world, the number of people killed in road accidents amounted to 1.17 million (2.17%).

According to the European Railway Agency, of the total number fatalities in railway accidents, 27% accounts at level crossings [5]. Traffic accidents at railway crossings are mostly consequences of improper and inattentive behaviour of participants in road traffic.

According to the statistics and forecasts of the EU [3], the volume of rail traffic in the next 30 years will be doubled, which is a direct indicator of the expected increase in emergencies at level crossings on all lines, including lines in Serbia. How the volume of traffic on the railways will increase, with a high degree of probability it can be concluded that the number of accidents at RLC will increase. In this context it will be necessary and to develop a plan of investing in RLC insurance in order to raise the level of traffic safety and accident reduction. Insurance RLC with automatic security equipment (barriers) is an investment that requires the allocation of significant funds while making decisions about investment management has a big responsibility, as approved funds must give proper effect. It is therefore very important that management has adequate tools to facilitate the process of selecting RLC and making investment decisions.

In this paper the application of MARICA method for making optimal investment decision in order to improve safety at RLC is presented. It starts from the premise that

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the observed RLCNO at a time when there are resources for a limited number of RLC on which to install new safety equipment for AO.

This paper presents a hybrid model of multi-criteria decision-making in which is implemented fuzzy DEMATEL method [2,4,6] and a new method of multi-criteria decision-making methods MARICA, which was developed at the Center for Logistics Research of Defense University in Belgrade. A modified fuzzy DEMATEL method was used in the evaluation process and criteria for determining weight coefficients. After determining the weight criteria, using the method MARICA, the value of criterion function are calculated. After determining criterion function the ranking of alternatives and the selection of the optimal railway level crossings for investing in safety equipment is peformed.

2. SETTING OF HYBRID DEMATEL-MARICA MODEL

Problem is formally presented by choosing one of the m options (alternatives) $A_i, i = 1,2\ldots.m$, which we evaluate and compare among themselves on the basis of n criteria ($X_j, j = 1,2\ldots.n$) whose values are known to us. Alternatives vectors are shown with x_{ij}, where is x_{ij} value of i-th alternative by j-th criteria. Because the criteria in varying degrees impact on final grade of alternatives, to each criterion we ascribe weighting coefficient $w_j, j = 1,2,...,n$ (where is $\sum_{j=1}^{n} w_j = 1$) which reflects its relative importance in the evaluation of alternatives. Weighting coefficients in this paper were obtained by applying fuzzy DEMATEL method. In the process of determining the weight coefficients of criteria most commonly more experts are included. Due to this, in the following section the process of implementing DEMATEL method in groups decision-making process is explained.

In the first step of fuzzy DEMATEL method the expert ratings is collected and calculated the average matrix $\widetilde{Z}$. For comparison of criteria pair experts use fuzzy scale in which are linguistic expressions represented by triangular fuzzy numbers $\tilde{z}_{ij}^{e} = \left(z_{ij,e}^{(l)}, z_{ij,e}^{(m)}, z_{ij,e}^{(r)}\right), e = 1,2,...,m$, where e represents the label an expert, and m represents the total number of experts. By aggregation of expert opinions the final matrix $\widetilde{Z} = \left[\tilde{z}_{ij}\right]$ is obtained. The elements of the matrix $\widetilde{Z}$ are obtained by using the expression (1), (2) and (3)

$$z_{ij,e}^{(l)} = \min_{M}\left\{z_{ij,e}^{(l)}\right\},\ M = \{1,2,...,e,...,m\} \tag{1}$$

$$z_{ij,e}^{(m)} = \frac{1}{m}\sum_{k=1}^{m} z_{ij,k}^{(m)} \tag{2}$$

$$z_{ij,e}^{(r)} = \max_{M}\left\{z_{ij,e}^{(r)}\right\},\ M = \{1,2,...,e,...,m\} \tag{3}$$

where $z_{ij,e}^{(l)}$, $z_{ij,e}^{(m)}$ i $z_{ij,e}^{(r)}$ represent the preference of the e^{th} expert, M represents a set of experts who participate in the research, e represents the label an expert, and m represents the total number of experts.

After calculation of matrix elements $\widetilde{Z}$, in the next step, elements of the normalized initial direct-relation matrix $\widetilde{D} = \left[\tilde{d}_{ij}\right]$ are calculated, where every element of matrix $\widetilde{D}$ belongs to the interval [0,1]. Calculation of matrix elements $\widetilde{D}$ (4) is performed by using the expression (5) and (6).

$$\widetilde{D} = \begin{bmatrix} \tilde{d}_{11} & \tilde{d}_{12} & \ldots & \tilde{d}_{1n} \\ \tilde{d}_{21} & \tilde{d}_{22} & \ldots & \tilde{d}_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ \tilde{d}_{n1} & \tilde{d}_{n2} & \ldots & \tilde{d}_{nn} \end{bmatrix} \tag{4}$$

The elements of the matrix $\widetilde{D}$ is obtained by summing the elements of the matrix $\widetilde{Z}$ by rows. After that, by applying expression (6), among the summarized elements the maximum element $\widetilde{R}$ are indentified. With simple normalization, expression (5), each element of the matrix $\widetilde{Z}$ is divided by the value which we get by applying the expression (6).

$$\tilde{d}_{ij} = \frac{\tilde{z}_{ij}}{\widetilde{R}} = \left(\frac{z_{ij}^{(l)}}{r^{(l)}}, \frac{z_{ij}^{(m)}}{r^{(m)}}, \frac{z_{ij}^{(r)}}{r^{(r)}}\right) \tag{5}$$

$$\widetilde{R} = \max\left(\sum_{j=1}^{n} \tilde{z}_{ij}\right) = \left(r^{(l)}, r^{(m)}, r^{(r)}\right) \tag{6}$$

where n represents the total number of criteria.

In the next step, the elements of the total relation matrix $\widetilde{T}$ are calculated. The total-influence matrix $\widetilde{T}$ is calculated by applying equation (7), where I represent identity matrix.

$$\widetilde{T} = \lim_{w\to\infty}\left(\widetilde{D} + \widetilde{D}^2 + ... + \widetilde{D}^w\right) = \widetilde{D}\left(I - \widetilde{D}\right)^{-1} \tag{7}$$

In the final step of DEMATEL method, elements of the matrix $\widetilde{T}$ are summed by rows and columns, bz the expressions (8) and (9).

$$\widetilde{D}_i = \sum_{i=1}^{n} \tilde{t}_{ij},\ i = 1,2,...,n \tag{8}$$

$$\widetilde{R}_i = \sum_{j=1}^{n} \tilde{t}_{ij},\ j = 1,2,...,n \tag{9}$$

where n represents the number of criteria.

Based on the values obtained by the expressions (8) and (9) the weight coefficients of criteria are calculated. The weight coefficients of criteria are determined using expressions (10) and (11)

$$\widetilde{W}_i = \left[\left(\widetilde{G}_i + \widetilde{R}_i\right)^2 + \left(\widetilde{G}_i - \widetilde{R}_i\right)^2\right]^{1/2} \quad (10)$$

$$\widetilde{w}_i = \frac{\widetilde{W}_i}{\sum_{i=1}^{n} \widetilde{W}_i} \quad (11)$$

where $\widetilde{w}_i$ represents the final weights of criteria which are used in the process evaluation of alternatives [4].

By determining the weight coefficients of criteria conditions for representing mathematical formulation of MARICA method are created. A basic setting of MARICA method reflected in determining the gap between the ideal and the empirical ponders. By summing the gap for each criteria of observed alternative the total gap for each alternative is determined. At the end, the ranking of alternatives is carried out; where for the best ranked alternative the one which has the lowest value of the total gap is chosen. The alternative with the lowest total gap represents an alternative that for the highest number of criteria had values that were closest to the ideal ponders (ideal values of criteria). MARICA method is implemented through six steps:

Step 1. The definition of the initial decision matrix (X). In the initial decision matrix the values of criteria (x_{ij}, $i = 1,2,...n; j = 1,2,...m$) for each of the considered alternatives are determined.

The elements of the matrix X are obtained on the basis of personal preferences of decision maker or aggregation of expert decisions.

Step 2. Determination of preferences according to alternatives P_{A_i} choice. It is assumed that the decision maker (DM) does not take into account the probability of some alternatives selection, i.e. there are no preferences according alternative choices. Then he can observe alternatives such way that each takes place with equal probability.

$$P_{A_i} = \frac{1}{m};\ \sum_{i=1}^{m} P_{A_i} = 1,\ i = 1,2,...,m \quad (12)$$

where m is the total number of alternatives that are chosen from.

In the analysis of decision-making with the a priori probabilities we assume that DM is neutral in relation to risk. In this case, all preferences according choice of the individual alternatives are equal i.e.

$$P_{A_1} = P_{A_2} = ... = P_{A_m} \quad (13)$$

Step 3. The calculation of matrix elements of theoretical ponders (T_p). The matrix of theoretical ponders (T_p), size n x 1 (n represents the total number of criteria) is defined. The elements of the matrix are calculated as the product of preference of choice alternatives P_{A_i} and the criteria weight coefficients (w_n).

$$\begin{array}{cc} & \begin{array}{ccc} w_1 & w_2 & \dots & w_n \end{array} \\ T_p = P_{A_i} & \left[\begin{array}{cccc} P_{A_i} \bullet w_1 & P_{A_i} \bullet w_2 & \dots & P_{A_i} \bullet w_n \end{array}\right] \end{array} \quad (14)$$

where n represents the total number of criteria and t_{pi} represents the theoretical ponder.

Step 4. Determination of the actual ponders (T_r) matrix elements.

$$T_r = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} t_{r11} & t_{r12} & \dots & t_{r1n} \\ t_{r21} & t_{r22} & & t_{r2n} \\ \dots & \dots & \dots & \dots \\ t_{rm1} & t_{rm2} & \dots & t_{rmn} \end{bmatrix} \end{array} \quad (15)$$

where n represents the total number of criteria and m represents the total number of alternatives.

Calculation of actual ponders (T_r) matrix elements is done by multiplying the matrix elements of theoretical ponders (T_p) and the elements of initial decision matrix (X) according to the expression:

- For criteria of „benefit“ type (higher value of criteria is preferable)

$$t_{rij} = t_{pij} \bullet \left(\frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \right) \quad (16)$$

- For criteria of „cost“ type (lower value of criteria is preferable)

$$t_{rij} = t_{pij} \bullet \left(\frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \right) \quad (17)$$

Step 5. Calculation of the total gap matrix (G). The elements of the matrix are obtained as the difference (gap) between the theoretical (t_{pij}) and actual ponders (t_{rij}).

Step 6. The calculation of the final values of criterion functions (Q_i) by alternatives. Values of criterion functions are obtained by summing the gap (g_{ij}) by alternatives (summing the elements of the matrix (G) by columns):

$$Q_i = \sum_{j=1}^{n} g_{ij},\ i = 1,2,...,m \quad (19)$$

3. APPLICATION OF DEMATEL-MARICA MODEL

The testing described DEMATEL-MARICA model was performed on example of prioritizing eight illustrative railway crossings. The eight criteria for the selection and evaluation of railway crossings were defined [3]:

$$G = T_p - T_r = \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1n} \\ g_{21} & g_{22} & \cdots & g_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ g_{m1} & g_{m2} & \cdots & g_{mn} \end{bmatrix} = \begin{bmatrix} t_{p11} - t_{r11} & t_{p12} - t_{r12} & \cdots & t_{p1n} - t_{r1n} \\ t_{p21} - t_{r21} & t_{p22} - t_{r22} & \cdots & t_{p2n} - t_{r2n} \\ \cdots & \cdots & \cdots & \cdots \\ t_{pm1} - t_{rm1} & t_{pm2} - t_{rm2} & \cdots & t_{pmn} - t_{rmn} \end{bmatrix} \quad (18)$$

K_1- The frequency of rail transport on the observed railway crossing (w=0.12);

K_2- The frequency of road transport on the observed railway crossing (w=0.19);

K_3- Number of tracks on the observed railway crossing (w=0.11);

K_4- The maximum permitted speed of trains on the chainage of level crossing (w=0.08);

K_5- The angle of intersection of the railroad and road (w=0.15);

K_6- The number of emergency events on the observed railway crossing in the past year (w=0.12);

K_7- Visibility of observed railroad crossing from the aspect of road transport (w=0.14);

K_8- The investment value of the activity in function of railroad crossing width (w=0.09).

For the evaluation of qualitative criteria (K_5, K_7 and K_8) fuzzy Likert scale was used [1]:

Table 1. Fuzzy Likert scale

R.b.	Linguistic terms	Fuzzy numbers
1.	Very good (VG)	(4.5,5,5)
2.	Good (G)	(3.5,4,4.5)
3.	Fair (F)	(2.5,3,3.5)
4.	Poor (P)	(1.5,2,2.5)
5.	Very poor (VP)	(1,1,1)

Table 2 shows the eight railway level crossings at which the presented model is tested.

Table 2. The evaluation of railway level crossings

Alter.	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
PPP 1	24	165	2	40	G	3	P	G
PPP 2	56	212	2	50	P	5	P	F
PPP 3	41	71	2	60	G	7	P	VG
PPP 4	36	168	1	50	F	5	VG	G
PPP 5	25	153	2	40	P	3	P	VG
PPP 5	12	220	2	50	P	5	P	F
PPP 6	28	137	4	60	F	6	F	VG
PPP 7	35	112	2	60	G	4	F	P
PPP 8	24	165	2	40	G	3	P	G

*PPP- Railway level crossings

Values of criteria functions (Q_i) by alternatives (Table 3) are obtained by summing the gap (g_{ij}) by alternatives, ie summing the elements of the matrix (G) by columns, the expression (19).

By using the expression (20) defuzzification of fuzzy numbers was performed.

$$defuzzy\ A = \left[\left(a^{(r)} - a^{(l)}\right) + \left(a^{(m)} - a^{(l)}\right)\right] \cdot 3^{-1} + a^{(l)} \quad (19)$$

where $a^{(l)}$ and $a^{(r)}$ respectively represent the left and right distribution of confidence interval triangular fuzzy number, $a^{(m)}$ represents the value in which a triangular function reaches its maximum value.

Tab. 3. Rank alternative by the method MARICA

Alternative	Q	Rank
PPP 1	0.0851	7
PPP 2	0.0629	3
PPP 3	0.0668	5
PPP 4	0.0614	2
PPP 5	0.1029	8
PPP 5	0.0729	6
PPP 6	0.0590	1
PPP 7	0.0635	4

It is desirable to have an alternative with the lowest value of the total gap. So, the highest-ranked alternative is the one that has the lowest value of the total gap i.e. alternative 7.

4. CONCLUSION

Through this paper the application of a hybrid DEMATEL - MARICA model is shown in making an investment decision on the selection of railway level crossings for installation the safety equipment. DEMATEL method is applied in part for determining weight coefficients. and a new multicriteria method – MARICA method in part of the alternatives evaluation. Application of the method has been elaborated through the steps and shown on the illustrative example.

Beside to the shown application in the selection of railway level crossings, MARICA method can be used to solve other problems of multi-criteria decision making. The main recommendations for further use of this method is: a simple mathematical form, the stability of solutions and the ability to combine with other methods, especially in the part relating to the determination of weight criteria.

REFERENCES

[1] Anandarao, S., Martland, C.D., *Level crossing safety on east Japan company: application of probabilistic risk assessment techniques*, Transportation 25 (3), 265–286, 1998.

[2] Buyukozkan, G., Cifci, G., *A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers*, Expert Systems with Applications, 39, 3000–3011, 2011.

[3] Ćirović,G., Pamučar, D., *Decision support model for prioritizing railway level crossings for safety improvements: Application of the adaptive neuro-fuzzy system*, Expert Systems with Applications, 40,6, 2208-2223, 2013.

[4] Dalalah, D., Hayajneh, M., Batieha, F., *A fuzzy multi-criteria decision making model for supplier selection*, Expert Systems with Applications, 38, 8384–8391, 2011.

[5] European Railway Agnecy, Railway safety performance in the European Union, 2011.

[6] Wang, Y.L., Tzeng, G.H., *Brand marketing for creating brand value based on a MCDM model combining DEMATEL with ANP and VIKOR methods*, Expert Systems with Applications 39, 5600–5615, 2012.

ON VALIDITY OF INTRODUCING THE ENERGY METERS ON ELECTRIC TRACTION UNITS

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Abstract *– In the new conditions in railway sector in Europe, energy efficiency is very important, both for reduction in CO_2 emmision, and for economical effectivness of railway operators. Mandatory instalation of devices for measuring electrical energy consumption can significantly contribute to this cause. Having in mind the relativly small costs of this obligation, and great possibilities for savings, introduction of this measure is completely justified. In addition, mandatory introduction of measuring devices will enable the fairer treatment of operators, and improve the competitivness of railway sector.*

Keywords – Energy metering, traction units, normative framework.

1. INTRODUCTION

Devices for measuring electricity consumption on railway vehicles are not a new technology, but they didn't have any significance for railway system so far. Although the metering consumption on the vehicle does not save any energy by itself, it is required for efficient managment of those procceses.

In current conditions in European railway sector there are three main areas where this is important:

- reduced electrical energy consumption,
- adeqaute and fair billing of consumed energy to each operator,
- possibility to choose the most favourable electrical energy supplier.

These three areas are very significant in railway operators buiseness, and the first one is also important for the entire society, because of the need to reduce the CO_2 emmision.

It is also required that the railway services market be regulated in a way that adequately valorizes energy efficient operators, and leaves them with the possibility to choose the most favourable energy supplier. In order for this to be possible, it is important to have the ability to accuratly measure the energy consumed in transporting as well as billing of metered consumption.

2. NORMATIVE FRAMEWORK FOR DEVICES FOR MEASURING THE ELECTRICITY CONSUMPTION ON RAILWAY VEHICLES, AND THEIR USE ON EUROPEAN RAILWAYS

Until the development of common european regulative for railway sector, devices for measuring the electricity consumption were not standardized in any of the european countries. Basis for enacting the common norms for these devices was created when European Union adopted a directive 2001/16/EC about interoperability of railway systems. Common technical specifications of interoperability (TSI) were based on the directive, and common norms for devices for measuring eletricity consumption were defined within them for the first time.

These devices are defined in two TSIs: “TSI for locomotives and passenger railway vehicles” and “TSI for infrastructure”. Both TSIs refer to the coresponding EN norms that explain the detailed demands and standards for these devices and their components. EN 50463-1 to 5 series of standards named “application on railway – measuring energy on train” were enacted for them. This system is defined to serve for managing energy consumption as well as serving for energy billing in EN 50463 (general part). Functional chart of the system is given on figure 1. Device for measuring energy consumption on platform vehicles is not mandatory according to the currents TSIs, unless it is used for billing the consumed energy.

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Use of this device in certain countries is defined by national regulations that the infrastructure manager must publish in his Network statement. Current situation about billing the energy consumption is as follows:

Out of 26 member states of EU (2 dont have any railway) and 5 candidate states (Serbia, BiH, Montenegro, Macedonia and Albania), device for measuring energy consumption board is only mandatory in Hungary. This device is mandatory in Belgium if the operator is not buying electricity from the railway infrastructure manager (Infrabel), but from companies on the electrical energy market. In all the other countries, the use of these devices is not mandatory, but it is possible in the most of the countries in western Europe and Scandianvia [1].

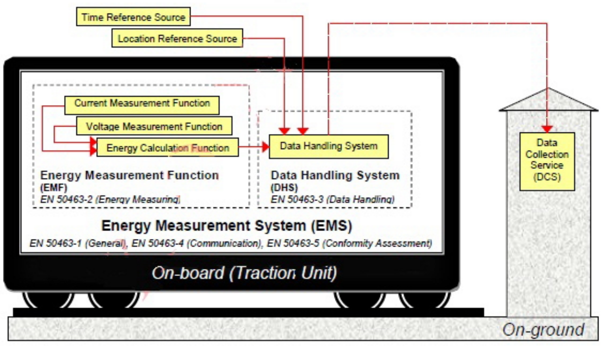

Fig.1. Functional chart of measuring system

Untill now, there was no unanimous attitude about mandatory installment. While the SNCF (French national railways) considered that those devices have no major significance, and that no significant effects can be expected from them, DB (German federal railways) had completly opposite attitude and decided that within few years, all their vehicles must be equiped with them. European commision, general directorate for transport (DB Move) currently has the attitude that the next revision of TSI should declare devices for measuring energy consumption on railway platform vehicles mandatory [2][3].

3. ANALYSIS OF JUSTIFICATION OF MANDATORY INSTALATION OF ENERGY METERS ON SERBIAN RAILWAY NETWORK

Analysis of justification of mandatory instalation of energy meters on traction units would include several steps:

3.1. Evaluation of possible effects on energy consumption for all considered types of the traffic

Railway traffic in Serbia can be divided into three categories: Passenger local, Passenger distant, and Cargo. Table 1 shows evaluation of effects of considered measures for reduction in electrical energy consumption expressed in precentage of reduction in electrical energy consumption that is expected when applying those measures, based on research on other European railways [4][5][6].

Tab. 1. Evaluation of measures for reduction of electrical energy consumption

No		Passenger local	Passenger long-distant	Cargo
1.	Reduction in weight	15 %	10 %	2 %
2.	Reduction of resistance	-	-	1 %
3.	Efficiency of propulsion	2 %	2 %	1 %
4.	Recuperation and storage of energy	15 %	10 %	15 %
5.	Optimization of heating and airconditioning	2 %	2 %	-
6.	Auxiliaries consumption (out of traffic)	4 %	2 %	-
7.	Energy efficient driving and traffic regulations	7 %	5 %	5 %
8.	Optimization of the timetable	2 %	1 %	1 %

3.2. Evaluation of significance of introducing the energy metering on traction units for realization of each of these measures

In order for some of the measures for reduction of electrical energy consumption to be effective, it is necessary to have accurate measurement of the electrical energy consumption, while for others, it is less important. Since Serbian railways are currently extremly energeticaly inefficient, it is clear that the operators will invest in some of these measures only if they are able to valorize them through reduction in costs of electrical energy.

Otherwise they will, regardless of their own efficiency, share the inefficiency of the existing operator, and they wont be interested in investments. On the other hand, for some of the measures, it is not of significant importance. For measures where the significance of measuring devices is great, we consider that 100% of the possible savings is related to the use of the devices, for those where the significance is moderate, it is 50%, and for those where significance is minor, we consider it to be 10%. Evaluation of significance is given in Table 2.

Tab. 2. Evaluation of significance of energy meters on individual measures

No		Evaluation of significance
1.	Reduction in weight	Minor (10 %)
2.	Reduction of resistance	Moderate (50 %)
3.	Efficiency of propulsion	Moderate (50 %)
4.	Recuperation and storage of energy	Great (100 %)
5.	Optimization of heating and airconditioning	Great (100 %)
6.	Auxiliaries consumption (out of traffic)	Minor (10 %)
7.	Energy efficient driving and traffic regulations	Great (100 %)
8.	Optimization of the timetable	Moderate (50 %)

3.3. Determining the possible reduction in electrical energy consumption

Based on the previous two tables, it can be estimated that measuring devices can effect the reduction in electrical energy consumption on Serbian Railways for 27,9% in local passenger traffic, 20,7% in distant passenger traffic, and 21,7% in cargo traffic. According to statistical data, electrical energy consumption on railway per type of transport was: local passenger traffic 14% distant passenger traffic 25%, cargo traffic 61% [7].

Based on this, we can estimate that mandatory instalation of devices for measuring energy consumption on board can affect the reduction in electrical energy consumption for all types of traffic on Serbian Railway network for about 22% for new vehicles and about 20,9% for existing vehicles (measures 1. and 3. cannot be applied to existing vehicles).

3.4. Comparing the achieved savings to the costs of introducing these devices

According to statistical dana for 2012, 143 002 155 KW/h of electrical energy was spent on the Serbian Railways netwok - about 5 737 572 euros, which means that the cost per one tractive unit of active rolling stock is 37 256 euros [7]. Savings in electrical energy consumption of 20,9% would total to 7787 euros per year. On the other hand, according to the DB study, cost of installing the measuring devices during the regular repairs on tractive vehicles are about 2 000 euros [3]. So the value of the reduced consumption of eletrical energy is surpassing the instalation costs by far in the first year.

4. CONCLUSION

Classical integrated railway companies measured their electrical consumption at the power station, cumulatively, and they didn't need to measure the consumption of every single train or vehicle.

Significant changes in European railway system in the past few decades influenced a change in this situation. One of the main goals of this reform was increasing the efficiency of the sector by reducing the costs and introducing competition. Efficiency in energy consumption has an important role in reaching this goal. Therefore it is neccesary for railway operators to be able to manage their energy efficiency. The first step of the process of management of energy efficiency is accurately measuring of the energy consumption.

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REFERENCES

[1] www.rne.eu/**network-statement**
[2] *Documents of Energy and Metering day*, Wiena 3rd Feb.2011.
[3] DB AG (2000): TEMA project
[4] EIM (2010): EIM Position Paper on Energy Meters on Electric trains
[5] Treige, P.; J. Olde (2000): *Energiemessung auf elektrischen Triebfahrzeugen bei der Deutschen Bahn*. Elektrische Bahnen 8/2000, p. 300.
[6] Bryan Donnelly, ATOC (2010): *Refurbishment of Rolling Stock*. Workshop Railenergy Final Conference 2010, Brussels
[7] Gunselmann W. (2005): *Technologies for Increased Energy Efficiency in Railway Systems*, EPE Dresden 2005 , pp. 1-10
[8] AD „Železnice Srbije“: Statistika za 2012. Želnid, Beograd 2013.

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '14

A COMPARISION OF DRIVER BEHAVIOR AT RAILWAY CROSSING WITH PASSIVE AND ACTIVE PROTECTION SYSTEMS

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Abstract –An observational study was conducted which compared the behaviour of drivers at a railway crossing as train approached. The effectiveness of a passive protection system was compared with one incorporating flashers and barrier gates for a particular crossing. The addition of the gates significantly reduced the percentage of drivers crossing in front of trains from 57% to 15.5%. Plots of crossing probabilities showed them reduced as time until train arrival and the distance of the train from the crossing decreased.

Keywords – Driver behaviour, Railway crossing safety, Railway crossing protection, Half-gates.

1. INTRODUCTION

On the territory of the Republic of Serbia total length of railway network is about 4,000 km, out of which 276 km are multiple tracks and 934 km are electrified. There are 2,138 railway crossings in total. All these crossings have various warning devices Serbian railway crossing inventory database (2007-2011) [1].

According to Statistics on accidents at Serbian Railways (Serbian Rail Administration, 2011) [2], the number of deaths and severe injuries at crossings is increasing every year, with a considerable material damage. For Serbian Railways it is very important to estimate safety in order to indentify high risk locations, as well as to develop an engineering treatment and estimate its impact.

There are generally three different types of measures which can be used to make crossing safer: 1) crossing closure or grade separation, 2) improving crossing geometry, and 3) upgrading traffic control devices. Active protection system that has been implemented by us are half-gate. As a complement to this system on two crossings with half-gates video enforcement system has been added. However, unsafe driver behavior is largely intact, and at railway crossings with active signaling. According to statistics [2], 21% of people killed on railway crossings with active protection systems.

In [3] was conducted a small observational study of driver behavior as trains approached at rural crossing in the south part of Serbia, in a populated area of Čapljinac near the city of Niš, for which the authors were aware that in the near future to provide an automatic device railway crossing with half-gate.

2. METHODS

Observational setting

Observed railway crossing Čapljinac is secured by active protection system which includes half-gates, flashing lights and sound warning devices (hereinafter active protection), in comparison to previous warning device which was St. Andrews cross and Stop sign (hereinafter passive protection). Approaching train on certain fixed distance activates protective system. There were no other significant changes except road surface on crossing was paved again.

The settlement is rural and the road is of a local character. Railway crossing has two of four sight triangles. The average daily traffic (ADT) is about 500 road vehicles. The approaching speed of road vehicles is limited to 30 km/h. Other details about this crossing are the same as in previous study.

The railway is a trunk single-track railway, a part of the international Corridor 10. The traffic on the railway is mixed, passenger and freight. The realised number of trains is around 20 trains daily. The permitted speed on

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the railway is 100 km/h, and measured speed over crossing is between 23 and 92 km/h, while on passive device study is from 30 to 95 km/h.

Subjects

Drivers of vehicles who arrived at the crossing after the flashers and gates are activated, but before train arrival constituted the subjects in the study. The observation lasted for one week during spring. It was conducted in different periods of the day only during daylight hours. The period of the day during which the observation was made depended primarily on the frequency of rail traffic. The weather conditions were good, with good visibility.

Procedure

For the purpose of observing and recording the behaviour of road traffic participants at the chosen railway crossing, two researchers were involved simultaneously. Two researchers were located in a small official railway warehouse and they recorded the road traffic from that building, using two installed video cameras. They were not visible by the traffic participants and neither did they affect their behaviour. Procedure was much simpler than in previous study.

When approaching train activates warning system, researchers started recording railway crossing regardless if road vehicle is present or not. Recordings were later analysed.

For each particular train arrival, video recordings were analysed and following data was processed: (1) whether the driver stopped in front of approaching train or continued driving, (2) the elapsed time (in seconds from signal onset) until a vehicle arrived at the crossing, (3) the moment when the road vehicle crossed the crossing, (4) the driver's behaviour before crossing, whether they stopped, decelerated or passed the crossing without deceleration, (5) the moment of the train arrival and (6) the moment when crossing device was turned off. Based on the collected data, database was constructed for further research. During the period from warning device upgrade until this study was conducted no accidents data was recorded.

At the outset of the study several hypotheses were entertained concerning the differences that might be observed between drivers approaching the two types of protection systems, passive and active.

The first hypothesis was that fewer drivers would elect to cross in front of the trains now that half-barrier gates were present. Second hypothesis was about drivers who crossed in front of approaching train. Hypothesis was that most of the drivers will cross on warning lights without stopping or slowing down.

3. RESULTS

During the observation period, 58 cases of approaching vehicles were recorded at the observed railway crossing. The period of day when vehicles appeared was from 7:30 to 18 h. This time distribution is not much different than one conducted in previous study (passive device). Driver visibility depending on the weather conditions was not changed considerably compared to weather conditions in previous study.

Variables analysed in active protection study were: train speed, train distance from crossing, time until train arrived, time between device activation and train arrival and existence of sight triangle for approaching vehicle. Analysis was conducted based on exact variable values for each vehicle arrival on crossing in front of approaching train. Variables analysed in passive protection study [3] were: train speed, train distance from crossing, remaining time until train arrived and existence of sight triangle for approaching road vehicle.

It is assumed that different types of violation are influenced by different variables. Therefore, the total number of violations observed was divided into three categories [4]. The first category of violations was defined as occurring between the onset of the flashing light signals and two seconds after the gate arms started to descend. The second classification of violations was defined as violations occurring after the gate arm had been in motion for two seconds until the gate arms were in their horizontal position, or occurring after the gate arms were completely horizontal and before the train arrived. The last violations classification occurred after the train departed but before the gates were completely raised, which was not considered because it does not pose a threat as the first two categories.

3.1 Crossing behaviour

Nine out of 58 drivers (15.5%). crossed the tracks despite active device When passive device was present, percentage of drivers who crossed in front of approaching train was significantly higher (35 of 61 or 57%). According to z-test there are statistically significant differences in behaviour of these two groups of drivers, those who crossed in front of the train at active and passive protection ($p = 0.000$).

From 9 drivers which crossed in front of approaching train, 8 drivers crossed on flashing light warning and one drove around half-gates.

From 9 drivers which crossed in study with active protection, two drivers or 22% stopped their car before crossing over. In study with passive protection 10 of 35 (29%) showed such behaviour. The resulting z-test shows that differences in old and new conditions are not significant ($p = 0.339$).

Similarly, 2 of 9 (22%) drivers in study with active protection slowed down before crossing, while 17 of 35 (48%) drivers slowed down before crossing in study with passive protection. ($p = 0.0835$).

The remaining group of crossing drivers neither stopped nor slowed down before crossing. In conditions with new protection 5 of 9 (55.5%) drivers showed this kind of behaviour. In study with passive protection device this classification is 8 from 35 (23%). Differences in proportion suggest existence of significant differences between observed events in old and new conditions ($p = 0.032$).

The analysed safety margin, which is the time interval from the moment a road user has left the crossing area to the moment a train arrives at the crossing area, ranges from 6 to 79s.

Safety margin in passive protection conditions was from 10 to 86s. Average safety margin for these two groups is 32.7s for passive and 54.6s for active protection. Safety margin shows significant differences in these two cases ($p = 0.004$).

Drivers who did not cross in front of approaching train were waiting in different time intervals. Among 49 drivers waiting in active protection conditions, waiting time interval was between 2 and 126s. Average waiting time in active protection conditions is 33.6s. Average waiting time in passive protection conditions is 19.7s. Average waiting time in both cases is statistically significantly different ($p = 0.000$). This waiting time difference is certainly consequence of different protection system in old and new circumstances.

Tab.1. Summary of differences in driver behaviour

Behaviour	Passive protection	Active protection	Difference probability
Stop and wait	26 of 61 (43%)	49 of 58 (84.5%)	$p = 0.000 *$
Cross desprite warning	35 of 61 (57%)	9 of 58 (15.5%)	$p = 0.000 *$
Stop before proceeding	10 of 35 (29%)	2 of 9 (22%)	$p = 0.339$
Slow before proceeding	17 of 35 (48%)	2 of 9 (22%)	$p = 0.0835$
Did not stop or slow	8 of 35 (23%)	5 of 9 (55.5%)	$p = 0.032 *$
Mean waiting times	19.7 s	33.6 s	$p = 0.000 *$
Mean crossing safety margin	32.7 s	54.6 s	$p = 0.004 *$

As railway crossing in this study has two of four sight triangles, behaviour of drivers with good and bad sight of approaching train was further analysed. In total, 27 drivers (46.5%) from 58 had good sight of approaching train. From 27 drivers 7 crossed (26%) and 20 drivers stopped and waited until train passed. Remaining 31 drivers had bad sight of approaching train, from which 2 crossed (6.5%), and remaining 29 waited (93.5 %). Warning time is time between device activation and train arrival on crossing, and it is between 44 and 95s. In case of one slower train that time was 141s. Average warning time in this sample was 71 seconds.

If t_1 is a moment of crossing device activation and t_2 moment of road vehicle arrival on crossing, difference between them, $t_2 - t_1$ is from 3 to 80s. This time will be discussed in crossing probability function.

Technical irregularities on crossing were observed in two cases. In one case railway crossing was not secured while in other device was activated although train arrival wasn't recorded. Data from first case was included, but data from second was disregarded because train parameters were missing.

See Tab.1 for an overview of the differences in driver behaviour observed between conditions.

3.2 Probability of crossing

The probability of drivers crossing in front of the approaching trains was determined for the two protection systems. Probability of crossing was plotted as a function of train location (distance of train from the crossing at the time the vehicle arrived) in Fig.1.

The time available to cross (a combination of train speed and location upon arrival) may be seen in terms of its impact on crossing decision in Fig.2. Finally, the speed of train relative to the probability of crossing may be seen in Fig.3.

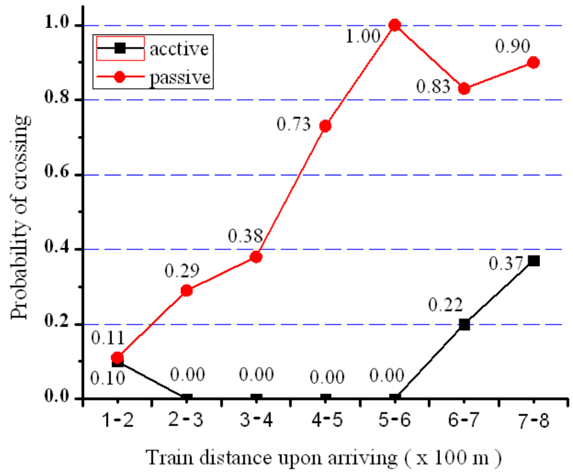

Fig. 1.Probability of crossing as a function of distance of the train from the crossing.

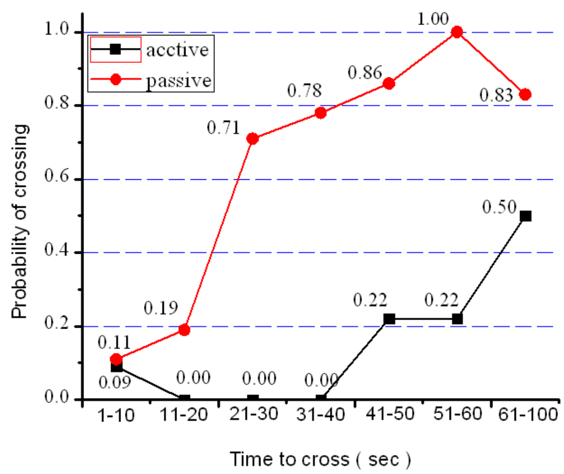

Fig. 2.Probability of crossing as a function of time available until train arrival.

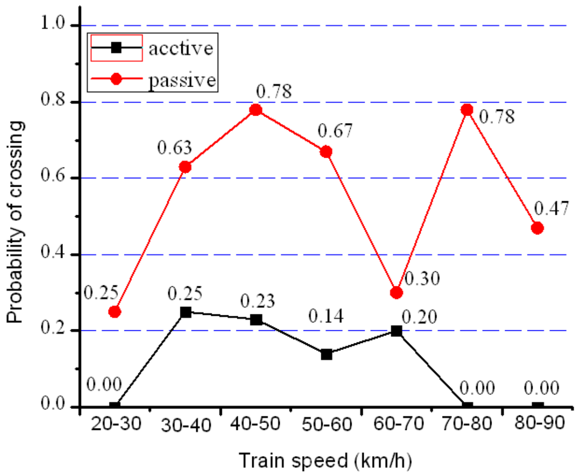

Fig. 3.Probability of crossing as a function of train speed.

4. DISCUSSION

It may be argued that upon arriving at the crossing drivers are making a decision as to whether or not to cross on the basis of their perception of the time available to them before the train arrives. Fig. 2. shows that drivers in both groups are more inclined to cross with longer times before train arrival. Note also that the decisions made by the drivers at the gated crossing are somewhat more cautious than those in the passive condition.

The judgment as to time until train arrival may be seen as potentially being affected by the distance of the train from the crossing and by the apparent speed of the train. Fig. 1. reveals that both groups are inclined to cross as expected, e.g. drivers are not inclined to cross when train is near the crossing. It can be determined, as above, that driver's decisions are more cautious in presence of active protection.

The apparent speed of the train should also affect the decision to cross since it affects the time available. The relationship between train speed and crossing probability shown on Fig. 3 does not show expected linear dependence of train speed and crossing probability ($y = -0.019x + 0.193$, $R^2 = 0.126$). It suggests that train speed estimate, particularly for those trains at some distance from the crossing, is a difficult one.

When drivers are assessing signalization, there is significant difference between drivers that stopped and those who crossed in front of approaching train, according to Analysis of Variance (ANOVA) test ($F = 15.60$, $p = 0.00189$). Effects of device working time on driver's decision to cross showed that drivers are more inclined to cross if device is working for a shorter time. It means that group of drivers which decided to cross done that while flashing lights were working.

The first hypothesis regarding the effects of upgraded protection system was clearly supported by the data. That is, the addition of half-gates appears to have substantially reduced the number of crossings made in front of oncoming trains. It was shown that active protection largely reduces percentage of drivers which cross in front of approaching train from 57% to 15.5%. It certanly explains why number of accidents is largely reduced on railway crossings with active protection system.

The second hypothesis is also backed up with data. It refers to fact that majority of drivers crossed exactly on flashing lights without stopping or slowing down. These results are consistent with study [5]. In that way drivers leave longer safety margin than in case of passive protection, p = 0.004.

5. CONCLUSION

This investigation does allow for some tentative conclusions. First the primary benefit of half-gates would seem to be that they reduce the number of crossings made in the presence of approaching trains compared to passive system. Furthermore, it was concluded that technical measurement, half-gates implemented on this site, was quite satisfactory regarding deterrence of drivers from irregular behavior. However, the crossing investigated was primarily used by persons who traversed it routinely and most likely had some knowledge of train speeds, sight restrictions, etc. Compliance to barrier gates would surely differ in other settings where, for example, traffic volume was higer and drivers were commonly influenced by the crossing decisions made by other drivers.

To understand the effect of this and other protection devices requires that they be investigated in many different contexts. Such research might then suggest those settings in which barrier gates might be most effective.

REFERENCES

[1] Serbian Rail Administration. The Serbian railway crossing inventory database (2007- 2011), Serbian Railways; in Serbian.

[2] Serbian Rail Administration. Statistics on accidents on Serbian railways 2011; in Serbian.

[3] Kasalica, S., Vukadinović, R., and Lučanin, V. (2012). "Study of drivers behaviour at a passive railway crossing." *Promet - Traffic Transp.,* 24 (3),193-201.

[4] Fitzpatrick, K., Carlson, P. and Bean, J. (1997). "Traffic violations at grade highway-railway grade crossings". Texas transportation institute, Research report 2987-1.

[5] Richards, S. H., and Heathington, K. W. (1989). " Driver Behavior at Rail-Highway Crossings". Report No. DTFH61-88-Z-00145. U.S. Department of Transportation, Federal Highway Administration. Washington, D.C.

RANKING OF HEADWAYS PRIORITY IN RAILWAY TIMETABLE

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Abstract *- Timetable construction aims to traffic planning all trains on one track as well as the interaction between them. Aspiration of designers is to connect the start and end station of every train in the shortest possible time, which would make possible to provide a higher level of transport services. On the other hand, it is impossible to make a perfect schedule in which there will be no operation delays. The aim of this paper is to define the criteria through which will be possible to determine the priority of the headways in which time reserves should be implemented, in order to improve robustness of the timetable, in order to keep difference between designed and real-life traffic at minimum.*

Keywords – railway timetable, buffer times, robustness, delay.

1. INTRODUCTION

In designing the timetable, in order to increase the stability and robustness, the headways should be increased by adding time reserves into them. These reserves are called buffer times. Besides them, there are reserves in driving times and the time reserves implemented in time dwelling time, aiming to reduce the possibility of disruptions caused by the entry and exit of passengers.

The more time reserves timetable has it is more robust, i.e. there is less possibility of the disruption to occur during implementation.

In the process of creating timetable, sometimes it is not possible to provide a buffer in all headways, or it is not possible to provide the necessary value of buffer times. On the other hand, implementation of any extension of travel time, lower the quality of transport services. In this paper, we will define criteria for the selection and priority ranking of headways, in which time reserves should be implemented. The work itself will not consider necessary amounts of the buffers.

2. DEFINITION OF IMPORTANCE OF TIME RESERVES BETWEEN TWO TRAIN PATHS

In case when in the projected timetable time reserves should be added, in order to prevent the delay propagation between the two trains, and when total available amount of time reserves is limited, question arise between which trains add buffer time, i.e. which train path should be more "protected".

Intuitively, in the case of interaction between trains of different ranks, train with higher rank should be more protect. This may not be the unique criterion, because it will be impossible to make a decision when trains have the same rank. In addition, the importance of the “path protection” from delay propagation is dependent on other factors.

In determining, the place of buffer implementation should take into account the time reserves already implemented in the previous part of each path.

For precise determination of the buffer time importance, in case of passenger trains also should take into account the number of major railway nodes through which the trains passes, because in them is higher possibility of delays.

2.1 Criterion of higher rank protection

Rank of trains allows us to determine to which train priority should be given, whether in timetable designing, whether in traffic realization. However, the rank of trains is important from the point of managing train traffic in real-time. Dispatchers usually do not take into account the stability and robustness of the timetable.

When the interaction is such that in the meeting station first comes lower rank train, buffer time, larger than average, should protect the higher rank train, in

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order to disable transmission of delays. In this way, train rank influence the value of the buffer time. However, when there is more than one of these cases, and when the available time reserves are limited and less than the sum of all required buffer time, one must choose a path to protect. Exclusively based on train rank, such decision cannot be reached.

The only that this criterion allows, is the principle of "in depth" meeting the demands, i.e. priority to protect the path of the highest rank until it is possible, and if there is remaining resources, protection of the path of the next rank, etc..

2.2 Criterion of length of the remaining travel distance

When considering the length of the remaining travel distance of the train whose path buffer time should protect two basic, but logically opposing ideas arises. First, the larger remaining travel distance is, the greater the possibility that the train has delay in the final station, simply because there is more places where delays may occur. On the other hand, the longer the remaining part travel distance is, the greater are the opportunities for later implementation of time reserves, which could enable neutralization of occurred delays.

The most accurate would be to set up this problem as a Pareto-optimal problem and thus prioritize headways in which to allocate a buffer times in, but it significantly increases the complexity of the problem.

To simplify the problem, with a sufficient level of precision, the importance of certain headways for implementing buffer time between the train paths ***at the station S*** should determine by the "coefficient of modified rank", using train rank and remaining travel distance of a path that should protect:

$$\rho(r) = \frac{r_t}{\sum_{msr=S}^{MSR} l_{msr}} \left[1/km\right],$$

when ($N_V$mod2) $\neq$ 0, or

$$\rho(r) = \frac{r_t}{\sum_{msr=1}^{S-1} l_{msr}} \left[1/km\right], \qquad (1)$$

when ($N_V$mod2) = 0,

where:

- *MSR* - total number of inter-station distance on train travel distance, where is valid *MSR* = *NS* – *1*,
- *NS* - total number of stations at line or section,
- *S* - station for which the priority of time reserves allocation we consider,
- *msr* – distance between two stations,
- *ρ(r)* - coefficient of modified rank of train,
- r_t – rank of train whose path buffer time protects and
- $\sum_{msr=S}^{MSR} l_{msr}$ or $\sum_{msr=1}^{S-1} l_{msr}$ - the remaining travel distance, depending on the direction of train, where the trains operating in direction east-west and north-south are marked by even numbers.

Train rank, r_t, can take a value from one, which takes the lowest ranks, up to total number of different ranks of trains, which run through the observed station.

The higher the "coefficient of modified rank", higher will be the priority protect that train's path. As this coefficient decreases with the increase of the remaining travel distance, it is clear that in this way we favors the possibility that in the rest of travel distance more reserves can be added, as we assume that this process is iterative.

2.3 Criteria of previously allocated time reserves

On arrival of the train in a meeting-station only two cases could occur: the train runs on schedule or that the train is late. Logically, the case when the train is late will be less likely if the path of the train from the starting-station to meeting-station is protected with larger amount of time reserves. In other words, a higher priority should give to locating the buffer time in headways in which the train that came first in station has less time reserves, at the distance traveled.

It can be assumed that it is more accurate to take into account only the time reserves for each path from the last scheduled stop of the train, up to the station S, for which a priority allocation we determine. However, in this way would be favored paths of trains that have frequent planned stops, and usually those are trains of lower rank. That is why we rejected that and we observe all time reserves, from starting station to station S.

It is important to emphasize that in this case, we are always watching time reserves in path of the train that first comes to the meeting, because the buffer time protects another train against possible delay transmission. As travel distances for different trains do not have to be the same for all trains, shall not consider only the sum of all time reserves. The most practical would be to take into account the "density of time reserves allocation" with regard to the distance traveled, and "density of time reserves allocation" is possible to define in many different ways:

1. "density of allocation" time represents the ratio of total amount of time reserves up to station S and the distance that the train passes to that point:

$$\gamma_1(t_{res}) = \frac{\sum_{msr=1}^{S-1} t_{msr}^{res} + \sum_{s=2}^{S} t_s^{buff} + \sum_{s=2}^{S} t_s^{dw-buff}}{\sum_{msr=1}^{S-1} l_{msr}} [min./km]$$

$(N_V \text{mod} 2) \neq 0$, or

$$\gamma_1(t_{res}) = \frac{\sum_{msr=S}^{MSR} t_{msr}^{res} + \sum_{s=S}^{NS-1} t_s^{buff} + \sum_{s=S}^{NS-1} t_s^{dw-buff}}{\sum_{msr=S}^{MSR} l_{msr}} [min./km] \quad (2)$$

$(N_V \text{mod} 2) = 0$

where:

- $\gamma_1(t_{res})$ - density of time reserves allocation,
- $\sum_{msr=1}^{S-1} t_{msr}^{res}$ or $\sum_{msr=S}^{MSR} t_{msr}^{res}$ - sum of driving time reserves, on each inter-station distance,
- $\sum_{s=2}^{S} t_s^{buff}$ or $\sum_{s=S}^{NS-1} t_s^{buff}$ - the sum of the buffer time in all stations up to station S,
- $\sum_{s=2}^{S} t_s^{dw-buff}$ or $\sum_{s=S}^{NS-1} t_s^{dw-buff}$ - the sum of dwell-time reserves in times of practicing, in all stations up to station S and
- $\sum_{msr=1}^{S-1} l_{msr}$ or $\sum_{msr=S}^{MSR} l_{msr}$ - path length, from the first station up to station S.

Thus defined, the "density of time reserves allocation" represents the average amount of time reserves, by distance traveled.

Greater the density of time reserves allocation is, the train path is better protected from possible disturbances, at already passed part of the line.

2. "density of time reserves allocation" represents the ratio of the total amount of time reserves and minimum travel time from starting station up to station S:

$$\gamma_2(t_{res}) = \frac{\sum_{msr=1}^{S-1} t_{msr}^{res} + \sum_{s=2}^{S} t_s^{buff} + \sum_{s=2}^{S} t_s^{dw-buff}}{\sum_{msr=1}^{S-1} t_{msr}^{travel} + \sum_{s=2}^{S} t_s^{dwell}},$$

when $(N_V \text{mod} 2) \neq 0$, or

$$\gamma_2(t_{res}) = \frac{\sum_{msr=S}^{MSR} t_{msr}^{res} + \sum_{s=S}^{NS} t_s^{buff} + \sum_{s=S}^{NS} t_s^{dw-buff}}{\sum_{msr=S}^{MSR} t_{msr}^{travel} + \sum_{s=S}^{NS} t_s^{dwell}}, \quad (3)$$

when $(N_V \text{mod} 2) = 0$

where:

- $\sum_{msr=1}^{S-1} t_{msr}^{travel}$ or $\sum_{msr=S}^{MSR} t_{msr}^{travel}$ - sum of smallest driving times for each inter-station distance, from the first one to the one which station S belongs to and
- $\sum_{s=2}^{S} t_s^{dwell}$ or $\sum_{s=S}^{NS} t_s^{dwell}$ - sum of the planned dwell times, without buffer times, in all stations, from the first one up to station S.

3. "density of time reserves allocation" represents the ratio of the total amount of time reserves, and total, planned, travel time up to the station S:

$$\gamma_3(t_{res}) = \frac{\sum_{msr=1}^{S-1} t_{msr}^{res} + \sum_{s=2}^{S} t_s^{buff} + \sum_{s=2}^{S} t_s^{dw-buff}}{\sum_{msr=1}^{S-1} t_{msr}^{travel} + \sum_{s=2}^{S} t_s^{dwell} + \sum_{msr=1}^{S-1} t_{msr}^{res} + \sum_{s=2}^{S} t_s^{buff} + \sum_{s=2}^{S} t_s^{dw-buff}} [\%],$$

$(N_V \text{mod} 2) \neq 0$,

$$\gamma_3(t_{res}) = \frac{\sum_{msr=S}^{MSR} t_{msr}^{res} + \sum_{s=S}^{NS} t_s^{buff} + \sum_{s=S}^{NS} t_s^{dw-buff}}{\sum_{msr=S}^{MSR} t_{msr}^{travel} + \sum_{s=S}^{NS} t_s^{dwell} + \sum_{msr=S}^{MSR} t_{msr}^{res} + \sum_{s=S}^{NS} t_s^{buff} + \sum_{s=S}^{NS} t_s^{dw-buff}} [\%], \quad (4)$$

$(N_V \text{mod} 2) = 0$.

In this way, the "density of time reserves allocation" represents the percentage of all time reserves in the planned travel time of the train for station S, for which priority of headways protection is determined. "Density of time reserves allocation" determine for the train that first comes at meeting station.

2.4 Criterion of time reserves existence by the end of the path

The purpose of defining of all train paths in the timetable is to determine all events in advance and to define the appropriate times regarding train travel from first to the last station. Therefore, the primary objective of the real-time traffic realization is to provide that each train leave from the starting station at planned time and to arrive at the final station without delay. Considering this, the defining buffer time allocation can take into consideration the possibility that at the remaining part of the path some earlier occurred delays can be reduced or neutralized. Therefore, we introduce the "coefficient of remaining time reserves" which is defined as:

$$\delta(t_{res}) = \frac{\left[\sum_{msr=1}^{MSR} t_{msr}^{res} + \sum_{s=2}^{NS} t_s^{buff} + \sum_{s=2}^{NS} t_s^{dw-buff} - \left(\sum_{msr=1}^{S-1} t_{msr}^{res} + \sum_{s=2}^{S} t_s^{buff} + \sum_{s=2}^{S} t_s^{dw-buff}\right)\right]}{(NS - S) \cdot \sum_{s=S+1}^{NS} n_{sas}} [min/sast.]$$

$(N_V \text{mod} 2) \neq 0$,

$$\delta(t_{res}) = \frac{\left[\sum_{msr=1}^{MSR} t_{msr}^{res} + \sum_{s=2}^{NS} t_s^{buff} + \sum_{s=2}^{NS} t_s^{dw-buff} - \left(\sum_{msr=S}^{MSR} t_{msr}^{res} + \sum_{s=S}^{NS} t_s^{buff} + \sum_{s=S}^{NS} t_s^{dw-buff}\right)\right]}{(S-1)\cdot \sum_{s=1}^{S-1} n_{sas}} [min/sast.] \quad (5)$$

$(N_V \mathrm{mod} 2) = 0$,

where:

- $\sum_{s=S+1}^{NS} n_{sas}$ or $\sum_{s=1}^{S-1} n_{sas}$ - number of planned meeting after the station S. To avoid the possibility of division by zero, the arrival of the train in last station we will consider as a final meeting.

In addition, as this ratio decreasing, priority for path protection, by implementing buffer time at the station S, increases.

3. DETERMINATION OF RELATIVE WEIGHT OF CRITERIA FOR BUFFER TIME ALLOCATION

Although using each of these criteria for determining the priority for time reserve allocation in timetable could easy define which train path should protect, depending on the importance and location of the stations, the significance of the criteria will vary from case to case. Therefore, it is necessary to determine weight of each criterion, before their application.

First, it is necessary to compose the decision-making matrix, presenting criteria as columns, and the alternatives, i.e. headways themselves, as rows. Normalization is carried out by dividing each individual value by criteria with the sum of values for all alternatives by the observed criteria:

$$r_{ij} = \frac{a_{ij}}{\sum_{i=1} a_{ij}} . \quad (6)$$

After normalization, the entropy of information, for each criterion, is determined according to equation:

$$e_j = -k \cdot \sum_{i=1} r_{ij} \cdot \ln r_{ij} \quad (7)$$

where:

- e_j - entropy according to the criterion j,
- k - constant.

The constant k is equal to:

$$k = \frac{1}{\ln n} , \quad (8)$$

where n is the number of alternatives, which ensures that the value of e_j is taken from the interval [0, 1].

In the second step, the so-called the degree of divergence for each of the criteria, d_j, is determined as a:

$$d_j = 1 - e_j \quad (9)$$

The higher the degree of divergence of a criterion is the higher is the importance of the criterion.

The final relative criteria weights obtain by normalization of the values and the relative weight of the criteria are determined as a:

$$w_j = \frac{d_j}{\sum_j d_j} . \quad (10)$$

In this way, after determining the relative weights of the criteria and, after collecting the necessary data from the timetable, in order to determine the values of alternatives for each criterion, by using any of the methods of multi-criteria decision-making is possible to determine the critical headways. Those headways are with high priority and should increase them by implementation of buffer times. In that manner, timetable robustness increases as well.

4. CONCLUSION

Presented model provides several criteria that allow us to perform buffer time allocation. As application of only one of the proposed criterion does not necessarily give the optimal solution, they should all be included in the decision making process. This can be done using a multi-criteria analysis tools. Previously, of course, the relative importance of each criterion must be determined. As a result, the model provides a suggestion which path in which station to "protect" by buffer time, as possibility to minimize impact of potential delays on the schedule of other trains, which is a measure of the robustness of the planned timetable.

REFERENCES

[1] Andersson E., *Assessment of Robustness in Railway Traffic Timetable,* Licentiate Thesis, Linkoping University, Sweden, 2014.

[2] Pachl J., *Railway Operation and Control,* Mountlake Terrace WA, USA, 2002.

[3] Jian M., Zhi-Ping F., Li-Hua H., *A subjective and objective integrated approach to determine attribute weights*, European Journal of Operational Research, Vol. 112 Issue 2, 1999., pp. 397-404.

APPLICATION OF OPENTRACK AT RAILWAY PROJECTS IN AUSTRIA

Andreas SCHÖBEL [1]

***Abstract** – OpenTrack is an user-friendly railroad network simulation program developed at the Swiss Federal Institute of Technology's Institute for Transportation Planning and Systems (ETH IVT). It is a microscopic model that simulates rail system operations based on user defined train, infrastructure, and timetable databases. OpenTrack functions as a railroad laboratory, by, for example, allowing users to define incidents and take infrastructure out of service to evaluate alternative scenarios. The program uses a mixed discrete/continuous simulation process that calculates both the continuous solution of train motion equations and the discrete processes of signal box states and delay distributions. It generates a wide variety data that can be easily presented in many formats including graphs (e.g. time-space diagrams), tables, and images. OpenTrack's main uses have been to evaluate and test infrastructure plans and operating schedules to optimize network and timetable design. In this paper show cases from successful application in Austria will be described. One example deals with the upgrade of the local line from Neusiedl am See to Pamhagen (Hungarian border). Another example is the narrow gauge line from Jenbach to Mayrhofen in Tyrol.*

Keywords – Railway operation, microscopic simulation, design of railway infrastructure, development of integrated timetable, calculation of technical running time.

1. INTRODUCTION

OpenTrack is a microscopic synchronous railroad simulation model. It provides users with a great deal of flexibility for defining different dispatching logic as well as operational variables in a user-friendly manner.

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

2. DATA FLOW DURING A SIMULATION PROJECT

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.

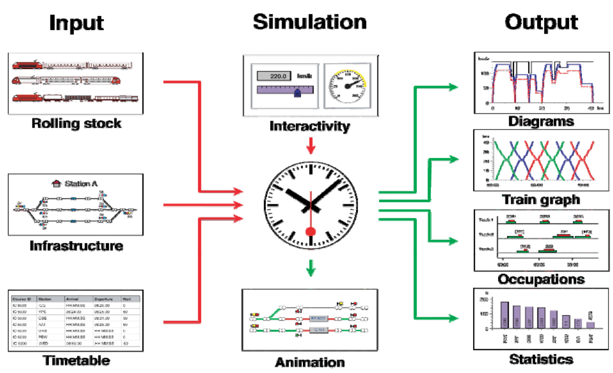

Fig.1. Data flow during a simulation project

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

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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.

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.

One advantage of OpenTrack is that it enables users to adjust many variables that impact railroad operations. For example, users can simulate the impact of weather on traction by specifying the adhesion scenario (good, normal, bad). OpenTrack then estimates locomotive traction power using a percentage (also user-defined) of that calculated using the Curtius and Kniffler formula. While OpenTrack provides standard default values for all variables, having the ability to adjust variables makes the program quite useful.

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 signaling systems as well as new moving block train control systems (e.g. European Train Control System – ETCS signaling).

OpenTrack is a dynamic rail simulation program. As such, the simulated operation of trains depends on the state of the system at each step in the process as well as the original user-defined objective data (e.g. desired schedule).

A simple way of describing dynamic rail simulation is that the program decides what routes trains use while the program is running. For example, when building the network, users identify various different routes that trains can use between two points; OpenTrack decides, during the simulation, which route the train will use by assigning the train the highest priority route available. If the first priority is not available, OpenTrack will assign the train the second highest priority route and so on.

OpenTrack's dynamic nature allows users to assign certain attributes to specified times in the simulation. Thus, users can assign a delay to a particular train at a given station and time, rather than being limited to assigning a delay at the start and using it through the entire simulation. Similarly, users can define other types of incidents (e.g. infrastructure failures, rolling stock breakdowns) for particular times and places.

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. SHOWCASE AT THE ZILLERTALBAHN

The Zillertalbahn operates the narrow gauge line from Jenbach to Mayrhofen. At Jenbach there is the connection to the network of Austrian Railways (ÖBB) where all regional, national and several international have a commercial stop. Figure 2 shows the graph for the topology of an upgraded design of the infrastructure to fulfill future requirements of service quality and density. Today there are already two double track sections in operation between Kaltenbach-Stumm and Aschau as well as between Zell am Ziller and Ramsau-Hippach. To offer an integrated timetable on a regular and symmetric basis another crossing opportunity between Aschau and Zell am Ziller is required where there is a plan to realize a new commercial stop close to a skiing center. For the calculation of the running time new electrical train units where assumed as well as an increase of the track speed limit towards 80 km/h where ever reasonable. This allows to shorten the running time from Jenbach to Mayrhofen from 55 to 45 minutes.

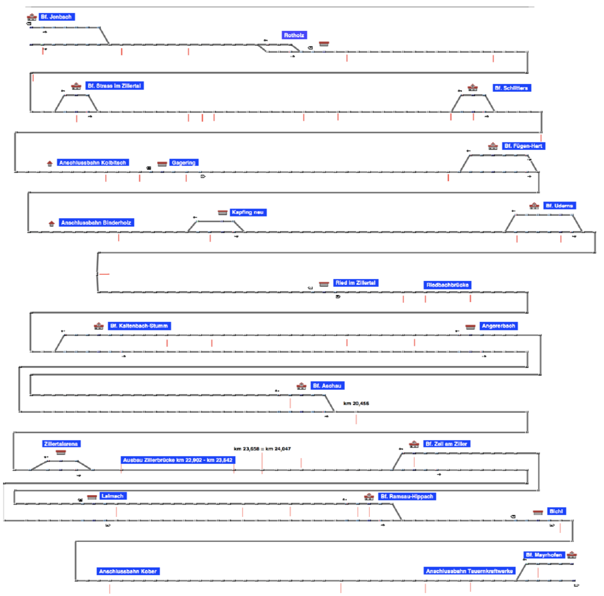

Fig.1. Infrastructure topology of the Zillertalbahn

Figure 3 shows the graphical timetable for the morning peak hours from 8 to 11 during winter season where additional services run to provide a 15 minutes interval. The blue lines represent the courses providing the 30 minutes interval during the entire day while the green lines indicate the additional services for the 15 minutes interval. By the application of OpenTrack it could be demonstrated that all services are able to arrive on time at their final destination. Therefore the proof of concept for the investment strategy for the next years could be provided by the results of the simulation of railway operation.

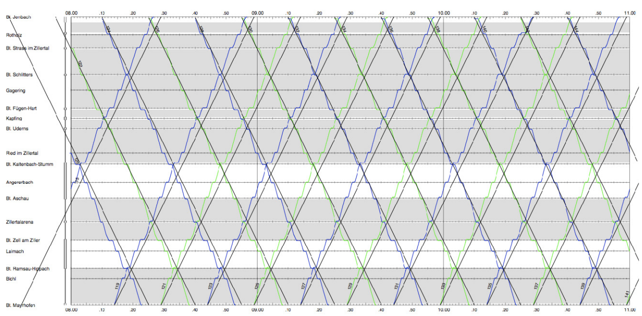

Fig.3. Integrated timetable

4. SHOWCASE AT THE NEUSIEDLERSEEBAHN

The NeusiedlerSeeBahn is responsible for the line from Neusiedl am See to Pamhagen. At Neusiedl am See the branch line from/to Eisenstadt is located. Pamhagen is the last station in Austria before the Hungarian border. From Neusiedl am See a line leads to Parndorf Ort where there is the connection to the Eastern line of Austrian Railways which is connecting Vienna and Budapest. People living at the villages located between Neusiedl am See and Pamhagen typically go for work to Vienna every single day of the week. Therefore the NSB is interested in offering shorter traveling times to Vienna. To achieve this goal some investments were done in the last years to increase the track speed. OpenTrack has been successfully used to evaluate the shortenings of running times for local trains and regional trains.

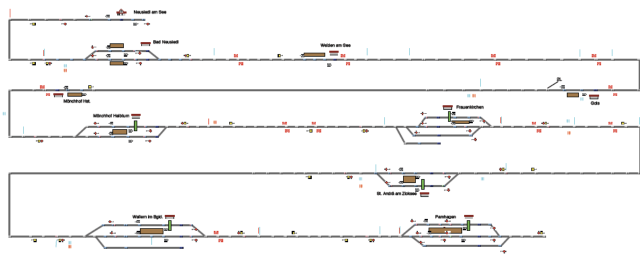

Fig.4. Infrastructure layout of the line from Neusiedl am See to Pamhagen

Figure 4 shows the topology of the line from Neusiedl am See to Pamhagen. Crossing opportunities are located at Bad Neusiedl, Mönchhof-Halbturn, Frauenkirchen, St. Andrä am Zicksee, Wallern and Pamhagen. The first step in the project was the check of the model with the existing timetable. This step allowed the exact calculation of running times reserves included in the existing timetable.

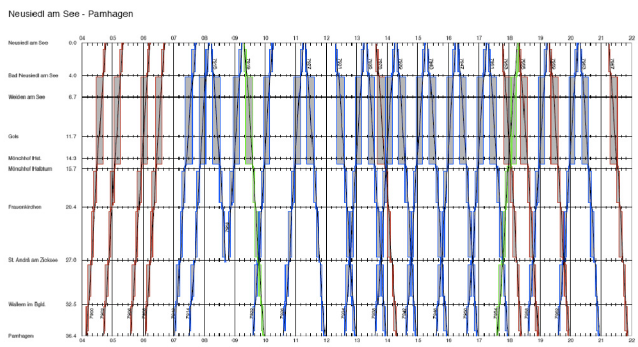

Fig.5. Simulation result of the existing timetable

Figure 5 shows the result from the simulation of the existing timetable. It has to be noted that one course during the day is only going to St. Andrä am Zicksee and not to the terminal station at Pamhagen. Additionally there is no service during the morning hours towards the region between Neusiedl am See and Pamhagen. Exactly the same happens during the evening when there is no service towards Vienna. The reason for this asymmetry in the timetable can be only explained by the saving of operational costs. For pupils there are two additional services during the day to allow them traveling to and back from school. Unfortunately the infrastructure does not allow a crossing between Bad Neusiedl and Mönchhof-Halbturn which would be required to run a 30 minutes interval in both directions. Furthermore the infrastructure model had to be extended with the upgraded track speed limits which had been indicated by markers at the related vertices. Due to the increase of the track speed the crossing shifts from St. Andrä am Zicksee towards Wallern because of keeping the arrival and departure times at Neusiedl am See (see Figure 6).

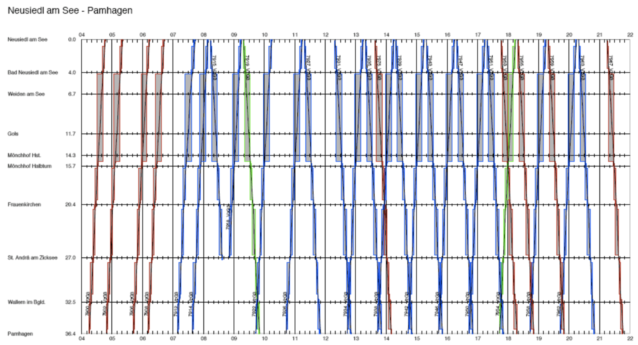

Fig.6. Simulation result of the upgraded infrastructure

Local and regional trains benefit from the increase of track speed by a shortening of running times of 5 minutes each. Local trains which stop at every single station run in 33 instead of 38 minutes and regional trains run in 28 instead of 33 minutes. A shortening of 5 minutes in terms of running time could be also achieved by introducing today regional trains. Of course the increase of the track speed in combination with the introduction of regional trains leads to an overall reduction of running time of 10 minutes for regional trains. An open point for further investigations is the integration of both services at the same time because each crossing of two trains will lead to an increase of running time while one train has to take the siding track in a crossing station. This could require the demand to upgrade also the frequently used switches to allow higher speeds for the siding track.

5. CONCLUSION

OpenTrack is an efficient and effective railroad simulation program. It has been successfully used 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.

ACKNOWLEDGEMENT

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REFERENCES

[1] Huerlimann, Daniel; Object oriented modeling in railways; ETH Dissertation Nr. 14281; 2001 (in German).

[2] Huerlimann, Daniel and Andrew Nash; OpenTrack – Simulation of Railway Networks, User Manual Version 1.6; OpenTrack Railway Technology GmbH; Zürich, Switzerland; 2010; 160 pages.

[3] www.opentrack.at

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SIMULATION MODELING OF TECHNOLOGICAL PROCESSES IN SUBWAY STATION

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Veselin STOEV [2]

Abstract *– A methodology for processes simulation in a metro station has been developed by using a direct-event approach. A metro station has been represented as a multi-level system for mass service. The research has been conducted by using a fully licensed software Arena Academic Rockwell. The exploiting criteria resulted from the simulation are such as time for passengers waiting at the different stages of servicing, availability of servicing machines, etc. Simulation modelling gives very useful information for exploitation of a metro station which could not be observed or gained otherwise such as an average time for passengers waiting at metro stations, an average time of available subsystems. This allows us to suggest technological decisions to improve service. The simulation modelling has been applied to examine the Metro Station Serdika from Sofia's metro system.*

Keywords – subway, subway station, simulation modelling, queue theory, ARENA software.

1. INTRODUCTION

A metro network system represents an ecological and high-speed rail transport which takes an important role helping public transport satisfy any needs for transportation in cities. Metro stations are places where incoming stream of passengers should be served quickly. Simulation modelling allows us to examine and analyse many tehnological situations in different time intervals, with different incoming and outgoing streams of passengers and different technological time for service, with different usage of capacity and capabilities of a metro system, which are very hard to be examined in real time. Metro stations is an intresting subject for simulation modelling and that is the reason why some authors have conducted studies in this area.

A queuing network analytical model of station is created in [1] for calculating subway station capacity, which is built by M/G/C/C state dependent queuing network and discrete time Markov chain. In [2] is elaborated a simulation model of the rail network including a group of four consecutive stations for simulation the vehicle operating and compute special system performance parameters. In [3] a simulation model for streams of passengers has been designed for metro stations. Principal states of systems for mass service have been developed in [4,5,6].

A detailed simulation of the processes in the entrance-hall, validating machines and subway leading to platforms, has not been conducted in the studies mentioned above.

The aim of this study is to develop a methodology of simulation modeling for technological processes in a metro station.

2. A PRESENTATION OF A METRO STATION AS THE QUEUE THEORY

A metro station is presented as a multi-level open system for mass service without priority with four consecutive servicing devices which have their own characteristics, fig.1.

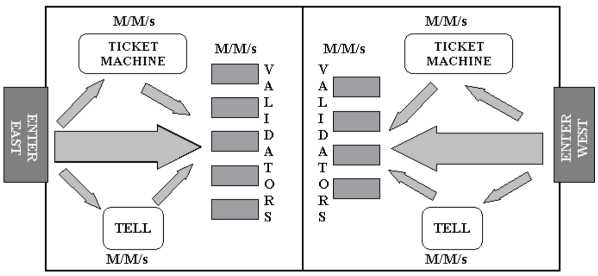

Fig.1. Sheme of metrostation

The stages of the multi-level model are:

- 1st stage: Entrance of the metro station. At this stage, passengers' waiting in the entrance-hall has been observed. As a matter of principle, metro stations might have one or two entrances. In the second case, entering a metro station is accomplished from two

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directions (East, West) therefore, entrance-halls are two. Because of that in the next stages servicing devices are examined for both directions separately.

- 2nd stage: Entrance-hall. Here, processes of servicing passengers from the entrance hall to the validating machines have been observed. The focus is on ticket offices and ticket machines.
- 3rd stage: Validating machines. Passengers’ going through validating machines is observed closely at this stage.
- 4th stage: Escalators and stairs. Passengers’ transition from validating machines to a platform.

In the defined multi-level system, there is not any buffers and that’s why it could be seen as compounded of separate single-level systems taking into account the transformations of streams of passengers between them. When the incoming stream of passengers is Poison, and the time of service is exponential and the system is without failures, then the outgoing stream of passengers is also Poison’s. In the study, the system M/M/s has been taken for all stages, e.g. Poison’s incoming stream of passengers, exponential time for service, and multi-channel system with a number of channels s. When a metro station as only one entrance then for the first level the system is M/M/1.

The intensity of a stream of passengers λ, coming in the metro station is formed by a stream of passengers which enter the entrance-hall from the two entrances of the metro station- East λ_1 and West λ_2.

$\lambda = \lambda_1 + \lambda_2$, passengers per hour; (1)

$\lambda_1 = \gamma_m.\lambda$, passengers per hour; (2)

$\lambda_2 = (1-\gamma_m).\lambda$, passengers per hour; (3)

where: γ_m is the coefficnent which shows the relative part of a stream of passengers coming in a metro station from an entrance with direction West. Dependng on the way of suppliment of tickets, a part of the stream of people goes directly to the validating machines (passengers provided with monthly passes or electronic tickets), another part of the stream of passengerts goes to places issuing tickets (ticket offices and ticket machines).

The intensity of the stream of passengers from an entrance with direction East λ_{1v} which goes directly to te validating machines is:

$\lambda_{1v} = \alpha_{1m}\lambda_1$, passengers per hour (4)

where: α_{1m} is a coeffient which shows the relative part of a stream of passengers that goes directly to the validating machines.

The intensity of a stream of passengers $\lambda_{1t,a}$ from entrance East which goes to buy tickets from ticket offices or ticket machines is:

$\lambda_{1t,a} = (1-\alpha_{1m}).\lambda_1$, passengers per hour; (5)

$\lambda_{1t,a} = \lambda_{1t} + \lambda_{1a}$, passengers per hour; (6)

The intensity of the stream of passengers λ_{1t} from entrance East which goes to buy tickets from ticket offices or ticket machines is :

$\lambda_{1t} = \beta_{1m}.\lambda_{1t,a}$, passengers per hour; (7)

where: β_{1m} is the coefficient which shows the relative part of the whole stream of passengers that goes to ticket offices and ticket machines with a focus on the part that goes to ticket offices only.

The intensity of the stream of passengers λ_{1a} from entrance East that goes to buy tickets from ticket machines is :

$\lambda_{1a} = (1-\beta_{1m}).\lambda_{1t,a}$, passengers per hour; (8)

The intensity of service of a stream of passengers by servicing machines is as follows:

μ_1, μ_2 is the intensity of service at a entrance of an entrance-hall of a metro station with direction East/West, passengers per hour.

μ_{1_t}, μ_{2_t} is the intensity of service of ticket offices at an entrance-hall with direction East/West, passengers per hour.

μ_{1a}, μ_{2a} is the intensity of service of ticket machines at an entrance-hall with direction East/West, passengers per hour.

μ_{1v}, μ_{2v} is the intensity of service provided by one validating machine at an entrance-hall with direction East/West, passengers per hour.

The number of servicing devices for each stage is:

n_{1t}, n_{2t} is the number of ticket offices at an entrance-hall with direction East/West

n_{1a}, n_{2a} is the number of ticket machines at an entrance-hall with direction East/West.

n_{1v}, n_{2v} is the number of validating machines at an entrance-hall with direction East/West at a metro station.

A mathemathical presentation of the intensity of a s tream of passengers from entrance West is identical to the formulation shown above.

To avoid detention at an entrance of a metro station the condition must be met:

$\lambda_1 \le \lambda_c$ и $\lambda_2 \le \lambda_c$ (9)

where: λ_c is the limit intensity of the incoming stream of passengers where there would be observed a passengers waiting at an entrance of a metro station.

$\lambda_c = p_m.F_m$, passengers per hour; (10)

where: p_m is the coefficient showing the optimal number of passengers per m^2 when conditions of comfort and safety are met, pass./m^2.

(p_m=7pass./m^2.). F_m is the area that could be used by passengers freely (without stepping on any restrict lines). For example, the Metro Station Serdika has λ_c=6706 passengers per hour.

The parametres of the system for mass service are shown in table 1.

Tab. 1. Parameters of system

System queue	Parameters	
	Direction East (1)	Direction West (2)
Entrance: M/M/1	λ_1, μ_1 ,1	λ_2, μ_2 ,1
Tells: M/M/s	λ_{1t}, μ_{1t}, n_{1t}	λ_{2t}, μ_{2t}, n_{2t}
Ticket machines: M/M/s	λ_{1a}, μ_{1a}, n_{1a}	λ_{2a}, μ_{2a}, n_{2a}
Machines for validation: M/M/s	λ_1, μ_{1v}, n_{1v}	λ_2, μ_{2v}, n_{2v}

3. APROBABTION OF THE METHODOLOGY

3.1. Basic parameters

A simulation model of the Metro Station Serdika which is a part of Line 1 (Obelya-Tsarigradsko shose) has been shown in the study. The station is one of the busiest metro stations of Sofia's metro system.

The study is conducted for a peak period in three different ways shown in table 2:

Tab. 2. Cases for simulation

Case	1	2	3
Incoming stream of passengers	λ = 3600 Passengers per hour		λ =6000 Passengers per hour
Coefficients	γ_m =0,70; α_{1m} =0,85; α_{2m} =0,75; β_{1m} =0,7; β_{2m} =0,7		
Tell	$\mu_{1t} = \mu_{2t}$ =360 Passengers per hour		
Ticket machine	$\mu_{1a} = \mu_{2a}$ =1000 Passengers per hour		
Machine for validation	$\mu_{1v} = \mu_{2v}$ =1800 Passengers per hour		
Number of tells	n_{1t} =1 n_{2t} =1	n_{1t} =2 n_{2t} =1	n_{1t} =2 n_{2t} =2
Number of ticket machine	n_{1a} =2; n_{2a} =2		
Number of machine for validation	n_{1v} =5; n_{2v} =4		

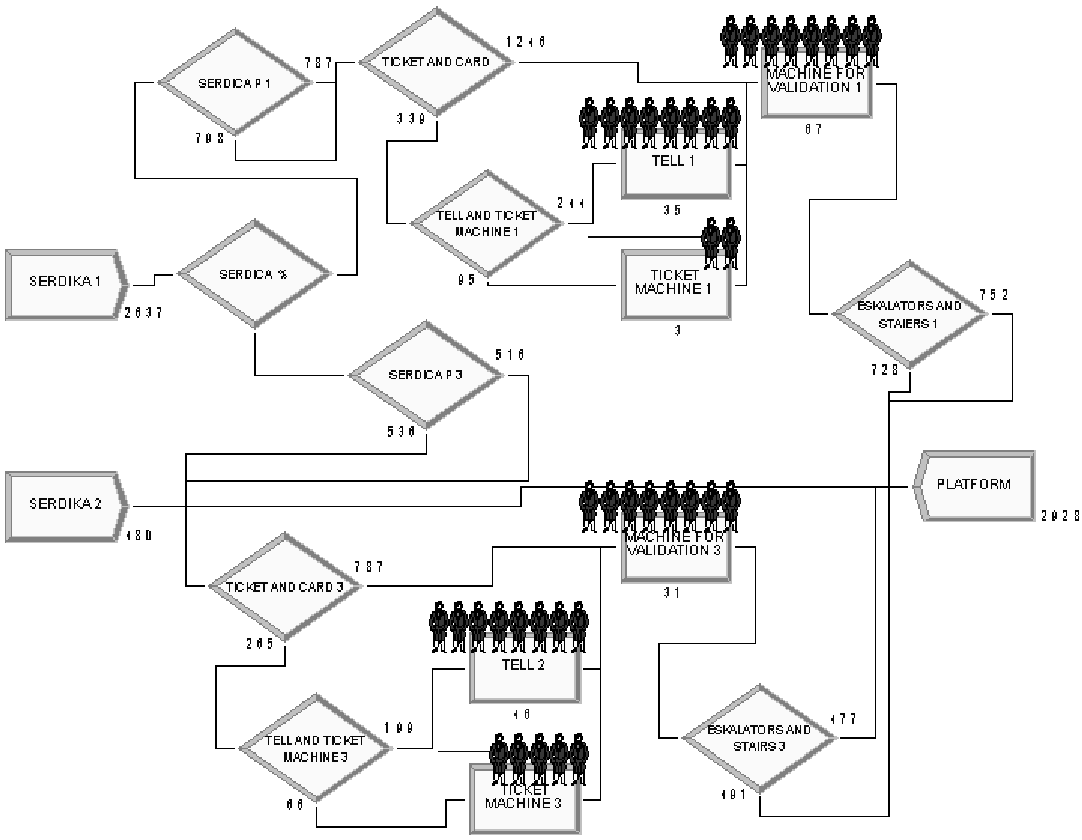

Fig.2. Simulation model in ARENA

3.2. An application of Arena Software for simulation modelling

The system for imitation modelling Arena allows us to shape dynamic model for hereogeneous processes which could be optimased [8]. Modelling is conducted by using the modelling language SIMAN and an animation system. It has been used blocks for modelling which connect to each other in accordance to dependences as well as operations in the studied system.

The simulation model for Metro Stattion Serdika of Sofia's Metro System has been shown in figure 2. Ten replications have been done for each of the cases after that an average value for each observed indicator is reported. A comparision of the results has been shown in table 3.

Tab.3. Results of simulations

Indicator	Variant		
	1	2	3
Number out system, pass.	3608	4061	6511
Total time in system, sec.	37	23	36
Number waiting in queue, passengers			
Machine for validation 1	5	6	20
Machine for validation 2	4	4	8
Tell 1	17	3	21
Tell 2	7	6	9
Ticket machine 1	0	0	1
Ticket machine 2	0	0	0
Waiting time in queue, sec.			
Machine for validation 1	9	10	19
Machine for validation 2	10	10	13
Tell 1	173	29	114
Tell 2	95	84	63
Ticket machine 1	2	2	10
Ticket machine 2	1	2	3
Unavailable device probability			
Machine for validation 1	0,24	0,24	0,40
Machine for validation 2	0,28	0,28	0,31
Tell 1	0,88	0,46	0,78
Tell 2	0,70	0,68	0,63
Ticket machine 1	0,05	0,06	0,18
Ticket machine 2	0,04	0,05	0,08

The maximum number of waiting passengers that would be served at one till in a ticket office is assumed to be ten for the study's purposes.

In the first case, the number of tills in ticket offices is not enough for direction East. When an additional till is opened, system state has been imporved (only three customers are waiting). One the other hand, the third case suggests a situation close to the critical point. In this case, both tills in the ticket office are loaded. Opening an additional till depends on the capailities and the infrastructure of the entrance-hall. In the third case, it is important to redirect customers to ticket machines for issuing tickets. The first and the third cases show situations which could happen during a peak hour in case of additional factors such as bad weather, special occasions and so on.

4. CONCLUSION

The conducted research allows us to make the following conclusions:

- A methodology for presenting a metro station as a multi-level system for mass service has been developed sucessfully.
- A multi-level system is examined as a compounded of separate single-level systems with Poison's incoming stream of passengers, exponential time for service and s number of channels (M/M/s).
- The decomposition of levels is consistent with passengers' going through and servicing them by the system: entrance, entrance-hall (ticket offices and ticket machines),escalators and stairs.
- A simulation model of a metro system has been developed with Arena software.

ACKNOWLEDGEMENT

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REFERENCES

[1] Zhang,Q., Baoming, H., Dewei., L., *Modeling and simulation of passenger alighting and boarding movement in Beijing metro stations,* Transportation Research Part C 38, pp. 28–43, 2014.

[2] Martinez, F., *Application of SIMAN ARENA Discrete Event Simulation Tool in the Operational Planning of a Rail System,* University of Puerto Rico, 2002.

[3] Ozturk, G., *Simulation & analysis of Izmir metro transportation system,*Department of Industrial Management and Information Systems, Bornova – IZMIR, p.95, 2012.

[4] Karagyozov, K., *Approximation of the moments of processes of traffic flow arrival, interruption and normalization,* Scientific journal "Mechanics, transport, communications"N3, 2013.

[5] Karagyozov, K, *Hierarchical decomposition and synthesis for logistics systems modeling by closed queuing networks,*Scientific journal "Mechanics, transport, communications"N3, 2013

[6] Razmov, T., *Analysis of the trasnport systems through discrete-event modeling,* Scientific journal "Mechanics, transport, communications"N3, 2013

[7] Kachaunov, T., *Modeling and optimization of the transportation processes*, 2nd edition, Publishing house of Todor Kableshkov University of Transport, Sofia, (written in Bulgarian), 2005

[8] http://www.arenasimulation.com

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '14

MULTICRITERIA SUSTAINABILITY EVALUATION OF TRANSPORT MODES

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Abstract *– Transport is a reflection of economic activity with substantial direct and indirect effect on economic growth and development. However, transport is also considered to be the sector with the fastest growth of pollution in environment. The main purpose of this paper is to application the VIKOR (VIšekriterijumsko KOmpromisno Rangiranje - Multicriteria Compromise Ranking) method to assess the sustainability of the transport modes. Criteria that were taken for the evaluation the sustainability of transport modes are: employment, turnover, final energy consumption, transport efficiency improvenment, green gas emissions from transport, people annoyed as a function of noise exposure of dwellings (55db(A)), external costs and number fatalities by transport mode. In paper, authors propose technique to identify according to which criteria some of transport modes needs to be improved and how much improvement is required to attain a certain level of sustainability.*

Keywords – VIKOR, Modes of transport, Development, Pollution, Sustainability.

1. INTRODUCTION

Transport plays a considerable role in the economy with its omnipresence throughout the production chain, at all geographic scales [9]. However, transport is also considered to be the sector with the fastest growth in environmental pollution [3]. Apart from energy generation and industrial processing, transport is a major contributor to pollution [2].

The transport sector is one of the main contributors to emissions of acidifying substances, ozone precursors and particulates. It is expected that the share of the transport sector in national total emissions may also increase in the coming years, due to a greater rate of progress in total emissions reductions from other sectors.

Sustainable development gets its full recognition in transport policy at the beginning 21st century, when this concept has become a priority long-term goal of European development. Orientation to the user, as well as other sociological aspects which introduced White Paper (2001), represent turnaround in the previous policy of transport sustainable development based on the ratio of transport-environment. In order to encourage economic growth, prevailing attitudes of the White Paper (2006) is that transport policy should support and facilitate the mobility instead is limiting. The new paradigm of the modern understanding of the concept of sustainable transportation becomes "sustainable mobility".

According to Richardson (1999), a sustainable transportation system is “one in which fuel consumption, vehicle emissions, safety, congestion, and social and economic access are of such levels that they can be sustained into the indefinite future without causing great or irreparable harm to future generations of people throughout the world [8].” The Environmental Directorate of the OECD defines environmentally sustainable transportation as “transportation that does not endanger public health or ecosystems and that meets needs for access consistent with (a) use of renewable resources that are below their rates of regeneration, and (b) use of non-renewable resources below the rates of development of renewable substitutes [6].“ The best definition of a sustainable transportation system was given by the Canadian Centre for Sustainable Transportation:
„A sustainable transportation system is one that:
- allows the basic acces needs of individuals and societies tobe met safely and in a manner consistent

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with human and ecosystem health, and with equity within and between generations;

- is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy;
- limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise [10]."

In order to determine the sustainability of certain modes of transport we will come from transport sustainability indicators that reflect the three components of sustainable development - economic, environmental and social. However, it is important to note that on the basis of one indicator can be determined one level of sustainability of a particular mode of transport, and based on the second some other level of sustainability.

Multi-criteria decision-making refers to situations where decisions are made starting from a large number of usually conflicting solutions. Ranking alternatives to the larger number of criteria simultaneously, contributing realities resolving such situations. Range of applications of multi-criteria decision-making is very wide, but it can be brought some common characteristics of all categories of problems that are solved in this way:

- Larger number of criteria ie attributes, which must create a decision-maker,
- Conflict among the criteria, as far the most common case for real problems,
- Incomparable units of measurement, as a rule, each criterion or attribute has different units of measurement,
- Design the best alternative or selecting the best alternative from a set previously defined finite alternatives [5].

Methods of multi-criteria decision-making allow that on the basis more indicators determine the level of sustainability of certain modes of transport, as well as their ranking. The above mentioned methods have significant application in decision-making in transport, but also to rank the transportation system from the perspective of sustainability.

There are several methods of multi-criteria decision-making that are best methods in the world, ie that are the "higher level" methods. The best-known methods of multi-criteria decision-making are ELECTRE (ELimination and Et Choice translating REality), PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluation), AHP (Analytical Hierarchy Process), TOPSIS (Technique for Order Preference by Similarity to Ideal Solutions) and VIKOR (Multicriteria Compromise Ranking).

VIKOR method was developed in the methodological foundations that enable decision makers to choose alternatives that represent a compromise between the different interests of subjects in decision-making. By applying the observed method and weight coefficients is determined the compromise ranking ie compromise solution.

Awasthi et al. investigate four multicriteria decision making (MCDM) techniques namely TOPSIS, VIKOR, SAW and GRA for sustainability evaluation of urban transportation projects [1]. TOPSIS and VIKOR are compared and applied to determine the best compromise alternative fuel mode. The result shows that the hybrid electric bus is the most suitable substitute bus for Taiwan urban areas in the short and median term [11].

The main objective of this work is to perform a comparative analysis of modes of transport from the perspective of their sustainability. To perform the ranking of modes of transport, starting from transport sustainability indicators we will apply VIKOR method.

2. INDICATORS OF SUSTAINABLE TRANSPORT

Indicators are frequently defined as quantitative measures that can be used "to illustrate and communicate complex phenomena simply, including trends and progress over time" [4]. During the last two decades measurement of sustainability issues by indicators has been widely used by the scientific community and policy-makers. Development of sustainable development indicators was first brought up as a political agenda issue at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992 [12]. Since then, the indicators represent an important tool for measuring different aspects of sustainable development, including the development of sustainable transport. A number of international organizations have been involved in the development of indicators aiming to achieve a more sustainable transport on the local, regional, and global levels. The differences observed in the mission and policy priorities of various organizations are accordingly reflected in the selection of indicators. However, the three-dimensional framework of indicators based on economic, environmental, and social impacts is a common way to perform an impact-based analysis of transport activities.

3. MULTI-CRITERIA ANALYSIS OF SUSTAINABILITY MODES OF TRANSPORT

To perform the ranking of modes of transport from the perspective of sustainability in below we will define alternatives and criteria in order to apply the Entropy and VIKOR methods. Alternatives that we will consider are: road (a_1), air (a_2) and rail (a_3)

transport. Criteria that will be used to rank alternatives are the indicators of transport sustainability on the example of the European Union (Table 1).

Tab. 1. Details about the indicators selected to evaluate the transport mode sustainability

Dimension	Indicator	Description	Measurement Unit	Source
Economical	CEC1	Employment of mode by transport	Number (In thousand)	Eurostat
	CEC2	Turnover by mode of transport	million eur	Eurostat
	CEC3	Final energy consumption by mode of transport	mtoe	Eurostat
	CEC4	Transport efficiency improvement	% change of consumed toe/Mpkm	European Commission http://ec.europa.eu.pdf
Environmental	CEN1	Greenhouse gas emissions from transport by mode of transport	thousand tonnes of CO_2 equivalent	Eurostat
	CEN2	People annoyed as a function of noise exposure of dwellings (55db(A))	%	WHO
	CEN3	The external costs due to air pollutants, global warming, noise, and accidents	ECU/1000 pkm	ftp://ftp.zew.de/pub/zew-docs/dp/dp0698.pdf
Social	CSC1	Fatalities	number	Eurostat

Tab. 2. The initial decision table

	CEC1 max	CEC2 max	CEC3 min	CEC4 max	CEN1 min	CEN2 min	CEN3 min	CSC1 min
w	0.136	0.065	0.158	0.001	0.257	0.023	0.069	0.291
a_1	4859.5	397685	297.6	13.5	874506	20	44.26	30268
a_2	394.4	122097	7.3	12	16253	30	21.91	6
a_3	678.2	74771	50.5	15.5	7359	10	4.87	38

Tab. 3 – The calculated values for the d_{ij}

	d_{ij}							
	CEC1 max	CEC2 max	CEC3 min	CEC4 max	CEN1 min	CEN2 min	CEN3 min	CSC1 min
a_1	0.0000	0.0000	1.0000	0.5714	1.0000	0.5000	1.0000	1.0000
a_2	1.0000	0.8534	0.0000	1.0000	0.0103	1.0000	0.4326	0.0000
a_3	0.9364	1.0000	0.1488	0.0000	0.0000	0.0000	0.0000	0.0011

Tab. 4 – Ranking of alternatives ie modes of transport

	S	R	QS	QR	Q V=0.5	Q V=0.25	Q V=0.75
a_1	0.7871	0.2910	1.000	1.000	1.000	1.000	1.000
a_2	0.2480	0.1360	0.056	0.053	0.054	0.053	0.055
a_3	0.2162	0.1274	0.000	0.000	0.000	0.000	0.000

Ratings of all modes of transport according to all criteria are given in the initial decision table (Table 2). Weight of criteria can be determined on the basis of subjective or objective approach. Weight of criteria can be determined and by using some of the methods of objective approach. The best-known objective methods are: method of Entropy, CRITIC, FANMA and DEA method. In the paper we apply Entropy method to determine weight coefficients. In each column of Table 2, within each criterion it is necessary to determine the maximum and minimum value, which refers to the observed modes of transport.

Starting from the values given in Table 2, the calculated size of the d_{ij} by all criteria. Starting from the size d_{ij} and weight coefficients are formed three ranking lists given in Table 4. According to the criteria QS_i and QR_i best level of sustainability of transport has achieved rail transport. In total, according to $Q_i(v= 0.5)$, has achieved rail transport.

Testing conditions U_1 [7]:
Condition U_1 is not fulfilled because:

$Q(a_2)-Q(a_3)=0{,}054-0{,}000<0{,}25$

$DQ=\min(0{,}25,\ 1/(3-1))=0{,}25$

Railway transport don't have "insufficient priority" in relation to air transport, which is in second place on the ranking list. Air transport has a set of compromise solutions, as the first alternative, ie railway transport don't have "insufficient priority" in relation to the second ranked alternative.

Analysis of the following alternative (third by rank - the alternative a_1):

$Q(a_1)-Q(a_3)=1{,}000-0{,}000>0{,}25$

Alternative a_3 does not enter in the set of compromise solutions, as the first alternative a_3 has "sufficient advantage" in relation to the third ranked alternative a_3.

Testing conditions U_2 [7]:
Condition U_2 is fulfilled because the alternative a_3 is "sufficiently" stable first place according to all criteria:
1. Alternative a_3 has the first position on the ranking list according to the QS and QR;
2. Alternative a_3 has the first position on the ranking list according to the Q for $v= 0.25$, $v= 0.50$ and $v= 0.75$.

So, the final solution is defined by a set of compromise solutions in which entering alternatives a_3 and a_2. However, since the alternative a_3, ie rail transport at on the all lists takes first place it can be concluded that this mode of transport with point of transport sustainability is in the first place, while the second is air transport, a third road transport.

4. CONCLUSION

Multiple criteria decision-making is a complex process that is widely used in all areas of human activity. Based on the above, the conclusion is that the multi-criteria analysis can be successfully applied to rank modes of transport with point of sustainability of their development. It was stated shown in the example, which is solved by the VIKOR method. By using this method were ranked road, rail and air transport with the sustainability of their development whereas application of indicators of sustainable transport. The results showed that rail transport has a first position on all the ranking lists and has achieved the highest level of sustainability in relation to other modes of transport.

Using VIKOR method achieves the objective consideration of sustainability modes of transport in the European Union. It should be noted that it is possible to change the criteria and their importance. Also, it is possible to apply other methods of multicriteria analysis when ranking modes of transport with point of sustainability of their development.

REFERENCES

[1] Awasthi, A., Omrani, H., Gerber, Ph. *Multicriteria decision making for sustainability evaluation of urban mobility projects*, Working Paper No 2013-01, 2013, http://www.statistiques.public.lu/catalogue-publications/working-papers-CEPS/2013/01-2013.pdf

[2] Dobranskyte-Niskota, A., Perujo, A., Prerl, M., *Indicators to Assess Sustainability of Transport Activities*, European Commission - DG Joint Research Centre Institute for Environment and Sustainability Transport and Air Quality Unit Via Enrico Fermi 1 , 2007.

[3] EC, Sustainable Development Indicators to monitor the implementation of the EU sustainable Development Strategy, Brussels, Belgium, 2005.

[4] EEA, EEA core set of indicators: Guide - EEA Technical Report, Copenhagen, 2005.

[5] Hwang, C. L., Yoon, K., Multiple Attribute Decision Making: Methods and Applications, New York, Springer–Verlag, 1981.

[6] OECD, http://www.oecd.org/home/

[7] Opricović, S., Tzeng, G., *Extended VIKOR method in comparison with outranking methods*, European Journal of Operational Research, 2007, 178(2):514-529.

[8] Richardson, B., *Towards A Policy On A Sustainable Transportation System*, Transportation Research Record 1999, 1670: 27-34.

[9] Rodrigue,.P., Comtois C., Slack, B., *The Geography of Transport Systems*, New York, Routledge, 2007.

[10] The Centre for Sustainable Transportation, http://cst.uwinnipeg.ca/documents/Definition_Vision_E.pdf

[11] Tzeng, G., Lin, Ch., Opricovic, S., *Multi-criteria analysis of alternative-fuel buses for public transportation*, Energy Policy, 2005, 33(11), p. 1373-1383.

[12] UN, *Agenda 21: Programme of Action for Sustainable Development*, Rio Declaration on Environment and Development, New York, 1992.

Infrastructure

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '14

THE ORGANIZATION OF CONSTRUCTION WORKS UNDER TRAFFIC ON OVERHAUL OF RAILWAY SECTION DOBOJ – KM 103+500

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Tatjana SIMIĆ [3]

Abstract *– The basis for the works on the Main railway overhaul is indicated in the Technical conditions, which define the conditions for works, technical inspection and acceptance of works with main overhaul in railway network of former Yugoslavia, which are still valid and used by Beneficiary. The organization of railway traffic during the works is related to organization and the phased technology of the works. The track overhaul has to include all required works on substructure and superstructure in order to reach the corresponding technical conditions of the railway line, to meet traffic volumes along the line and to fulfil traffic safety requirements. Technical solutions defined in ToR, regarding the superstructure type and required extensive rehabilitation of substructure, significantly opting technology and technological approach to the overhaul. They are deriving from the railway rank on the Corridor Vc and by the standards of TER. For them and in all its details to be freely applied, it is necessary in the future definitely adopt and formalize regulations and standards. That is also the presupposition for the subsequent quality and professional supervision on similar projects and for maintenance process during operation. Prior to beginning of works it necessary to prepare and create conditions for accommodation of personnel, equipment, machinery and services, i.e. the preparation of Construction site. Complexity of the construction, dynamic map of various process activities and their mutual compliance as well as compliance with railway traffic during the works, which were an integral part of project documentation in the Main overhaul of section Doboj - km 103+500 on Corridor Vc are the subject of this paper.*

Keywords – railways, main overhaul, construction technology, traffic organization.

1. INTRODUCTION

The subject section Doboj – km 103 + 500 (entrance to tunnel Orline) is located in Republic of Srpska (18.21 km of double track railway)

In short, scope of works in the Main overhaul on railway contains:

- Complete overhaul of the track superstructure on main tracks including at least one siding track and switches at stations Doboj and Ševarlije,
- Rehabilitation of the substructure – railway formation, drainage,
- Rehabilitation of drainage systems on structures and tunnels,
- Rehabilitation/installation of new signaling and interlocking devices at stations and on open line,
- Works on OCL and telecommunication equipment.

The purpose of this overhaul is to bring the railway and its elements into originally designed standards and to meet traffic requirements.

The first prerequisite in order to perform any type of site works in the area of the railway zone is to perform cleaning of the mine fields from the war, done by presence of experts from MAC during the construction works on Main overhaul of railway on section Doboj - km 103+500.

Single track railway was built in 1947 and in 1978 was build a second track. On this double track railway section there are two stations Doboj and Ševarije and five halts Pridjel, Jabučić Polje, Trbuk, Paklenica Donja and Rječica. Due to war activities and poor maintenance, railway is in a very bad condition.

Under general provisions of Rulebooks, it is

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clearly defined when these works should take place and what is the scope of such works. The track overhaul has to include all required works on substructure and superstructure in order to reach the corresponding technical conditions of the railway line, to meet traffic volumes along the line (Figure 1.) and to fulfil traffic safety requirements.

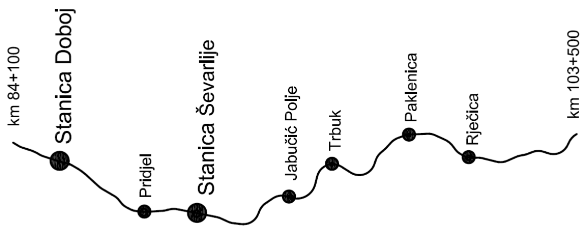

Fig.1. Section Doboj – km 103+500

The works on substructure include overhaul of railway substructure with widening of the formation and placement sand layer, geotextile, transitive and protective layer and rehabilitation of the drainage system in station and on open line.

The works on standing halts consider arrangement of standing halts on open line and construction of side boarding with prefabricated assembly wall for platform (0,55m, MB30) and canopies with benches. Superstructure of open track and station tracks is with 60E1 rails, welded in CWR, on concrete sleepers (2,60 m) with elastic fastenings and ballast of crushed stone of eruptive origin, specified thickness and granulation. According to the Beneficiary request, wooden sleepers were designed on bridges and new switches with 60E1 rails, welded in CWR, on wooden sleepers (2,60 m) with elastic fastenings.

2. DESCRIPTION OF WORKS ON MAIN OVERHAUL

Preliminary works are related to the quality functioning of the process of main overhaul belongs a series of activities that individually or together are conducted by Investor, through its specialized services Contractor and its subcontractors, suppliers and external collaborators. These activities take place before contracting business, during the contracting and after it until the initiation of works.

Geodetic works are very important precondition for execution of works, and require permanent presence of one, or more geodetic teams on the track and in the railway zone. Geodetic teams must include the experienced professionals specially trained and equipped in the field of specific requirements of railway geodesy.

Reconstruction of substructure should be performed with installation a protective layer of soil formation. Soil formation is being protected with geotextile and (or) geocomposite materials which must unconditionally to be laid up to drainage zones. Fifteen-year experience with applying of geotextile and lately especially geocomposite materials shows their exceptional properties.

In technological terms differ:

- Conventional methods of reconstruction with applying classical construction machinery (bulldozers, excavators, loaders, trucks, rollers, etc.) which implies pre-removal of track and
- Modern methods with use of tracks machinery that does not require prior removal of the tracks (individual machines and operating trains).

Replacement of track, depending on applied work technology, can be accessed before simultaneously, or after substructure reconstruction. Experiences with the reconstruction of substructure and ballast before, during, or after the replacement of track are known.

Welding of track in longer sections and its gradual including into CWR track is next after ballast excavation and track replacement, no matter on schedule of these operations. The most rational method is thermite welding (AT).

Purchase, transport, installation and control of ballast material, from the track in the process of excavation and (or) distributing of ballast removed dirty materials must be supplemented with a new amounts. Transport of a new crushed stone material is being carried out with FAD wagons. Unloading is being done directly from the wagons as fair as possible in the ballast prism and gradually in amounts that are appropriate to capabilities of applied tamping machines that are used for levelling and regulation of track in vertical and horizontal alignment.

Dismantled track materials have the title of environmentally hazardous waste. Different types of lubricants, impregnating oils, pesticides and other the materials used in vehicle, rail and railway equipment lubrication, or removal of vegetation, are contained in the dismantled track are true environmental hazard.

Laying of new switches depends on the form in which the switches are going to supplied. Switches can be supplied in three different ways.

- Completely separated switch components (trimming and assembly on site),
- Partially separated switch components (partial assembly on site) and
- Complete pre-assembled switches (on site just assembling and regulation).

Mechanical tamping, levelling and lining of tracks is performed when the new track is being placed in a new layer of loose gravel, it is necessary to lift and lateral shift it, in order to tamp new ballast material below the sleepers. Tamping is carried out according to regulations and the documentation of the performed works through measurement books.

3. ORGANIZATION OF TRAFFIC DURING THE WORKS

3.1 Temporary railway connections

In order to keep the traffic on the section it was nessecary to perform temporary railway connections (Figure 2.) on the entences end exits from the stations, so they could take the traffic from the ones being reconstucted.

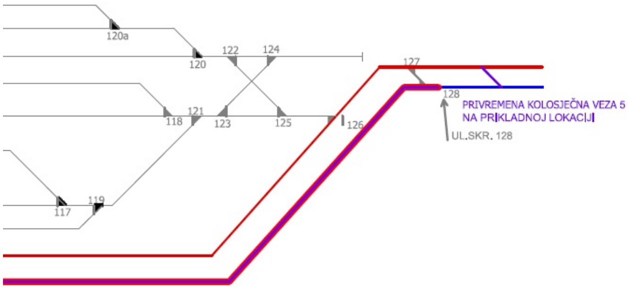

Fig.2. Temporary railway connection

3.2 Phases of construction works

The organization of railway traffic during the works is connected with the organization and the phased technology of the works (Figure 3.).

The train diagram number 60 shall will be out of use during the execution of works. The special train diagram and Instruction on the organization and performing of traffic services during the execution of works will be in application. It will be valid only during the execution of works and they will be made by representatives of RRS

The turnout Ševarlije should be inspected with staff 0^{00} - 24^{00}, prior to start of works.

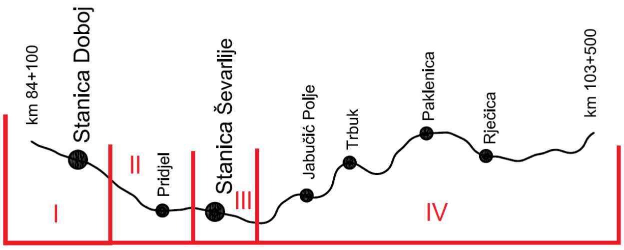

Fig.3. Phases of construction works

Station Doboj – Works in station Doboj are divided in three phases. Phase one takes under consideration station entrance. Regulation of railway traffic is done between station Doboj and adjacent stations with staff. Prior to the commencement of work Traffic Control Center 2 (TCC2) must be put into operation. Phase two takes under consideration station exit. Regulation of railway traffic is done between station Doboj and stations Ševarlije with staff. Traffic Control Center 1 (TCC1) must be put into operation. In the third stage performs the repair of the left and right tracks at the station.

The works are divided to three phases, the first phase should be carried out with device TCC 1 turned off, while other two with device TCC 2 turned off:

1. Phase I represents main overhaul of the input head and 2, 3, 5 tracks and 11 in station Doboj under control of device TCC 1,
2. Phase II represents main overhaul of the output head station of Doboj under control device TCC 2,
3. Phase III is a main overhaul to an exit switches from station Doboj under control device TCC 2.

In Phase I it is preferable to use specialized track machinery, because the work is performed in the station itself, so it is not very convenient to access to it from surrounding roads. Relocation of right tracks is performed from the axle distance of 4.00 m to 4.75 m, this includes extensive works on the relocation of OCL, and access to this area is not possible from nearby roads. Regulating the railway traffic must be made between station inspectors in Doboj and the neighboring stations toward Tuzla and Srpska Kostajnica.

While in Phase II local road located next to the railway line, which provides access from the road. It should not exclude the possibility of a combination of conventional and non-conventional construction methods. Regulating the railway traffic must be made with between station inspectors in Doboj and the neighboring turnout Ševarlije.

In phase III, by establishing a temporary railway connections it is given the possibility of transfer from regular to irregular track toward Ševarlije.

Station Doboj is logistical base not only for this phase, but for the rest of the section. Its capacities will be used for accommodation of work trains and other track machinery, wagons with material for embedding, fastening, sleepers and ballast, as well as the disposal of the removed material.

Section Doboj – Ševarlije – Works are performed first on the left and then on the right track. During the works, traffic is carried like on a single track railway line (on a regular or irregular track, depending on the direction). Traffic regulation is carried out in station distance.

In this phase local road is located next to the railway line, which provides access from the road. It should not exclude the possibility of a combination of conventional and non-conventional construction methods, depending on the efficiency.

Works on halt Pridjel imply the removal of existing platforms, construction of drainage between the tracks, replacement the superstructure, construction of new platforms, relocation of OCL poles out of platforms, as well as their grounding on the rail through the body of platform with plastic pipes and construction of canopies, fences between the tracks and lighting system. Tracks are on such axial distances which requires, during the intervention on one track, the stability of the second track to be ensured with the ramming of sheet piles or some other method in order to enable traffic on second track in regime of restricted running speed.

Station Ševarlije – works will be performed in two phases. Regulation of railway traffic shall be made in announcement interval.

Track capacities in turnout Ševarlije will be temporarily used for supply of materials, as soon as the track are put in function.

In both phases it is preferable to use specialized track machinery, because the work is performed in the station itself, so it is not very convenient to access to it from surrounding roads and due to mine surround mine fields.

By establishing a temporary railway connections it is given the possibility of transfer from regular to irregular track toward Maglaj and Ševarlije.

Section Ševarlije – km 103+500 – All works on this section are similar like on section Doboj – Ševarlije, so the same construction methods are used like there. Due to the length of the section it is divided in three subsections.

With an exception that after a halt Jabučić polje until the end of subsection axial distances between tracks are such that there is no need for ensuring the stability of another track.

4. DYNAMIC PLAN

Dynamic plan of construction works should be developed based on the level of known data and quantities. In the Gantt chart should be given types of works and structures, with the aim to show the approximate time of construction, in phases and in total, phased construction of certain facilities and approximate necessary time, and the order to get needs time for construction works and individual objects (Figure 4.).

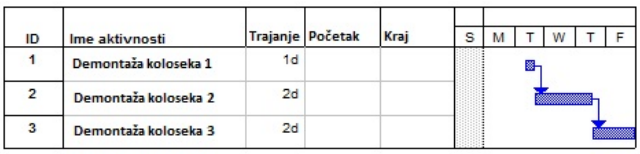

Fig.4. Gant chart

Duration of works are approximate (empirically possible). Detail technology of construction works will be conducted by the Contractor and accepted by the Investor, with special conditions for safe railway traffic that is determined by responsible institutions and accurate time required for main track overhaul of sections.

During the construction works, speed on a neighboring track (within stations or on open track) principally must be reduced and constant control and inspection of tracks.

This is indicated in the initial, approximate the securing of investment material and supply of energy source. For Investor is important as much as possible to reduce the total cost of construction to deliver materials to the site by rail, which coincides with the general social interest in the preservation from environmental pollution. Generally, for procurement of all necessary re-sources it is advised to be procured by domestic producers, if they fully meet the requirements in terms of: quality, quantity and delivery schedules, proximity, and competitive price.

5. CONCLUSION

The task of the Consultant was to propose the optimal technology of works that will be followed by temporary traffic organization. Optimal generally implies quality, deadline and cost of the works. It is necessary to strive for the implementation of organizational and technological measures and solutions that imply the maximum concentration of activities in the railway zone. Any activity out of this zone causes problems with collision with other types of transport or access. When choosing modern machinery and equipment it should be strived towards optimal, not ultimate high-performance solutions and find a balance between construction and railway traffic flow. Temporary traffic organization during the works aims to minimize disruptions in rail traffic to the rest of the rail network and that prior to the commencement of works provide information for all participants in the planning and organization of rail transport. For all the rides on irregular track it is necessary to create a temporary timetable for single track railway.

ACKNOWLEDGEMENT

This paper is done within a framework of a project Track overhaul of the railway sections Doboj – 103+500 on Corridor Vc within Book 8 Organization and technology of construction and with assistance of representatives of PE Railways of Republic of Srpska who provided access to material necessary for preparation of entire Design.

REFERENCES

[1] Tomislav Milićević, Danijel Vučković, *Book 8. Organization and technology of construction*, Project: Track overhaul of the railway sections Doboj – Maglaj i Jelina – Zenica on Corridor Vc PHASE II: Main Design Section Doboj – km 103+500, 2013.

[2] Relevant Rulebooks and Guidelines regarding the railway and road design, construction, traffic and maintenance in Republic of Srpska.

BASIC CHARACTERISTICS OF COMPLETED WATERPROOFING ON REINFORCED CONCRETE BRIDGES ACCORDING TO THE ACCEPTED EUROPEAN STANDARDS

Snejana VALKOVA [1]
Nikolina POROJANOVA [2]

Abstract *– This report views the basic characteristics of the already applied over the bridge bitumen waterproofing membranes and the significance of these characteristics for the facility durability. The methods for testing of these characteristics and their deployment in the laboratories, which estimate waterproofing materials to be used in the road constructions will be considered.*

Keywords – Waterproofing, reinforced concrete bridge, road construction, characteristic, European standards.

1. INTRODUCTION

Road and railroad bridges waterproofing makes approximately 2% of the facility total price, which is a relatively small part in comparison with the other elements of the construction. However, consequences of a bad choice of the waterproofing, application of inappropriate materials, making defects during the works and others can be drastic for the facility condition.

Prices of repairs and their consequences can exceed manifold the initial investment price. It will be necessary to remove the waterproofing layer, to reconstruct the basis under it. There is also damage due to traffic congestion, which sometimes has to be complete.

2. PROCESS

Most of the railway bridges in the Bulgarian railway system are with damaged waterproofing, which makes them unreliable, not enough secure and with a bad exterior. To ensure a longer life of the concrete and reinforced concrete facilities the waterproofing and the joints are not to allow water penetration to the parts of the construction. Sick concrete becomes porous, its strength diminishes and there are conditions for reinforcement destruction.

The bridges waterproofing has to prevent water penetration to the construction. It is laid directly under the road surface. The materials used for concrete bridge surfaces waterproofing are mainly of three types: cast asphalt, liquid rubber compositions and bitumen-polymer membranes. The bitumen-polymer membranes are quite recently applied and their share in comparison with the other waterproofing materials types is growing. Bitumen is modified with SBS (styrene-butadiene-styrene rubber) elastomer or APP (atactic polypropylene polymer) plastomer. Polyester nonwoven fabric is used as reinforcing basis. Thus waterproofing membranes achieve good temperature resistance and high mechanic performance.

The road surface asphalt or gravel bedding in case of railway bridges is laid directly above waterproofing membranes.

3. CHARACTERISTICS

In 2009 CEN accepted EN 14695, introduced in Bulgaria as BSS (*Bulgarian State Standard*) EN in 2011. This standard specifies basic characteristics and performance of bitumen waterproofing membranes, which are used as waterproofing of concrete bridges and other concrete surfaces for passing of vehicles. It also contains testing methods to check the membranes characteristics and their in-service performance.

A bridges waterproofing system presents layers between the bridge concrete slab and the surface covering (Figure 1). Usually this system consists of a bitumen primer, one or more bitumen membrane layers and a protective layer if it is specified by the manufacturer.

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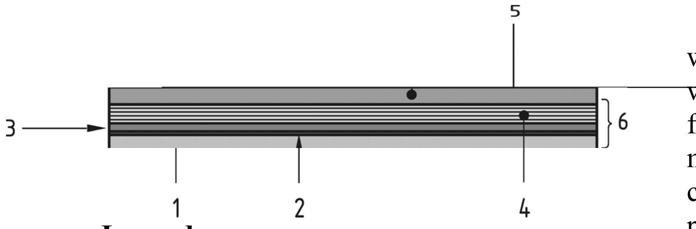

Legend:

1. Bridge concrete slab;
2. Primer;
3. Reinforced bitumen membrane(s);
4. Protective layer;
5. Surface covering;
6. Bridge waterproofing system (2 + 3 and 4, if specified).

Figure 1 – Components of a Bridge Waterproofing System

Bitumen membranes which are part of waterproofing systems have the following basic characteristics:

- visual defects;
- unit area size and weight;
- initial amount of the protective mineral coating;
- strain force characteristics;
- water absorption;
- bending at low temperatures;
- flow resistance at high temperatures;
- size stability at high temperatures;
- thermal aging performance.

The following characteristics are specific only for bitumen waterproofing membranes and application for concrete bridges:

- initial amount of protective mineral coating on the membrane surface mainly with the grain size of more than 0,125 mm. It is important to be determined as too high surface protection may cause sliding between the membrane and the layer above it.
- Size stability of bitumen waterproofing membranes for concrete bridges to be specified according to BSS EN 1107-1, but at the temperature of 160°C. This test simulates the effect of the cast asphalt application above the membrane.
- Thermal aging performance is estimated during exposure to the temperatures from -15°C to +100°C. This characteristic is important for the waterproofing membranes durability.

Characteristics of the laid membranes are estimated beside these characteristics. There is a separate standard for each of them.

All the mentioned characteristics of the ready laid waterproofing are connected with a concrete application and are estimated using special methods specified in the corresponding standard.

These characteristics guarantee that the waterproofing possesses a definite resistance to withstand specific loads and impacts of the bridge facility, i.e. shock, temperature and weather impacts, mechanization load during the asphalt laying and compaction, continuous dynamic loads caused by the passing vehicles, etc. That's why they are so important and described in the standard. They are to be considered during concrete applications. They are:

- strength of adhesion to the concrete base (BSS EN 13954) – a basic requirement to ensure the waterproofing system durability is to strictly follow the application technology. Very good adhesion to surfaces, especially to the concrete ones is necessary to be ensured to keep the insulation from damages in case of the bridge construction deformation.
- Cutting resistance (BSS EN 13653) determines the resistance to cutting of the waterproofing system laid above a concrete surface, covered with an asphalt layer. This test simulates the dynamic forces impact, e.g. application of vehicles brakes.
- Cracks bridging properties (BSS EN 13224) – ability of reinforced bitumen membranes to resist the concrete surface cracks movement while preserving their quality.
- Compatibility in case of heating (BSS EN 14691) – waterproofing systems laid on a concrete construction are to keep their characteristics for a long period of time. Many of bending membranes used for concrete bridges waterproofing are produced of materials subject to migration, diffusion and absorption of the components inside the system and/or of the ones the system is glued to. These physicochemical effects appear with the time and accelerate with the temperature increase. Accelerated temperature heating test will allow us to estimate changes of the specific mechanic property of cutting resistance for a significantly shorter period of time than a waterproofing system aging under the normal ambient conditions. Using of the cutting resistance test will allow us to state each change in the properties by means of indication of a migration or incompatibility between the glued elements above the separating surface for a long period of time.
- Bitumen membranes behavior during cast asphalt laying (BSS EN 14613) – determines their resistance to the bitumen component increase when laying cast asphalt.
- Water impermeability
- The following requirements are to be observed during bridge waterproofing application:
- the concrete to be the waterproofing basis is to

be laid at least 14 days before and to have a minimal strength of 20 MPa;
- the basis is to be clean, sound and level not to allow the material deformation or rupture in case of big unevenness. It is to be free from dust and organic pollutants;
- application during rain is prohibited;
- the ambient temperature is to be above 0°C. The surface temperature is to be above +2°C;
- the waterproofing is to be covered with a protective layer or a road surface layer as soon as possible;
- the surfaces to be protected are to be obligatory treated with a primer for a better waterproofing adhesion. Thus fine dust particles which could break the adhesion will be additionally removed.

<table>
<tr><td>CE
01234</td><td rowspan="3">CE conformity marking
consisting of the CE mark introduced by Directive 93/68/EEC

Identification number of the certification body

Manufacturer name or identification sign and official address

The last two numbers of the year, when the marking was put

Certificate number

European standard number

Product description
and
information on the mandatory characteristics</td></tr>
<tr><td>AnyCo Ltd, PO Box 21, B-1050

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01234-CPD-00234</td></tr>
<tr><td>EN 14695

1 m x 10 m x 5 mm, nonwoven polyester, modified bitumen with elastomer, fine mineral sanding, for heat welding only.
For laying of a single layer with asphalt protective layer.
Primer used for testing: primer XYZ…. (trade name)

Strain force in longitudal direction:
900 N/50 mm ± 50 N/50 mm
Strain force in cross direction:
850 N/50 mm ± 50 N/50 mm
Extension in both directions: (45±4) %
Bending at low temperatures: ≤ -20°C
Water impermeability: resistant
Water absorption: ≤ 5%
Cohesion strength:
- for concrete: ≥ 1,0 N/mm^2
- for asphalt: ≥ 0,5 N/mm^2
- for cast asphalt: ≥ 0,8 N/mm^2
Cracks bridging property: type 3 – resistant at -20°C
Cutting resistance:
- asphalt: ≥ 0,2 N/mm^2
- cast asphalt: ≥ 0,3 N/mm^2
Compatibility: 5%
Thermal shock resistance: NPD
Puncture resistance: resistant
Durability:
- water absorption: ≤ 0,5%
- thermal aging performance (-15±5)°C / ≥ 100°C
Compatibility: 5%</td></tr>
</table>

Figure 2 – Example of the CE Marking and Information Provided with the Accompanying Technical Documentation to the Product

BSS EN 14659 standard provides also information on the requirements to the content of the manufacturer technical information:

- product trade name;
- manufacturer / supplier;
- origin / manufacture source;
- product description – type and amount of reinforcing elements; surface layer type; product weight or thickness; surface layer type;
- primer and the amount to be applied;
- protective layer type;
- type of the cover for laying;
- designated use and application method;
- product characteristics and their limits;
- certification mark;
- other information for consumers – e.g. requirements to transportation and storage; safety precautions during the work with the material.

4. CONCLUSION

In conclusion we can say that over the last few years these new European standards have significantly increased the quality requirements to the waterproofing, both planned and under implementation, of bridges and surfaces for the vehicle traffic. This corresponds to the public and economic importance of these facilities, which have an important role to connect countries, cities, towns and even continents.

Bulgarian designers, construction personnel and investors are also to take into consideration the new and very important requirements for the facilities durability and to harmonize the existing regulatory documents, to foresee financial means to equip at least one laboratory to examine all necessary characteristics of this waterproofing type, especially of the ones connected with the useful life.

REFERENCES

[1] BSS EN 14695
[2] BSS EN 1107-1
[3] BSS EN 13954
[4] BSS EN 13653
[5] BSS EN 13224
[6] BSS EN 14691
[7] BSS EN 14613

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
RAILCON '14

EXTENSION OF ARCHITECTURAL STRUCTURES ON RAIL STATIONS AND SPECIAL REQUIREMENTS OF PLANNING IN INFRASTRUCTURE AND CIVIL ENGINEERING

Tomasz REMUS [1]

Abstract *– Construction at railway stations is a specific task to operators planners and entrepreneurs especially if the perimeter which is to be built is located in close range to the platforms. Here many conditions have to be taken into account. Engineering measures often influence the essential infrastruckture of railway operations which must be maintained at any time. The following presentation deals with the tasks and challenges that have to be overcome primarily by planners and engineers during the design phase to ensure that the implementation of construstion measures can be successfully completed in terms of cost, quality, schedule and train operation.*

Keywords – Railway infrastructure, architecture, civil engineering, construction near railway tracks

1. INTRODUCTION

The railway network of Switzerland is well developed and has expanded as it is at a high utilization level. Switzerlands rail company the SBB is one of the main transport systems of the country for people and goods. Numbers of transported individuals and goods are rising permanently which makes a constant expansion of the infrastructure and stations mandatory.

1.1 Starting point

Extension of architectural content to railway stations is very complex in planning and requires a variety of professional planners and experts. For example, a railway station, which is a listed building and the center of an urban space can in most cases only be expanded underground or by construction of a footbridge over the railway tracks. The adjacent railway tracks and platforms are usually strongly affected by such measures so are the infrastructure of the railway tracks such as electricity, energy and telecommunications.

1.2 Objective

Based on the practical experience this paper is intended to explain the impact of enlargement of railway station buildings during the civil engineering planning in the pre-project phase.

2. CONDITIONS OF CONSTRUCTION NEAR RAILWAY TRACKS

The most important conditions for construction near to tracks can be divided into the following main sections:

- work safety
- operational safety of the track
- preservationof infrastructure for possible operation of the track.

2.1 Work safety and passenger safety

In Switzerland the BAV[1] published a central document which is advising and providing a guideline for construction sites near railway tracks and railway stations it is the AB-EBV[2].

The work safety is the highest priority while constructions near platform areas. It is to be ensured by technical, operational and organizational measures. so the aspects of security have been a top priority in the design phase.

Maintaining the security of passengers follows a simple principle: "The simpler the better." Derived from the complexity of the whole SBB has defined the

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following security cascade:

1. traveler safety is maintained primarily by fixed assets (buildings).
2. If the security can not be mantained by a structural measure additional operational measures must be taken (eg: speed reduction).
3. If safety can not be maintained through operational measures the schedule must be adjusted.

Schedule change may cause operational or structural measures (modification Railway station). To maintain the safety of construction the danger potencials have to be identified. Possible dangers can be:

- accidents with electricity
- collisions with train vehicles
- accidents with hanging cables
- high amount of dust or smoke reducing ilumination and vision and therefore limiting rail traffic
- eruptions through e.g. frame work and excavation work.

Danger areas as well as minimum distances to electrified parts (e.g.: overhead wires, railway power systems) for individuals machines and other items. Further the sidewise distances for constructions near to railway tracks have to be respected. The basis for those regulations of all minimum distances are given by the equivalent structure gauges for meter- and normal tracks of SBB.

2.2 Error free operation

To secure the regular operation of the railway during the constructional actions near the rail tracks a surveilance concept has to be prepared to control roadways, overhead lines, temporary bridges, and power systems cables. The components of such a surveilance concept are foreseen by the corresponding regulation published by the SBB.

Depending on the construction plan and the range to the railway track a trouble-free operation might not even be possible without previous planning and approval of the SBB. Therefore the timewindows for service interruptions have to be defined precisely. This means that the planner of the project has to pre calculate the work load of workers and machines at a untypical and dangerous work site. The know-how of railway operators and their support is necerssary to plan such construction work

3. ARCHITECTURE RELATED GOALS AND CONDITIONS OF RECONSTRUCTION PROJECT

Stations are not only platforms for the public, today increasingly also combined transport but also comprehensive service centers. The need for more and more services for the SBB clientele grows restive and causes the need of development of station buildings in construction.

3.1 Project objectives

The project objectives are already defined by the client with the notice of competition and their achievement is already being targeted in the phase of the competition by the architectural team. In general, the goals for the expansion of architectural contents of a railway station building can reasonably be summarized as the following:

1. Long-term consolidation of the commercial site.
2. Increase the quality of stay and usability.
3. Paid to the historical.
4. Optimization of the flow of personnel in and around the building.
5. Functionality and economic solution to the problem.
6. Higher energy efficiency of the building.

If perron or even the track is affected by the project trouble-free rail operations are to be taken into concern.

3.2 Project organization and responsibilities

The organization of complex construction projects is divided into the strategic and operational levels (project level). While composing the strategic level representatives from the building owners and their advisors, including the project level in their core: architects, planners, experts, users and tenants. The core team (Consulting) is supported by various departments within the SBB (finance, law, historic preservation, infrastructure, communications, security, etc.) and the Coordination Office of the passenger traffic of the station concerned. With the creation of a project organization chart and the most responsibilities are clarified within the project and created a base for the comunication and coordination.

3.3 Project costs and schedules

The construction costs of the project are already formulated with the preparation of the study and are calculated with an accuracy of about 20% +/- this is the basis for the budget formation. With increasing processing depth the cost accuracy is about 10% during the construction project. The project budget remains unchanged.

The scheduling framework is first marked out with key milestones and supplemented with the necessary operations. The procedure laid down in the competition phase as milestones remain the same such as: Design, permit procedures, tendering, implementation and end of construction.

4. IMPACT OF ENLARGEMENT OF STATION BUILDINGS ON THE CIVIL ENGINEERING PLANS

The greatest challenge lies in the recognition and then in the formulation of the project task. An expansion project, which extends up to the tracks in the platform area and under the railway brings up the following questions for civil engineering:

1. Can the Perron part or completely be blocked and for how long?
2. Are minimum distances to the track kept?
3. What systems of infrastructre will be affected or interrupted?
4. Are service interruptions of the tracks necessary and possible?
5. Which execution times are disposal?
6. Who is responsible for what?

Answering these questions can only be done with the help of the SBB. Now the greatest challenge for the civil engineer is locating the competent authorities of the SBB. As well as specification of interfaces to the project and coordination of both staff offices (general planning team and SBB) to be compliant to the milestones. If the questions are answered execution times, machinery and materials and the civil engineering costs can be defined.

Furthermore, in all major building renovations strict environmental aspects must be taken into account. So the rain water according to Swiss law has to be led from the roof surfaces has to be seperated from the existing mixing water and sewer systems to be deducted to an infiltration system in the groundwater. The geological conditions such as contamination free sites, drainage capability of the soil, and depth of the groundwater to the ground surface must be met here. For reconstruction of station buildings, it means that due to lack of space on railway station areas, the rainwater infiltration can only be done underground. Often this infiltration system will be built under the existing station building or underneath the rail tracks.

However, the challenge to this is rather the clarification of the presented questions then a engineering solution.

5. CONCLUSION

The early involvement of the civil engineer in the preliminary design will guarantee on time and safe handling of architectural design of railway stations and meet at the same time with the ambitious quality requirements of the operator. Here, the analysis of the structure of various organizational units, governmental offices corporation offices and agencies and their competences and the competences of their staff for the efficient handling of planning is essential. This information guarantees a comprehensive recognition and resolution of project tasks in civil engineering.

REFERENCES

[1] Ausführungsbestimmungen zur Eisenbahnverordnung; Das Eidgenössische Departament für Umwelt, Verkehr, Energie und Kommunikation: Bundesamt für Verkehr (BAV), 3003 Bern, 2006, www.sbb.ch

DESIGN SOLUTION OF CONTAINER TERMINAL WAREHOUSE CASE OF FREE ZONE CITY OF NIŠ

Vojislav TOMIĆ [1]
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Boban NIKOLIĆ [3]

Abstract *– The paper puts focus onto the procedure of developing a technical project design solution of a railway-highway Container terminal warehouse in the free zone - city of Nis. Container terminal warehouse is complex, serviceable, dynamic and material flow system defined by its own performances: objectives, functions, components and links. They are also the points of intersection between macro and micro-distribution within the supply chains. In the first part of the paper, some basic remarks about container terminals, their functions, structure and characteristics are given. In the second part, special attention is given to design of such a terminal at the location of "Konstantin Veliki" Airport in the city of Nis. In this part of research subsystems of warehouse container terminal are on discussion. The aim of this paper is to attract investments, accelerated industrial development and increase employment rate in the southern part of Serbia.*

Keywords – Container terminal, design, railway, road, logistics.

1. INTRODUCTION

Container Terminal (CT) is a facility where cargo containers are transshipped between different transport vehicles, for onward transportation [1]. CT and their warehauses have one of the most important roles in the logistic supply chains, i.e. in transport networks. Various types of transport meet each other at CT warehauses, where also transformation of material flows is accomplished [2, 3, 4, 5]. One of the crucial factors for a highly efficient distribution network is a suitable choice of CT warehouse design. The main aim of this paper is to find the most suitable design for the CT warehouse.

The paper gives the procedure of developing a technical project design solution of a public CT warehouse in the free zone - city of Nis. In this paper structural and parametric solutions of all necessary elements of the CT warehouse are given, including the design of a public warehouse. Such a system, offers a great synergic effect as well as a great influence onto the industrial development in the city of Nis and southern part of Serbia. [6, 7, 8].

2. LITERATURE REVIEW

The warehouse layout depends on many factors e.g: the items stored, space available, height, the layout of road, and rail tracks around the warehouse, etc. Because of that design planning and location of warehouse has been formally studied and researched as a discipline since the mid 1950s. In literature, Simon [9] suggests that the layout problem is a design problem but the location problem is an optimization problem. On the other hand, according to Francis et al [10] location problem should be treated as a design problem not an optimization problem. In our opinion, the layout and location problems have elements of both design and optimization problems. A confirmation of our thinking we found in the source [11]. In any case, all authors agree in one, warehousing is a time-consuming activity that does not add value. However, the need to provide better service to customers and be responsive to their needs appears to be the primary reason to have warehouse [12]. Based on all stated above, it can be concluded that designing a warehouse is a complex problem. Because of that, Rouwenhorst et al. [13] classify the warehouse design and planning problems into three levels of decisions – strategic, tactical and operational. In this paper, we used the strategic decision as a relevant decision.

3. CONTAINER TERMINAL DESIGN

There are several reasons for building and

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operating warehouses for CT. In many cases, the need to provide better services to customers and to responsive their needs appears to be the primary reason. Although it may seem that the only function of a warehouse is warehousing, that is, temporary storage of goods but in reality many other functions are performed. Because of that, characteristics of flows, which pass through of the CT warehouse, are necessary to analyze before design process. The first step in the design of a CT warehouse is to determine the general flow pattern for material, parts and work in process through the system [11]. Based on the aforementioned, the material flows model of CT warehouse in Niš is analyzed in this paper and it is shown in fig 1. Flow pattern refers to the overall pattern in which the product flows from beginning to end. Beginning started from raw material at the receiving stage (goods are unloaded from wagons), through storage of goods in racks and finally distributed goods in trucks.

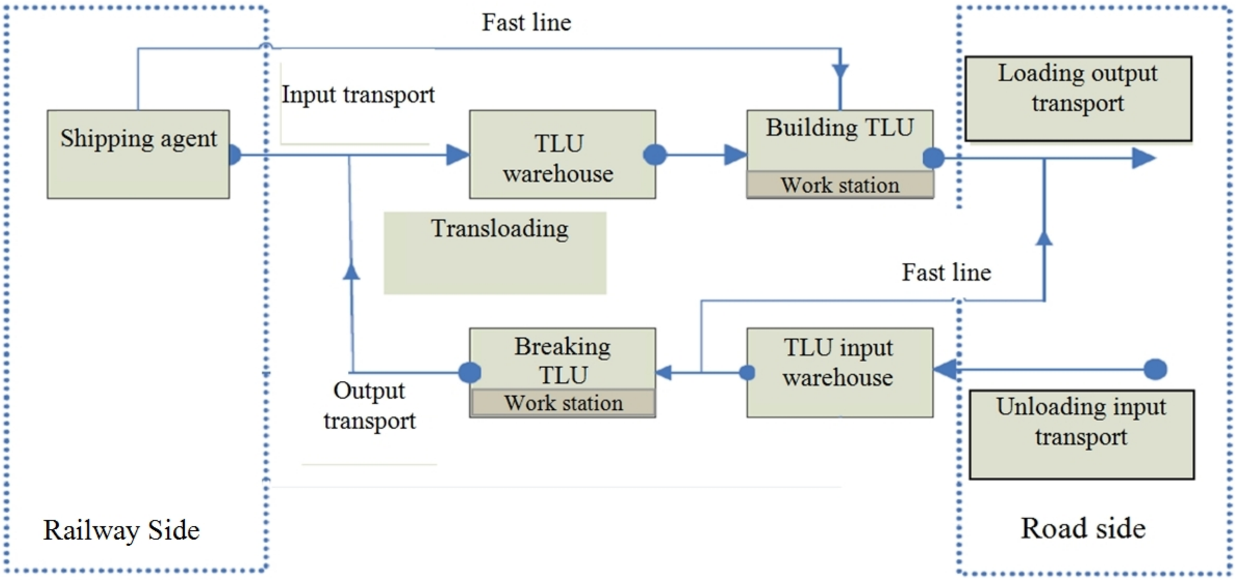

Fig 1. Material flows model of CT warehouse in Free zone Niš

According to the presented flows model of CT warehouse in Niš, the load is delivered to the CT warehouse in transport logistic units (TLU). The load is delivered using both road and rail sides of the terminal. The load arriving in TLU can be directly transformed into the final output TLU using the fast line. The goods that arrive in inadequate TLU, or which are not for any other reason ready to be shipped directly, are sent to the section where TLU are built or broken (work stations).

Such a great amount of load is consolidated into TLU in the construction section using workforce at work stations. After building of an adequate TLU, the goods are directly stored or shipped using the fast line to the output transport.

If the input transport is in inadequate transport logistic units, it is necessary to break it at work stations. At these stations, load is separated, sorted, scanned, and wrapped in thermal shrinking foil, building a compact warehouse TLU. Such new TLU is then stored, and the goods a wait for the commissioner to remove them.

When the commissioner receives an order for removing a certain quantity of goods, TLU are sent to the TLU construction zone, where new TLU are built in accordance with the picking list. As mentioned above, certain TLU do not need to be sent to the construction section, but they are directly moved to the storing zone for shipment preparation. In the same way, certain transloaded transports can be moved directly to the next connection transport over the fast line without the need to break and build TLU again. This happens only in the case when the connection route is compatible with the previous one, that is, when it requires the same TLU containing the exact same goods.

The possible goods at the work stations in this model are:

- output goods that need to be built,
- input goods that need to be broken,
- and transloaded goods that need both to be broken and built.

4. MATHEMATICAL PROBLEM DESCRIPTION

On the basis of general flow in fig 1 we present a design solution of a final Lay-out for CT warehouse on fig 2. 2D design of the warehouse with the surface of 3600 m^2 has been done by AutoCAD software tools.

One of the main tasks of this paper beside design of a CT warehouse is to determine the necessary forklifts for proper functioning of the CT warehouse system. On the basis of the obtained design it is possible to evaluate the number of the forklifts. The evaluation comprises the following parts:

- calculation of forklifts needed to store/remove goods,
- calculation of pellet turnover on the annual level,
- calculation of forklift time for storing/removing pallets,
- final calculation of forklift efficiency.

In order to determine the required number of forklifts, it is necessary to set the forklift road paths in the receipt area (Fig. 2). Three possible road paths can be noticed: the longest one (S_3), the shortest one (S_2) and the middle/average one (S_1).

The average road path length S_{ms} it is evaluated as a summation of partial paths S_1, S_2 i S_3,:

$$S_{ms} = S_1 + S_2 + S_3 \tag{1}$$

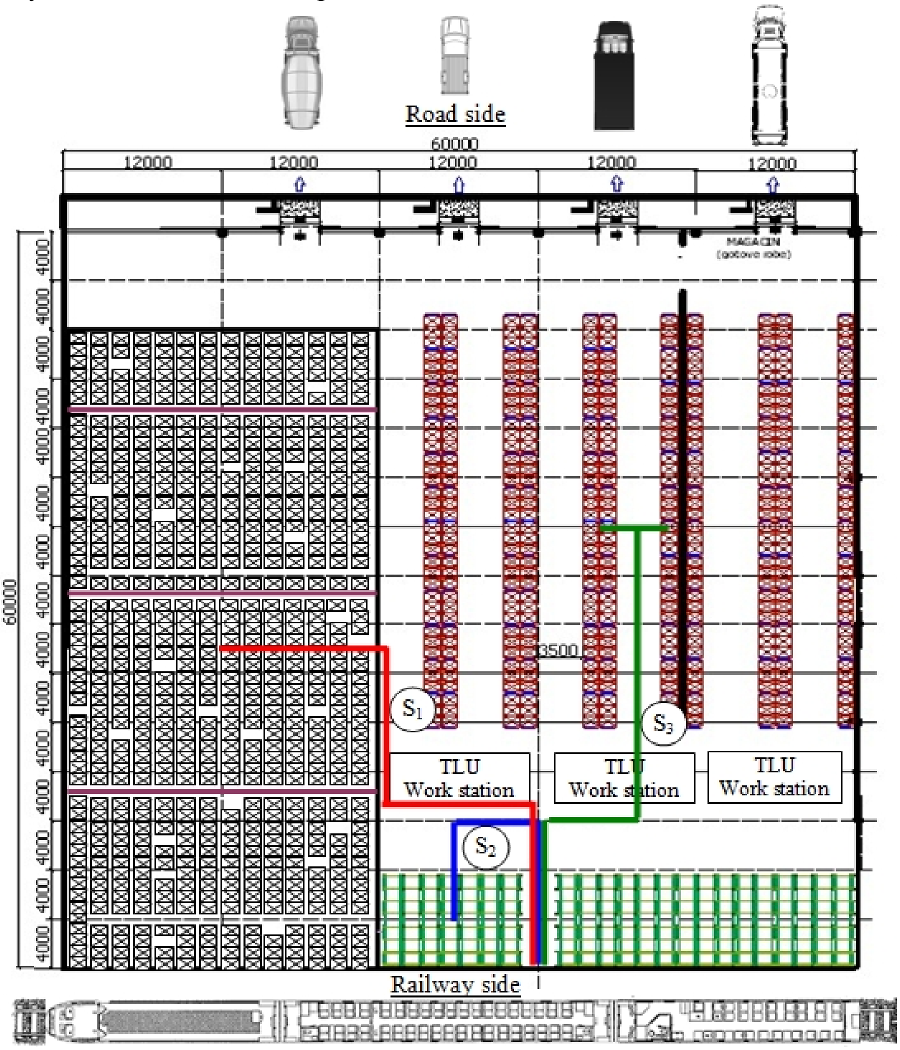

Fig. 2. 2D Lay-out drawing solution of the CT warehouse

The warehouse is divided into three zones:

- S_1 is the average forklift time in the storage area where floor storage spaces are present for the TLU,
- S_2 is the average time for forklifts in the storage area where selective storage shelves are present,
- and S_3 represents the average time for forklifts in the area of storage where only drive-in storage shelves are present.

Using the average path length S_{ms} and the forklift properties provided by the producer, the average time to transport a pallet from a truck to the rack (S_{ms}) and back ($S = S_{ms}$), i.e. the time of an average work cycle (t_{ms}), is determined as:

$$t_{ms} = t_{up} \cdot S_{ms} \cdot t_{pv} + t_s + S \cdot t_e \tag{2}$$

with all the quantities defined in Table 1.

Tab. 1. Times of forklift manipulation

Taking goods from a palletizer t_{up}	0,29 min
Storing goods into a rack t_s	0,43 min
Taking goods from a rack t_u	0,43 min
Loaded forklift drive t_{pv}	0,012 min/m
Unloaded forklift drive t_e	0,008 min/m
Dropping goods onto the ground t_o	0,18 min

In this procedure, the forklift proceeds according to the flow diagram in Fig. 3.

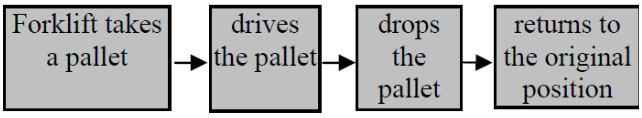

Fig. 3. Forklift pattern road diagram

For the specific task, the time required for the forklift to perform this operation for a single TLU is *0.98 min*. Using this information as well as the annual turnover of the warehouse, which is additionally augmented by 20%, it is a straightforward task to compute the time necessary to store all the pallets in the warehouse (*GOD*):

$$GOD = 1{,}2 \cdot t_{ms} \cdot GOP \tag{3}$$

where:

GOP – the annual turnover of the warehouse (the total number of pallets).

Assuming $P = 22$ as the number of work days per month and $T = 6h$ as the number of effective work hours per day, one may compute the number of effective work hours per year *tg* by means of Eq. (4) and, furthermore, the required number of forklifts, N_v, by means of Eq. (5):

$$t_g = 12 \cdot P \cdot T \tag{4}$$

$$N_v = (t_{ms} + t_{is}) / t_g \tag{5}$$

For the considered case, the evaluated number of forklifts is 3, with the usage coefficient of effectiveness is approximately 75%. In practice, this is, however, considered to be quite high usage, so it was decided to take 5 forklifts.

5. CONCLUSION

This research provides an analysis of potentials and obstacles in the process of South Serbia integration in the Balkan logistic system. The idea of this paper is to give the methodology of designing CT warehouse using the multi-modal method access. The first part of this paper gives an analysis of CT warehouses activities (flow activities). The key part of this paper is related to the idea of a design modern CT warehouse that would provide conditions for a successful work of the free zone Nis. Focus is put onto the technological design of a public warehouse within the CT. Upon modeling, a thorough analysis of material flow in the warehouse has been conducted in order to determine the required number of forklifts important for the warehouse functionality. Hence, a functional and parametric analysis of the complex CT warehouse system has been done, which was actually the original aim of this paper.

REFERENCES

[1] Arnold D.: *Material flusslehre*, Vieweg & Sohn Verlagsgesellschaft mbH, Braunschweig / Wiesbaden, 1998.

[2] Lippolt C.: *Lager-und Distributations systeme,* Vorlesung, IFL, Universitaet Karlsruhe, Karlsruhe, 2005.

[3] Zečević S.: *Robni terminali i robno-transportni centri*, Saobraćajni fakultet Univerziteta u Beogradu, Beograd, 2006.

[4] Marinković Z., Marinković D., Tomić V.: *Concept solution of logistic center in the free zone Pirot*, International Conference MHCL 2012., pp. 227 – 230.

[5] Aiying, R., Martin, G.: *Shift designs for freight handling personnel at air cargo terminals*, 2009, Journal of transportation research, pp. 725–739.

[6] Marinković Z., Marinković D., Tomić V., Marković G.: *Značaj osnivanja logističkog (kargo) centra u Nišu i njegov uticaj za privredni razvoj regiona*, TIL 2011., Niš 2011., pp. 31 - 38.

[7] Marković G., Gašić M., Marinković Z., Tomić V.: *Suština i značaj formiranja regionalnog koncepta – strateški pravci razvoja regiona*, TIL 2011., pp. 7 - 14.

[8] Vasić G.: *Inženjerski pristup dizajniranju distributivnog centra u okviru slobodne zone Pirot*, diplomski rad, Mašinski fakultet u Nišu, Niš 2012.

[9] Simon, H.A. *Style in design*, in C.M., Spatial Synthesis in Computer-Aided Building Design, Wiley, New York, 1975.

[10] Francis, R.L., Mc Ginnis and J.A White, *Facility Layout and Location: An Analytical Approach 2ndEdition*, Prentice-Hall, Englewood Cliffs, NJ, 1992.

[11] Sunderesh S. Heragu, *Facilities Design third edition*, Taylor & Francis Group, New York, 2008.

[12] Kulwiec, R.A, *Advanced Material Handling*, The Material Handling Institute, Charlotte, NC, 1980.

[13] Rouwenhorst, B., B. Reuter, V. Stockrahm, G.J van Houtum, R.J. Mantel, and W.H.M. Zijm, *Warehouse design and control: Framework and literatures review*, European Journal of Operational Research, 2000, pp. 515-533.

MODULAR MICROPROCESSOR LEVEL CROSSING PROTECTION SYSTEM TYPE RLC23 FOR SAFETY INTEGRITY LEVEL SIL4

Zvonimir VIDUKA [1]
Darko BARIŠIĆ [2]

Abstract *– Big differences in speed, weight and braking distance between railway and road vehicles make unprotected level crossings critical places for collisions. Mostly, level crossings in the world are equipped only with St Andrew's Cross or are protected with some kind of old electro-mechanic protection device. Lately, a spotlight is on quality of level crossing protection in order to lower the number of human and material losses. New protection devices are based on microprocessor technology and they have to fulfill highest safety demands required in CENELEC standards EN 50126, EN 50128 and EN 50129. This article describes level crossing protection system type RLC23 which is certified for safety integrity leve (SIL) 4. The system is highly modular and configurable through the PC application which enables easy adjustment to any new kind of railway level crossing situation.*

Keywords – Level crossing protection, SIL4, configurability.

1. INTRODUCTION

In 2006 in Croatia just 30% of the total number of level crossings was equipped with a certain kind of the automated protection devices, usually those were relay based LC control unit at the end of the life time. Similar situation is in many countries all around the world. In this perspective the target of the company ALTPRO was to develop an unique, configurable, modular LC protection system based on a universal microprocessor based platform which will be suitable to solve (from functionality point of view) all the existing requirements not only in Croatia but in the rest of the world too. Special efforts were done to satisfy all the requirements necessary to comply with the highest safety level according to CENELEC standards) SIL4. ALTPRO has finally reached this target with the Level Crossing protection system type RLC23.

Special feature of this system (related to some other concepts with the same functionality) is a simple adaptation to the new customer requirements. Compete functionality is assured by the same software solution without needs for any robust relay interfaces and just with changing configuration data-file. Easy adaptation to any new requirements is also assured by high level of modularity and with very easy maintenance procedures with modern and simple test equipment. The system can also be equipped with some innovative additional subsystems as video-monitoring system with event recorder, additional LED signalization installed on the road surface (before half-barriers), obstacle detectors or additional LC protection devices such as spikes in the concrete (road surface).

2. LEVEL CROSSING PROTECTION SYSTEM RLC23

2.1 System description

Level crossing protection system RLC23 controls light and sound signalization, half barrier drive and driver's indication signals placed on the level crossing area. Basic configuration includes four wheel detectors (axle counter counting points) with two switch-on and one switch off section, two road signals, two main driver's indication signals and two half-barrier with the barrier drive.

Basic structure of the level crossing protection system RLC23 is configuration with driver's indication signals and configuration with remote control functionality. The basic control central units of the system RLC23 are two microprocessor based platforms APIS-RLC23 (A and B) which control all the elements of the system. Control functionality is

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made by a doubled redundant structure due to the reliability and availability requirements. In basic configuration of the platform system works on the 2 out of 2 (2oo2) principles. And by duplication some of executive modules of the platform (A/B) it is possible to achieve 2 out of (1 out of 2) which additionally increases availability of the level crossing control system.

Central control microprocessor based platform APIS-RLC in the level crossing protection system RLC23 has the following functions:

- It drives red and white lights of the light road signals and sound road signals (bells) depending on the train presence or on the manual LC activation.
- It monitors current of red and white lights of road signals and by that controls their correct function; each platform (A/B) controls the current of absolutely all lights, although it drives only certain lights. Current control is performed continuously while the light is switched on (e.g. while the train is approaching in a case of red light), and by short pulse in configured periods (e.g. each 10 seconds) while the light is switched off (so called “cold check” – refers only to red lights).
- It controls lowering/lifting of (half) barriers depending on a presence of a train or by manual LC switch-on. Optionally it can control blinking of bulbs on barrier arm if they are required, and control their correct function. Certain platform (system A/B) controls lowering of barriers in safety OR-function with other platform (barriers are lowering if at least one system provides lowering command), i.e. lifting of barriers in safety AND-function with other platform (barriers are lifting only when both systems provide lifting command).
- It controls correct function of barrier drive and integrity of barrier arm in a way that it detects final positions of arm (up/down), it measures time of arm lowering/lifting and it detects possible interruption of electrical contact on weakest part of the arm upon break.
- It receives information about track sections clearance/occupancy from axle counter BO23 and about train passage over certain counting point in specific direction.
- It drives indication elements on control board in LC housing/cabinet, and it receives manual commands from switches/pushbuttons for LC switch-on/switch-off, forced manual restoring to the basic state and testing/simulation of disturbance and failure.
- It drives white lights of track driver’s indication signals (on LC version with driver’s indication signals) depending on correct function/failure and LC switch-on/switch-off state and it monitors their current, i.e. controls their correct function.
- It continuously communicates with microprocessor platform APS-RLC DK in nearest station (on LC version with remote monitoring), and with it exchanges data of LC state (disturbance / failure / correct state, barriers position, switch-on/switch-off of road signals, etc.). Microprocessor platform APIS-RLC DK which controls remote monitoring in station is smaller version of main platform APIS RLC in LC housing/cabinet, in charge for control of indication elements on operators desk in station operator room (optionally on display unit in operator room) and pushbuttons for LC control by station operator (manual switch-on/switch-off, restoring to the basic state, etc.).
- It receives command for switch-on (possible even for switch-off) from station interlocking system (in a case when LC is located near station area or within station area) over microprocessor platform APIS-RLC DK in station. Also, for dependency with interlocking many other functions can be configured; such as keeping the station exit signal on the aspect of forbidden drive for certain time after LC switch-on, etc.
- It controls DC voltage of battery power supplies 1 and 2, correct function of battery chargers 1 and 2, and presence of mains AC voltage.
- It exchanges vital data of LC state with platform APIS-RLC of counter-system (B/A) over two CAN buses (double bus due to redundancy / wider availability).

Maximum capacity of the external devices which can be connected on one RLC23 system is: 8 road signals (not depending on the light technology – LED, bulbs...) with bells, 4 main driver's indication signals, 4 auxiliary driver's indication signals, up to 4 sections on the open track, two pairs of half barriers (third is possible if the functionality is the same as for first pair of the half barriers).

Schematic of the maximal configuration is on figure 1.

2.2 System configurability

The level crossing protection system RLC23 is extremely configurable and flexible for use and adaptation on certain specific application requires minimum time consumption.

Standards, traffic rules, norms and regulations issued by certain railways (country) are different and many suppliers of the signaling equipment very often face problems how to change the basic concept of the system (SW, HW) in order to satisfy these requirements and to keep the required safety integrity level SIL4 at the same time. Depending on specific situation it increases costs of development and seriously aggravates process of certification or approving of safety for these new versions of the systems.

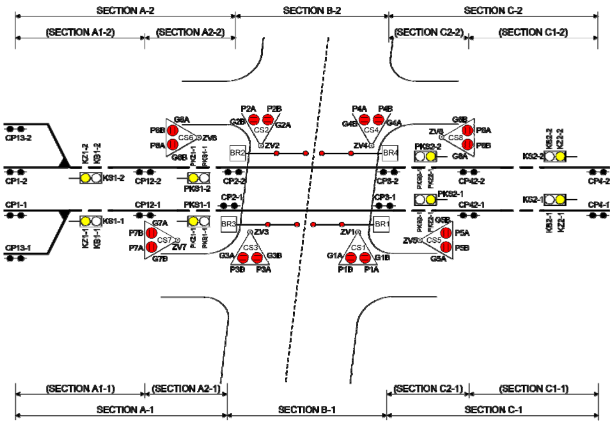


Fig.1. Maximal quantity of the external devices which can be connected on one RLC23 system

Due to these reasons the main engineering challenge was development of the device which should have a unique hardware (HW) platform (power supply modules, module for communication and monitoring inside any redundant system and different number of U/I modules depending on the situation) with the same software (SW) not depending on certain application. With Windows PC application it is possible to configure any situation (application) which meets customer/market requirements.

The biggest amount of time was spent by ALTPRO in analyzing of the standards, traffic rules, norms and regulations issued by the railway authorities all around the world and this application includes huge spectrum of configuration possibilities. As an example we are listing some options which can be chosen by the configurator tools:

- Number and type of road signalization – traffic light principle, two blinking red lights with one/double bulbes.
- Frequency of blinking, period of so called „cold control".
- Lowering/lifting time of the barrier, ringing time (sound signalization), use of heaters, behavior of the system in case of the broken arm/gate, use of the obstacle detectors…
- Number of the sections, switching off time delay, time to return to basic state.
- It is also possible to control which events will set the system into the failure state (which is automatically annulled by eliminating of the condition under which it was created) or error (it is necessary to annulled it manually) etc.

2.3 Product certification

Since ALTPRO has performed a lot of projects all around the world delivering the axle counters, train detectors, switch on/off electronic treadle as the part of modernization of the level crossing system, ALTPRO engineers collected huge experience related to railway signaling. This experience, knowledge and know-how in design, development and certification (according to CENELEC standards) of the signaling products helped company during certification of the level crossing protection system RLC23. Figure 3 shows EMC testing of the system RLC23 according to standard EN50121-4 in TÜV Rheinland EMC labs in Nürnberg. Figure 4 shows SIL4 certificate according to standards EN 50126, EN 50128 and EN 50129.

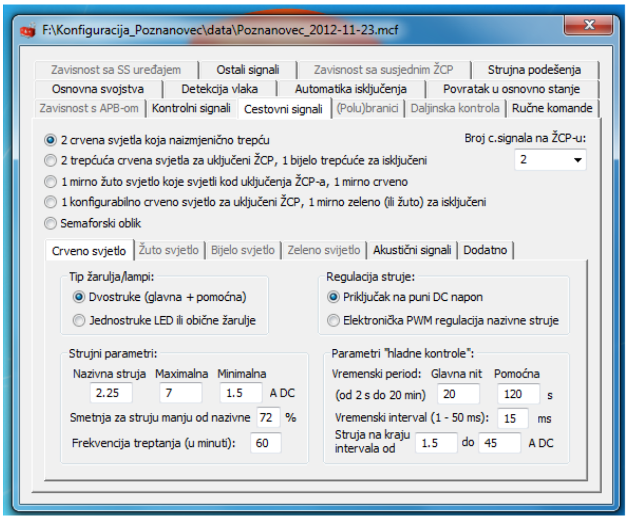


Fig.2. Example of the configuration possibilities for road signals

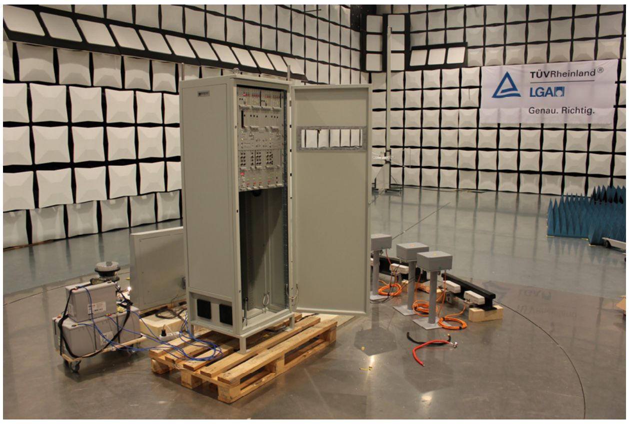
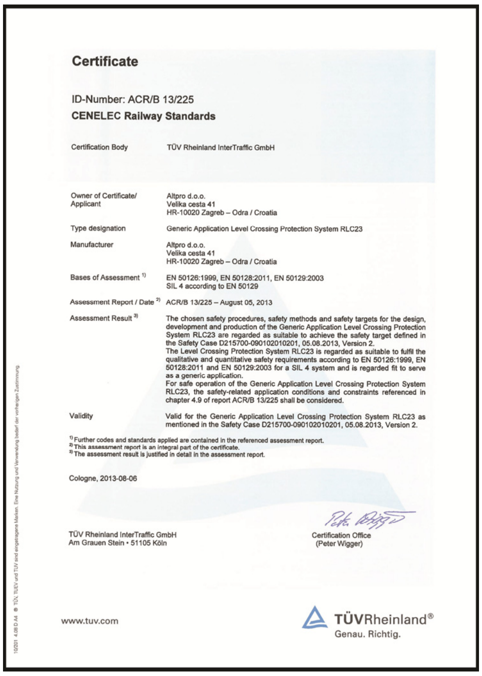


Fig.3. LC protection device RLC23 during the EMC testing

Level crossing protection system RLC23 (figure 5) is sometime (depending on the project requirements) installed with some additional features; a) an innovative additional road signalization consisted of white and red LED diodes installed in the road surface in order to give to train driver one additional warning that they approach the level crossing area, b) on the pillars of the road signals (or on separate pillars) are also sometime installed the cameras for event recording with video event recorder and c) special additional LC protection device as "boom spikes in the concrete (road surface)". Figures 6 and 7 show some of the RLC23 installations all around the world.



Certificate

ID-Number: ACR/B 13/225

CENELEC Railway Standards

Certification Body	TÜV Rheinland InterTraffic GmbH
Owner of Certificate/ Applicant	Altpro d.o.o. Velika cesta 41 HR-10020 Zagreb – Odra / Croatia
Type designation	Generic Application Level Crossing Protection System RLC23
Manufacturer	Altpro d.o.o. Velika cesta 41 HR-10020 Zagreb – Odra / Croatia
Bases of Assessment 1)	EN 50126:1999, EN 50128:2011, EN 50129:2003 SIL 4 according to EN 50129
Assessment Report / Date 2)	ACR/B 13/225 – August 05, 2013
Assessment Result 3)	The chosen safety procedures, safety methods and safety targets for the design, development and production of the Generic Application Level Crossing Protection System RLC23 are regarded as suitable to achieve the safety target defined in the Safety Case D215700-090102010201, 05.08.2013, Version 2. The Level Crossing Protection System RLC23 is regarded as suitable to fulfil the qualitative and quantitative safety requirements according to EN 50126:1999, EN 50128:2011 and EN 50129:2003 for a SIL 4 system and is regarded fit to serve as a generic application. For safe operation of the Generic Application Level Crossing Protection System RLC23, the safety-related application conditions and constraints referenced in chapter 4.9 of report ACR/B 13/225 shall be considered.
Validity	Valid for the Generic Application Level Crossing Protection System RLC23 as mentioned in the Safety Case D215700-090102010201, 05.08.2013, Version 2.

1) Further codes and standards applied are contained in the referenced assessment report.
2) This assessment report is an integral part of the certificate.
3) The assessment result is justified in detail in the assessment report.

Cologne, 2013-08-06

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Fig.4. SIL4 certificate

Fig.5. RLC23 cabinet

3. CONCLUSION

ALTPRO has applied years of its practical experience in fields of railway safety, electromagnetic compatibility and environment conditions in this project of development of the level crossing protection system RLC23 for safety integrity level SIL4. Hardware modules of the platform, interface modules, overvoltage protection modules and train detection (axle counter) modules are designed in Eurocard form in order to facilitate the process of eliminating failures. Wiring is designed in the way to facilitate serial production of the device and any new project (requirements) will differ with existing ones just in the configuration data file what assures uniformity of the systems, very easy maintenance, easy performance control and simple operation. With specially designed testing unit it is possible to test the central unit of the LC system as well as all the peripheral devices connected to the central unit. With this design a uniform system is achieved which allows the simple maintenance for the customer and low life cycle costs. ALTPRO level crossing protection system RLC23 (in different versions) is already supplied and installed in various railways all around the world.

Fig.6. Level crossing protection system RLC23 installation (worldwide)

Fig.7. : Level crossing protection system RLC23 installation (worldwide)

REFERENCES

[1] CENELEC EN 50129:2003, Railway applications – Communication, signalling and processing systems – Safety related electronic systems for signalling

[2] ALTPRO d.o.o. Zagreb, User manual for level crossing protection system RLC23

TOOLS FOR TRANSITION CURVE DESIGN - APPLICATION FOR RAILWAY RECONSTRUCTION

Luka LAZAREVIĆ [1]
Zdenka POPOVIĆ [2]
Milica VILOTIJEVIĆ [3]

Abstract *– European standard EN13803-1:2010 prescribes the application of six forms of transition curves. Two of these six forms are prescribed for the use by Serbian regulation - clothoid and cubic parabola. Entire railway network in Serbia was initially designed using cubic parabola. During recent reconstructions of railway sections, this form of transition curve was still used in order to maintain spatial position of railway centre line. The aim of this paper is to explore the possibility of application of clothoid transition curve on existing railway sections using tools for transition curve design.*

Keywords – railway, transition curve, clothoid, cubic parabola, reconstruction.

1. INTRODUCTION

Transition curve is the element of alignment that connects straight line and circular curve or two circular curves with the same or different radius, which can have the same or opposite direction of curvature [1].

At first, when trains travelled with low speeds, the transition from straight line to circular curve was direct. On the other hand, cant was either not designed or the change of cant was applied on the straight section before the beginning of the circular curve [2]. The later increase of the speed of rail traffic showed disadvantages of this type of alignment - passage from the straight section to the circular curve followed the abrupt centrifugal force i.e. lateral jerk, which influenced the ride comfort, the appearance of damages on transported goods and the potential for derailment. Obviously, transition element that would provide gradual change of curvature and cant was necessary. Transition curve is the alignment element that met these two conditions.

Regarding railway design in Serbia, in 1875. engineer Mihailo Petrović ih his book „Instructions for railway design“ suggested the use of transition curve, either in the form of circular curve with twice bigger radius (2R) or in the form of curve with variable radius and curvature. Transition curves were used only in railway design until the end of the World War II. After 1945. transition curves were also introduced in the road design.

Although cubic parabola was used as the transition curve in railway design, it showed to be inapplicable in the road design. It was already known that cubic parabola has the problem with error that increases with length. This error is the consequence of approximations that were adopted in derivation of cubic parabola. Since principles of road design implies the application of longer transition curves (comparing to railways), it was necessary to use different form of transition curve. Therefore, clothoid was presribed as the form of transition curve that should be used in road design.

Current regulations for railway design in Serbia implies the use of both, cubic parabola and clothoid [3], but in praxis there is not even a single case of application of clothoid. On the other hand, clothoid is used in railway design worldwide, especially on many European railways. Also, it is important to emphasize that European standard EN13803-1:2010, among clothoid and cubic parabola, also prescribes the use of Bloss curve, cosine curve, Schramm curve and sine curve [4].

Since all the railways in Serbia were initially designed using cubic parabola, the main reason for its continious application is maintaining the spatial position of railway centre line.

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After the short history of the applications of transition curves in railway and road design, the paper presents mathemathical background of transition curve and derivation of formulae for calculation of cubic parabola and clothoid. Next part of the paper shows the comparative analysis of these two forms of transition curves, and also the consequences that would arise from the application of clothoid instead of cubic parabola in railway design. The analysis was performed using tools for design of transition curves according to EN13803-1:2010, that were previously reported in [1, 5, 6]. This paper presents the consequences of the application of clothoid for reconstruction of a section on the rail line Belgrade (SRB) - Bar (MNE).

2. THE SHORT HISTORY OF TRANSITION CURVES APPLICATIONS

The first known application of the transition curve in railway design happened in 1828, when William Gravatt used one form of the sinusoidal curve as the transition curve [7]. On German railways, Wilhelm von Pressel applied cubic parabola as the transition curve. His method was published in 1854. in „Eisenbahn-Zeitung“ journal, but he didn't provide practical mapping procedures [2]. This problem was solved by Wilhelm Nordling in 1867, and that was the beginning of the application of cubic parabola in railway design.

Application of the transition curve in the road design came more than 50 years later, although there were numerous investigations and recommendations in this field. The main reason was the fact that car speed became competitive with train speed around 1930s, and there was the need to use the same design principles as in the field of railways. Regulation „RAL-1937” adopted in Germany in 1937. prescribed the use of clothoid as transition curve for road design.

From the current standpoint, it can be noticed that cubic parabola and clothoid were derived from the same starting problem, but using the different presumptions. Both transition curves were derived from the spiral that was first used in 1694. by James Bernoulli. This spiral was later described by Leonhard Euler, who also gave mathematical generalization and solutions in 1744 and 1781 [7]. Hence, this spiral is widely known as Euler spiral.

3. MATHEMATICAL BACKGROUND OF TRANSITION CURVES

Many transition curves, that were used from the beginning, were derived using Euler spiral as the basis. The main reason was the fact that these curves provided good overlaping in the first, relatively stretched part of Euler spiral. Fig.1 shows the relation between Euler spiral and three derived forms of transition curves: cubic parabola, rectangular curve and lemniscate.

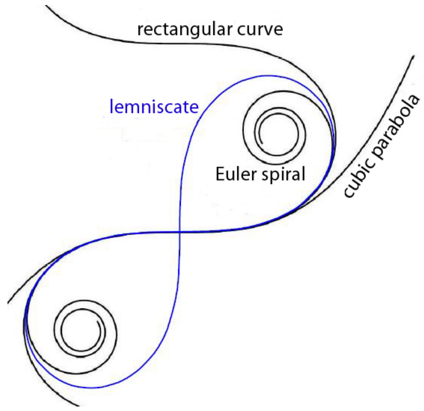

Fig.1. The relation between Euler spiral and three forms of transition curves

As it can be observed, clothoid was not marked in Fig.1. In practical terms, clothoid represents part of the Euler spiral that provides:

- either the change of radius from ∞ (straight line or inflexion point) to R (designed circular curve), or
- the change of radius from R_1 to R_2 (designed circular curves).

Clothoid has linear change of curvature, which means that curvature in arbitrary point (k) is proportional to the distance from the beginning (l), measured along the curve length (L):

$$k = \frac{1}{r} = \frac{l}{L} \cdot \frac{1}{R} \tag{1}$$

If θ is an angle between tangent in the beginning of transition curve and tangent in arbitrary point of transition curve, it follows:

$$\frac{d\theta}{dl} = \frac{1}{r} = \frac{l}{L \cdot R} \tag{2}$$

Solving differential equation (2) and taking the boundary conditions [5, 8], it can be derived formula for calculation of angle θ:

$$\theta = \frac{l^2}{2 \cdot R \cdot L} \tag{3}$$

The derivation of clothoid can be done using local coordinate system, with origin in the beginning of clothoid, one axis parallel to tangent line and another perpendicular [5, 8], as shown in Fig.2.

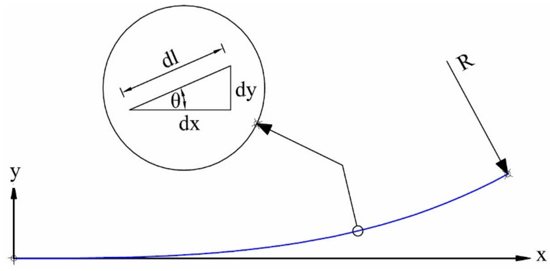

Fig.2.Local coordinate system for derivation of transition curve [5]

From observed, infinitely small element in Fig.2, it follows equations for *x* and *y* coordinates:

$$cos\theta = \frac{dx}{dl} \Rightarrow x = \int cos\theta\, dl \tag{4}$$

$$sin\theta = \frac{dy}{dl} \Rightarrow y = \int sin\theta\, dl \tag{5}$$

Integrals (4) and (5) were first derived by Euler. The solution of these integrals can be found using Taylor series for sine an cosine function. Since these are fast converging series, using first two or three series members provides necessary precision for calculation of clothoid. Described method can also be used for any other form of transition curve, regardless of the function of curvature.

4. DERIVATION OF CUBIC PARABOLA

When it began the application of transition curves in railway design, clothoid was already well known. But it was very difficult to calulate it using the existing tools and techniques. Therefore, certain aproximation were adopted - it was assumed that angle θ has small value. This assumption implies that $cos\theta = 1$ and $sin\theta = \theta$. Solving integrals (4) and (5) with these assumptions and taking the boundary conditions [5, 8], it follows:

$$x = l \quad , \quad y = \frac{l^3}{6 \cdot R \cdot L} \tag{6}$$

Rectangular coordinates (6) for cubic parabola were used from the beginning, when short transition curves were applied. Later, with changes in rail vehicle design, longer transition curves were necessary, but longer cubic parabola had larger difference between *x* and *l*. Therefore, (6) was modified to provide calculation relative to tangent:

$$x \in [0, l_X] \quad , \quad y = \frac{x^3}{6 \cdot R \cdot l_X} \tag{7}$$

where l_x is orthogonal distance from the beginning to the end of cubic parabola. Cubic parabola was changed once again, when in some cases (larger length) occured the difference between the end of cubic parabola and the beginning of the following circular curve. The corrected form of cubic parabola is known as Heffer curve.

Since equation for l_x is same for both, clothoid and cubic parabola, the difference between these two curves occurs due the different calculation of *y* coordinate. Equations (8) defines rectangular coordinates for clothoid.

$$x = l - \frac{l^5}{40 \cdot R^2 \cdot L^2} \quad , \quad y = \frac{l^3}{6 \cdot R \cdot L} - \frac{l^7}{336 \cdot R^3 \cdot L^3} \tag{8}$$

Fig.3 shows the matching between clothoid and cubic parabola. Parameter Δy denotes deviation of cubic parabola from clothoid. It can be observed well matching up to L=A. For length L>0.72·A, it began violation of fundamental equation of a transition curve [9]. Therefore, from the aspect of mathematics, there is no reason to use cubic parabola instead of clothoid in cases of construction of new or reconstruction of the existing railway.

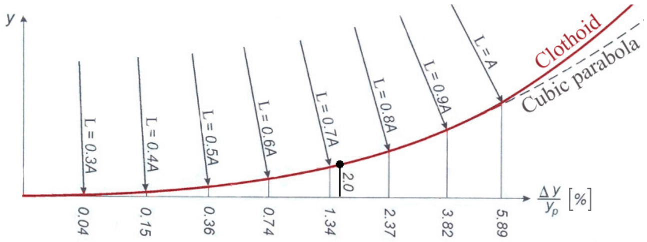

Fig.3.Matching between clothoid and cubic parabola

5. APPLICATION OF CLOTHOID FOR RAILWAY RECONSTRUCTION

As it was shown above, the differences between clothoid and cubic parabola are not significant. However, it would not be practical to use clothoid instead of cubic parabola in the cases when design speed is kept the same.

According to [10], reconstruction of sections on Corridor X in Serbia will imply design speed of 140 km/h. This design speed increases the minimum radius of circular curve. This being the case, high reconstruction costs are expected. Therefore, the use of clothoid should be mandatory.

The analysis of application of clothoid for railway reconstruction, using design tools described in [1, 5, 6], was performed for the section Trebaljevo - Kolašin of the rail line Belgrade (Serbia) - Bar (Montenegro). The length of this section is 8652.14 m and it is located in Montenegro.

According to the longterm plans, speed of passenger trains on this rail line should be 100 km/h and speed of freight trains should be 75 km/h. Design speed of 100 km/h for reconstruction implies the change of minimum radius of circular curve ($R_{min,new}$= 475 m in this case).

Part of the section from station 331+562.33 to station 335+433.28 includes six curves (of eight) with radius R<475 m, which necessarily led to the design of the new railway route on this part.

Second part of the section from station 335+433.28 to station 340+141.72 includes one curve (of five) with radius R<475 m. Tab.1 summarizes the consequences of application of clothoid for reconstruction of this part of the section Trebaljevo - Kolašin. Parameter Δ denotes maximum distance between existing and newly designed railway centre line.

Tab. 1. Application of clotohoid for reconstruction of railway section Trebaljevo - Kolašin

No	R [m]	L[m]	Δ [cm]	Old/New route
1.	800	80	1.70	O
2.	5000	0	0.22	O
3.	20000	0	0.19	O
4.	500	140	2.64	O
5.	400*	100*	707*	N
* - if $R<R_{min,new}$, it was adopted $R=R_{min,new}$=475 m				

As it can be seen in Tab.1, application of clothoid instead of cubic parabola for railway reconstruction would not lead to the significant changes of spatial position of railway centre line. All needed changes could be applied within the existing width of railway embankments. It is important to mention that Δ in the fifth case in Tab.1 is the consequence of curve radius change, which would demand the construction of new track substructure according to the new railway design.

However, all transition curves with linear change of curvature and cant have the problem of irregular curving of outer rail, as it is shown in Fig.4.

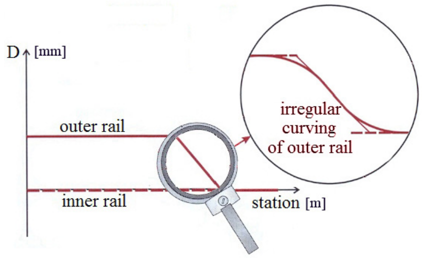

Fig.4. Irregular curving of outer rail

6. CONCLUSION

Transition curve is the most important alignment element of the railway. Since the first solutions for transition from straight section to circular curve, nowadays there are several forms of transitions curves that can be used in railway design.

While European standard EN13803-1:2010 presribes the use of six forms of transition curves, Serbian regulations prescribes the usage of two forms-clothoid and cubic parabola. Although clothoid can be used for railway design, in praxis it is rarely applied.

This paper explored the history of application of transition curves and presented the mathematical method for derivation of transition curves.

As it was shown, cubic parabola is the form of transition curve that is derived from clothoid using ″rough″ approximation. Later adjustments of cubic parabola were the consequence of this approximation.

Application of clothoid instead of cubic parabola was considered for the section Trebaljevo - Kolašin of the rail line Belgrade - Bar. The consequences, as expected, were displacements of the railway centre line. These displacements varied from several millimeters to several centimeters, depending on the radius of circular curve and length of transition (assuming that curve radii remains the same).

Summing up the previous, in cases of construction of new or reconstruction of the existing conventional railway (change of design speed) the use of clothoid is recommended. On the other hand, in cases of rehabilitation or other maintenance works that do not imply change of design speed, the use of existing form of transition curve (cubic parabola) is recommended. Also, due the irregular curving of outer rail (Fig.4), application of transition curves with nonlinear change of curvature and cant is recommmended for the high speed railways and slab track.

Developed tools for design of transition curves [1, 5, 6] according to EN13803-1:2010 makes the work of railway designers more comfortable.

ACKNOWLEDGEMENT

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REFERENCES

[1] Lazarevic, L., Popovic, Z., Puzavac, L., *Computer aided design for spatial railway transition curves*, First International Conference on Railway Technology: Research, Development and Maintenance, Las Palmas de Gran Canaria, 2012.
[2] Žnideršić, B., *Prelazne krivine na putevima i železnicama*, Ministarstvo železnica, Odeljenje za štampu i propagandu, Beograd, 1949.
[3] Ministarstvo saobraćaja, *Pravilnik o projektovanju rekonstrukcije i izgradnje određenih elemenata železničke infrastrukture pojedinih magistralnih železničkih pruga*, Službeni glasnik Republike Srbije, br. 100, 2012.
[4] CEN, *EN 13803-1:2010 Railway applications - Track alignment design parameters –Track gauges 1435 mm and wider - Part 1: Plain line*, 2010.
[5] Lazarević, L., *Cant transition as spatial element of railway*, MSc Thesis, University of Belgrade, Faculty of Civil Engineering, Belgrade, 2010.
[6] Lazarević, L., Popović, Z., Puzavac, L., Ivić, M., Belošević, I., *Curve with nonlinear change of curvature - 3D modeling*, 19th International Symposium "Recent Challenges for European Railways", Žilina, 2011.
[7] Levien, R., *From Spiral to Spline: Optimal Techniques in Interactive Curve Design*, PhD thesis, University of California, Berkeley, 2009.
[8] Puzavac, L., Popović, Z., Lazarević, L., *Transition curve design according to European standards*, XIV Scientific-Expert Conference on Railways RAILCON '10, Niš, 2010.
[9] Roy, S.K., *Fundamentals of surveying*, PHI Learning Private Limited, New Delhi, 2010.
[10] ITALFERR, *General Master Plan for Transport in Serbia*, 2009.

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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AUTHORISATION FOR PLACING IN SERVICE OF STRUCTURAL SUBSYSTEMS PRESENTED ON THE EXAMPLE OF THE SUBSYSTEM "INFRASTRUCTURE"

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Dragana JOKANOVIĆ [3]

Abstract *– The subject matter of this paper is issuance of authorisations for placing in service of structural subsystems presented on the example of the subsystem "Infrastructure". At the beginning, the paper presents the legal base for issuing of an authorisation for placing in service, the different elements of the subsystem "Infrastructure" and technical rules applied to the subsystem "Infrastructure". Explanations concerning the concept of verification of subsystems and entities carrying out the verification depending on the applied technical rules. Modules for verification of the subsystem "Infrastructure". Explanation concerning the modules SG and SH1 and their different stages. Submission of an application for verification of subsystems and original technical file to be submitted with the application. Control carried out by the assessing entity. Certificate of verification and declaration of verification of a subsystem. Technical file accompanying the declaration of verification. Content of the application for issuing of the authorisation. Technical conformity and safe integration of structural subsystems. Issuing of an authorisation for placing in service of structural subsystems and form of the authorisation. Example of an authorisation for the subsystem "Infrastructure" through different stages.*

Keywords – Authorisations for placing in service, subsystem infrastructure, verification.

1. INTRODUCTION

According to the Railway Safety and Interoperability Law [1], in order for the structural subsystems, interoperability constituents and elements of structural subsystems to be placed in service and used on railway lines of the Republic of Serbia, they must have an authorisation for placing in service issued by the Directorate for Railways.

2. RAILWAY SYSTEM

Railway system consists of structural subsystems and functional subsystems.

2.1 Structural subsystems

Structural subsystems are: infrastructure, energy, control, command and signalling – track side part, control, command and signalling – on-board part and railway vehicles.

2.2 Infrastructure subsystem

The infrastructure subsystem includes railway tracks, switches, engineering structures (bridges, tunnels etc.) and the accompanying infrastructure in stations (platforms, access areas, including parts meant for persons with reduced mobility etc.). The interoperability constituents of the infrastructure subsystem are rails, fastening accessories and sleepers.

2.3 Placing in service of structural subsystems

Structural subsystems may be placed in service only if they have been designed, constructed and installed in such a way that enables them to fulfil the essential requirements applied to them. The essential requirements are defined by the Uniform Technical Prescriptions (UTPs) and national technical rules.

Uniform Technical Prescriptions (UTPs) represent technical specifications that subsystems must comply

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with in order to fulfil the essential requirements and ensure interoperability of the railway system and they are integral part of COTIF [2].

3. VERIFICATION OF SUBSYSTEMS

Verification of subsystems is a prerequisite for issuing of an authorisation for placing in service. It is a procedure in which the notified body checks and confirms that the subsystem fulfils the essential requirements and that it complies with the UTPs and/or national technical rules.

Subsystems shall be verified in each of the following stages:

1. design as a whole:
2. manufacturing: construction, including especially construction works, manufacture, assembling of integral parts and adjustment of the entire subsystem;
3. final testing.

Verification of a subsystem shall be carried out by a Notified Body, in case that a subsystem is subject to UTPs, by the Directorate for Railways if a subsystem is subject to national technical rules, that is, by a Notified Body and the Directorate for Railways if a subsystem is subject to both UTPs and national technical rules.

3.1 Modules for verification of the infrastructure subsystem

The following modules can be used for verification of the infrastructure subsystem:

1. Module SG – Verification based on product verification or
2. Module SH1 – Verification based on full quality management system including design examination.

The verification module shall be chosen by the applicant.

3.2 Module SG - Verification based on unit verification

The verification procedure according to the Module SG includes the following activities:

1. The applicant prepares a technical file enabling assessment of conformity with the applicable rules prescribed within the Module SG;
2. The applicant takes all the necessary measures so that the process of manufacture and/or installation/construction and its supervision ensures the conformity of the subsystem with the requirements of the applicable rules;
3. The assessing entity shall carry out, or have them carried out, examinations and tests defined by the relevant technical rules, as well as a final testing of the subsystem;
4. If the subsystem fulfils the requirements laid down by the relevant technical rules, the assessing entity shall issue a certificate of verification;
5. The applicant shall draw up a declaration of verification;
6. The assessing entity shall compile a technical file accompanying the declaration of verification.

3.3 Module SH1 - verification based on full quality management system plus design examination

The verification procedure according to the Module SH1 includes the following activities:

1. Approval of the quality management system for design, manufacture, final inspection and testing of the subsystem;
2. The applicant shall prepare a technical file enabling conformity assessment with the applicable rules, as defined within the Module SH1;
3. The assessing entity shall examine the design documentation and, where it meets the requirements of the relevant technical rules, it shall issue a Design examination certificate;
4. The assessing entity shall carry out periodical checks in order to ensure that the applicants maintains and applies the approved quality management system;
5. Where the subsystem meets the requirement of the relevant technical rules, the assessing entity shall issue a certificate of verification;
6. The applicant shall draw up a declaration of verification for the subsystem;
7. The assessing entity shall compile technical file accompanying the declaration of verification.

3.4 Certificate of verification of a structural subsystem

Certificate of verification is a conformity document issued by the assessing entity, once the verification of a subsystem has been completed. The certificate of verification shall include:

1. name of the assessing entity which has issued the certificate;
2. title „Certificate of verification" and number of the certificate;
3. title/short description of the subsystem;
4. name and address of the contracting entity or manufacturer of the subsystem;
5. list of technical rules and standards that the subsystem complies with;
6. date of issuance;
7. validity;
8. seal and signature of the responsible person.

The certificate of verification can comprise one or more annexes including a list of the different parts of the technical file, examination and testing results, etc.

3.5 Declaration of verification

Declaration of verification is a document issued by the applicant guaranteeing that the subsystem meets the essential requirements laid down by the relevant rules. It shall include:

1. title „Declaration of verification" and number of the declaration;
2. name of the applicant;
3. title/short description of the structural subsystem;
4. list of technical rules and standards the structural subsystem complies with;
5. name of the assessing entity which has issued the certificate of verification;
6. number of the certificate;
7. limitations and conditions concerning the use of the subsystem, if any;
8. modules applied on the verification of the subsystem;
9. list of annexes – technical file
10. validity;
11. date of issuance;
12. seal and signature of the responsible person.

3.6 Technical file accompanying the declaration of verification

Technical file accompanying the declaration of verification shall consist of:

1. inital technical file;
2. list of interoperability constituents and other elements included in the subsystem;
3. copy of the declaration of conformity for the elements from point 2, including the appropriate calculation documents and a copy of testing and examination reports carried out by assessing entities;
4. intermediate statement of verification and declarations of intermediate statement of verification, if any;
5. certificate of verification of the structural subsystem, including the appropriate calculations in annex, signed by the assessing entity; the certificate shall be accompanied by reports on controls drafted by the assessing entity;
6. report of the independent assessor on the applied Common Safety Method (CSM) on risk evaluation and assessment in order to enable a safe integration of the structural subsystem in the existing system.

4. TECHNICAL CONFORMITY AND SAFE INTEGRATION OF STRUCTURAL SUBSYSTEMS

Before issuing an authorisation for placing in service of a structural subsystem the following issues shall be checked:

1. technical conformity of the structural subsystem with the system it is integrated with and
2. safe integration of the structural subsystem in its environment by application of the Common Safety Method (CSM) on risk evaluation and assessment.

Technical conformity of structural subsystems is one of the essential requirements which must be met by a railway system and it means that technical characteristics of fixed structural subsystems must comply with each other, as well as with technical characteristics of trains used within the railway system.

Technical conformity of structural subsystems with the system they are integrated with is obtained by ensuring their conformity with the applicable technical rules and standards.

Safe integration shall be proved by application of the CSM on risk evaluation and assessment, where the applicant shall:

1. refer to the applicable technical rules and standards, which is considered as „code of practice " (the first principle of risk acceptance), in case they define interfaces between the concerned subsystem and the surrounding subsystems or
2. if that is not the case, the applicant shall make a comparison with a similar subsystem or make an explicit risk evaluation (second and third acceptance principle)

The correct application of the CSM on risk evaluation and assessment shall be assessed by an independent assessing entity.

5. APPLICATION FOR ISSUING OF AN AUTHORISATION FOR PLACING IN SERVICE

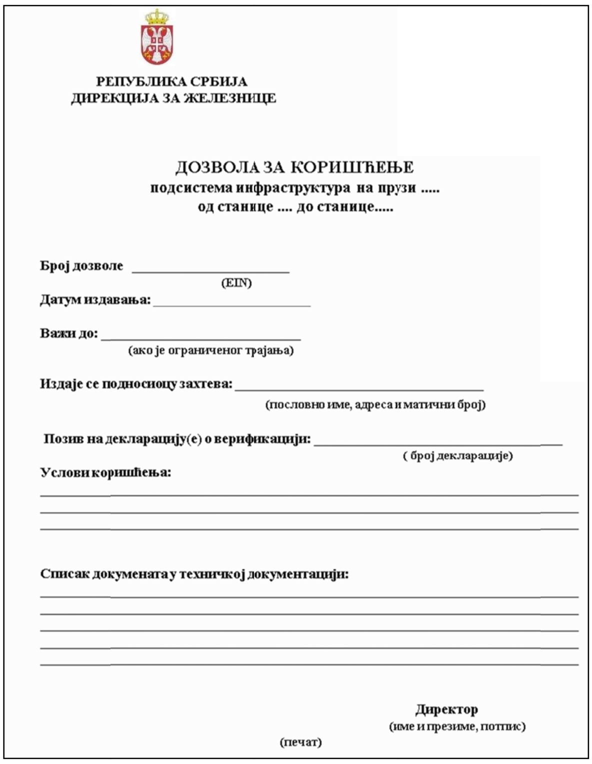
Application for issuing of an authorisation for placing in service shall include:

1) name of the authority the application is submitted to;
2) name, address, seat, TVA number and registration number of the applicant;
3) business register certificate;
4) subject matter of the application (title/short description of the subsystem, its location, etc);
5) name and address of the contracting entity or manufacturer of the subsystem and manufacturer of interoperability constituent and other elements of the subsystem;
6) in annex: declaration of verification of the subsystem including the accompanying technical documentation.

Technical documentation shall be submitted in at least two copies.

6. AUTHORISATION FOR PLACING IN SERVICE

Authorisation for placing in service shall be issued on the form [3] shown in figure 1.


РЕПУБЛИКА СРБИЈА
ДИРЕКЦИЈА ЗА ЖЕЛЕЗНИЦЕ

ДОЗВОЛА ЗА КОРИШЋЕЊЕ
подсистема инфраструктура на прузи .....
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Број дозволе ______________________
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Датум издавања: ______________________
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(број декларације)
Услови коришћења:

Списак докумената у техничкој документацији:

Директор
(име и презиме, потпис)
(печат)

Fig.1. Form of the Authorisation for placing in service

7. STAGES OF THE AUTHORISATION FOR PLACING IN SERVICE

Figure 2 shows the stages of the authorisation for placing in service of the new railway line for international traffic with stations and tunnels. UTPs have not been applied in full because of open points and derogations, so national technical rules apply as well. This line consists of Infrastucture, CCS and Energy subsystem, each verified by NoBo (where UTPs apply) and by Directorate for railways (where national technical rules apply). In a given example, Directorate for railways acts as Designated body and as National safety authority.

8. CONCLUSION

The main difference, comparing to the previous procedure for issuing of authorisations for placing in service of structural subsystems, consists of introduction of the verification, that is, conformity assessment of structural subsystems with the requirements of the applicable technical rules carried out by the assessing entity and issuance of the corresponding conformity documents.

The Republic of Serbia still does not have a notified body to carry out the conformity assessment with the UTPs and, therefore, the applicants must engage a notified body from Europe.

According to the Article 17 of the Interoperability Directive, the conformity assessment with national technical rules shall be carried out by a body designated by the Member State. Following the implementation of that Directive in the Railway Safety and Interoperability Law, the Directorate for Railways has been designated as such a body. The reason for such a decision is the fact that, at the time of drafting of the law, the Republic of Serbia did not have a body for conformity assessment of any structural subsystem, appointed by the competent Minister in the railway sector, in accordance with the Law on Technical Requirements for Products and Conformity Assessment [4], and it still does not have one.

Applicant	Notified Body (NoBo)			Designated body (Directorate)	Directorate for railways (NSA)
	NoBo for INF	NoBo for CCS	NoBo for ENE		
Subsystem INF - design - production - final testing UTPs applied in full, except for open points and derogations **UTP + nat. declaration of verification**	Verification procedure for INF, conformity to: - UTP INF - UTP PRM - UTP SRT **UTP certificate of verification + technical file**			Verification procedure for INF, conformity to national technical rules **National certificate of verification + technical file**	
Subsystem CCS - design - production - final testing UTPs applied in full, except for open points and derogations **UTP + nat. declaration of verification**		Verification procedure for CCS, conformity to: - UTP CCS (track side) - UTP SRT **UTP certi-ficate of verification + technical file**		Verification procedure for CCS, conformity to national technical rules **National certificate of verification + technical file**	
Subsystem ENE - design - production - final testing UTPs applied in full, except for open points and derogations **UTP + nat. declaration of verification**			Verification procedure for ENE, усаглашено ст са: - UTP ENE - UTP SRT **UTP certi-ficate of verification + technical file**	Verification procedure for ENE, conformity to national technical rules **National certificate of verification + technical file**	
UTP + national declarations +Risk assessment report **Placing in service**					**Checking tech. comp-atibility and safe integration** **Authorisa-tion for placing in service**

Fig.2. Stages of the authorisation for placing in service [3]

REFERENCES

[1] Railway safety and interoperability law, 2013

[2] Convention concerning International Carriage by Rail (COTIF), 2006

[3] Directorate for Railways, Draft Rule book on issuing authorisation for placing in service of structural subsystems, interoperability constituents and other elements of structural subsystems, Beograd, 2014

[4] Law on technical requirements for products and conformity assessment, 2009

Vehicle and infrastructure maintenance

XVI SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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REPAIRING OF BROKEN LAMINATED SPRINGS OF FREIGHT WAGONS BY WELDING

Dragan PETROVIĆ [1]
Milan BIŽIĆ [2]

***Abstract** – The task of this paper is to explore the possibility of repairing broken laminated springs of freight wagons by welding. Previous studies have shown that fractures of laminated springs are very common, especially for freight wagons used in extreme operating conditions. One of the most economical ways to solve this problem is reparation by welding of the fractured leafs. In that case the question about the behaviours and characteristics of repaired laminated springs rises. The approach in this paper is based comparative experimental testing of repaired laminated springs and new laminated springs. The main aim is to determine the influence of welded leafs on the behaviours and characteristics of repaired laminated springs. The applied methodology is based on static and dynamic tests. The obtained results have shown that welding of leafs does not significantly affect behaviour and characteristics of repaired laminated springs. During the fatigue tests, the fracture in the heat affected zone of welded connection is not registered. As expected, the results also have shown that life-cycle of repaired laminated springs is slightly lower with regard to the new laminated springs. The final conclusion is that welding can be possible solution for reparation of broken laminated springs.*

Keywords – Repairing, broken, laminated springs, freight wagons, welding.

1. INTRODUCTION

The one of the main ways to increase the competitiveness of railway compared to other modes of transport is reducing of the maintenance costs. The failures on railway do not happen often, but when it happens, the consequence is usually derailment accompanied with enormous material damage and losses of human life. In addition, there is huge material loss caused by the interruption of the traffic and reparation of the infrastructure. In the process of resolving of failure consequences on the railway vehicles, two approaches can be applied. The first approach involves replacing the damaged element (subassembly or assembly) with the completely new element. The second approach involves repairing the damaged element and its restoring into the appropriate function in the vehicle. It should be noted that repair is not possible for some damaged elements of railway vehicles (e.g. broken axles or wheels), but for many parts it is an extraordinary way for an enormous reduction in maintenance costs. Of course, the quality of repaired elements must be satisfactory, and their reliability should be at least approximate to the reliability of completely new elements, in order to make this approach techno-economically justifiable.

One of the most important subassembly of each railway vehicle is suspension system. The problems of the suspension system have always been among the central problems in the field of railway engineering. They have been widely analyzed in the large number of literature, scientific publications and professional papers. The main objective of all these research is to identify the behavior and design of the suspension system with the aim of improving the existing performance [1]. The quality of suspension system is one of the most important parameters which determine the reliability, quiet running and running safety of railway vehicles. The fault of suspension system is very important topic that is the subject of many scientific papers [2, 3]. The aim of all these research was to indicate the potential problems and to give the motivation for improvements in existing or newly-designed solutions of suspension systems.

The fractures in the suspension system are very often, especially at freight wagons operating in extreme operating conditions. The suspension system

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of such wagons is usually based on the laminated springs. In most cases there is a failure of main leaf, and the problem is usually solved by replacing the entire laminated spring with completely new, or by changing the broken leaf with completely new leaf. As one of the best solutions to reduce the costs of maintenance, the welding of the fractured leafs is considered. This is a very complex issue as it is well known that spring steels are not suitable for welding. Also, the additional problem is experimental testing and proving the behaviours and characteristics of such repaired laminated springs. This is the motivation for the research presented in this paper. The study was conducted on the laminated springs of Fbd wagons used in railway transportation of coal from mining basin ''Kolubara'' to the thermal power plant ''Nikola Tesla'' in Obrenovac, Serbia. The transport of coal for many years is performed with about 400 Fbd wagons, made in Wagon factory Kraljevo (Serbia).

2. PROBLEM DEFINITION

The four-axled wagon Fbd consists of two two-axle units that are interconnected by joint connection. The gross wagon tonnage is 80 tons, and its purpose is to transport of coal. The wagon is primarily designed and adapted for efficient loading in the mining basin and unloading in the thermal power plant. For this reason, the design of wagon has specific solutions of body, underframe, and mechanisms for unloading. Numerous mechanisms for opening and closing the door in the floor have reduced the space for placing of elements of suspension system. Because of these specifics, the design of suspension system which is based on the laminated spring departs from the standard design solutions. Reducing the length of the laminated spring in relation to the standard solutions and very intense loadings in exploitation caused the increasing of stresses of elements of the suspension system. The steel limiter is fixed for the underframe of wagon and has the task to limit the stroke of laminated spring (Fig. 1).

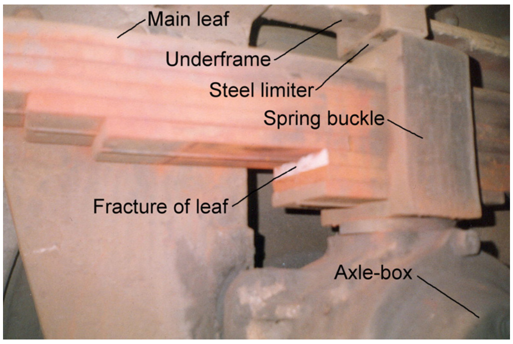

Fig.1. The example of laminated spring fracture

In extreme operating conditions at maximum loads there are intense dynamic rigid impacts of spring buckle in the steel limiter which is very unfavorable for the suspension system and the underframe of wagon. As a result there were very frequent fractures of elements of suspension system and cracks on the underframe. Statistical analysis shows that among the most dominant failures of the suspension system are fractures of elements of laminated springs [4]. Among them, the most common are fractures of leafs (as shown in Fig. 2), and especially of main leafs. The frequent fractures of leafs caused derailments in many cases [5]. The consequences were huge material damage and significant decreasing the efficiency of railway transportation of coal from mining basin to the thermal power plant.

The problem of fractures of laminated springs is usually solved by replacing the entire laminated spring with completely new, or by changing the broken leaf with completely new leaf. Because of frequent fractures, this required a huge funds for the maintenance and purchase of new leafs and laminated springs, which caused decreasing the efficiency and profitability of rail transport of coal. Research of these problems leads to the aim to reduce the enormous costs of maintenance of wagons and it is realized in two directions. The first direction was implied improving the suspension system through subsequently installation of rubber elastic element. This element is very easy to install in all existing wagons, between the laminated spring buckle and underframe [4]. The second direction was implied exploring the possibility for repairing the laminated springs by welding of fractured leafs. That is the topic of this paper, and its main task is to explore the influence of welded leafs on the behaviours and characteristics of repaired laminated springs.

3. EXPERIMENTAL RESEARCH

The basic idea of repairing of damaged laminated spring implies that its broken leaf is welded in the place of fracture, with the aim of preservation of overall designed geometry and function (Fig. 1).

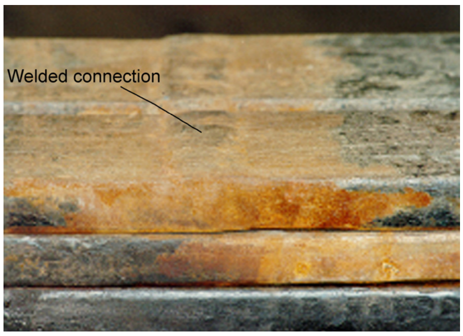

Fig.1. The welded connection of the main leaf

Research related to welding technology is realized by the company "Termoelektro" in Belgrade, Serbia. The technology is intellectual property of mentioned company, and it is not the focus of this paper. The main segments of welding technology are related to the physical, chemical, metallurgical and technological aspects of welding of broken leaf. The technology prescribes the election of welding electrodes, procedure for disassembling of laminated spring, preparation of surfaces for welding, procedure of welding, etc. Based on the projected welding technology, two characteristic laminated springs with fractured leafs in factories "Gibnjara" in Kraljevo and "Želvoz" in Smederevo, Serbia, are repaired. In the aim to explore their behaviors and characteristics, these laminated springs are subjected to the experimental tests.

The experimental tests were performed on pulsator, to the fracture of laminated springs, with prescribed amplitudes and frequency. For this purpose, the test stand for dynamic testing of production "MTS" was used (Fig. 3).

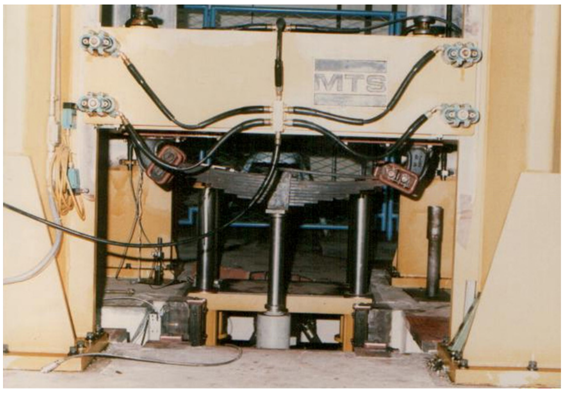

Fig.3. The dynamic testing of laminated springs on the test stand of MTS production

The comparative tests were performed on the following laminated springs:

- previously damaged laminated spring with welded main leaf repaired in a factory "Želvoz" in Smederevo (laminated spring 1),
- previously damaged laminated spring with welded main leaf repaired in a factory "Gibnjara" in Kraljevo (laminated spring 2),
- completely new laminated spring that is not welded (laminated spring 3).

Laminated springs with welded leafs (laminated spring 1 and laminated spring 2) were repaired in according to the prescribed welding technology from Chapter 3. The testing program is designed in accordance with applicable international UIC standards for testing the static and dynamic strength of springs. It included the following tests:

- testing the geometric accuracy,
- identification of static characteristics,
- dinamic fatigue testing to the fracture.

The number of cycles and the amplitudes of deflection of laminated springs are defined in the regulations, and are presented in Tab. 1. The frequency of change of deflection amplitudes is defined in the regulations, and is equal 2 Hz. In dynamic tests, it was necessary to define the static load of laminated spring around which the amplitude of the deflection oscillates.

Tab. 1. The prescribed number of cycles and the amplitude of deflection

Test	Num. of cycles	Amplitude of defl. [mm]
1	260000	12
2	1500	30
3	93000	15
4	2200	27
5	37000	18
6	6300	24
7	18500	21

Taking into account the gross wagon tonnage of 80 t, and subtracting the non-suspended mass of four wheelsets of approximately 6 t, the static load per one laminated spring should be about 9.25 t. However, the static load per one laminated spring was determined from the data of exploitation [5] and is Q_{st}=103 kN, which is about 10.3 t. This value is significantly higher (about 10 %) than the designed static load of one laminated spring with a fully laden wagon. Overloading of laminated springs during the exploitation is caused by uneven distribution of load on the wheels during the filling of wagons with coal. Given in mind the increased static load of 103 kN, it can be expected to obtain a lower life-cycle for all three tested laminated springs, compared to the values given in Table 1. In addition, the amplitude is also increased in relation to the prescribed. The aim of research in this phase was primarily to lead laminated springs to the fracture, and to determine if the fracture occurs in the heat affected zone of welded connection. Thus, the dynamic tests were performed with the static load of 103 kN and the amplitude 15 mm, with the frequency of 2 Hz.

4. RESULTS

In the first step, according to the prescribed testing program, the geometric accuracy of all three laminated springs was tested. It is concluded that it is within the prescribed limits. In the second step, the static characteristics of laminated springs 1, 2, and 3 were tested. It is concluded that deviation of static characteristics of laminated springs with welded leafs (laminated springs 1 and 2) from the static characteristic of not welded laminated spring 3, is less than 1%. Of course, a similar deviation should be obtained in the case of all three laminated springs whose leafs are not welded. Based on that, it can be concluded that all three tested laminated springs have almost identically static characteristic. The diagram of static characteristic of laminated springs is shown in Fig. 4. The results obtained by the experimental fatigue tests of laminated springs are shown in Tab. 2.

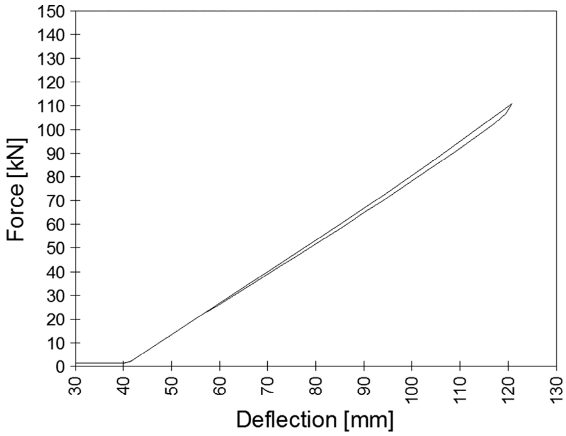

Fig. 4. The static characteristic of laminated springs

Tab. 2. The number of cycles until the fractures

Lam. spring	Num. of cycles	Remark
1	161820	Fracture of main leaf
2	92820	Fracture of third and fourth spring leafs viewed from below
3	216240	Fracture of main leaf

In the case of laminated spring 1, 161820 cycles were achieved to the occurrence of fracture of main leaf. In the case of laminated spring 2, 92820 cycles were achieved to the occurrence of fracture of third and fourth leafs viewed from below. At the end, in the case of laminated spring 3, 216240 cycles were achieved to the occurrence of fracture of main leaf. In experimental tests of both laminated springs with welded leafs it was concluded that fracture did not occurred in the zone of welded connection or heat affected zone. These extremely important results are shown in Figs. 5 and 6.

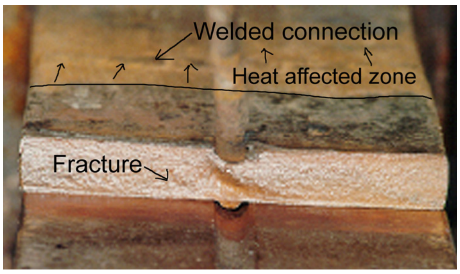

Fig. 5. The fracture of laminated spring 1

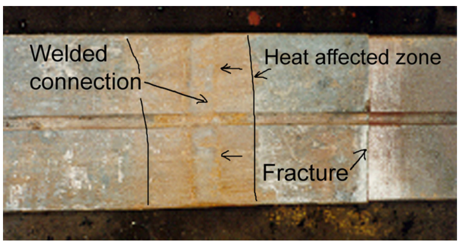

Fig. 6. The fracture of laminated spring 2

As expected, it was concluded that in these fatigue tests have not reached the expected lifetime of the laminated springs. The reasons for this lie primarily in the inadequate quality of embedded material, as well as in the increasing of static stress during the exploitation and in the aforementioned experimental tests. Poor quality of material is caused by the presence of chemical impurities, as already noted in previous researches [5], with the aim of solving the problem of frequent failure on the suspension system of Fbd wagons.

5. CONCLUSION

It can be concluded that welding can be possible solution for reparation of broken laminated springs. Repairing of broken leafs of damaged laminated springs by welding can allow to restore these laminated springs into exploitation. The welding does not affect the behaviours and characteristics of laminated springs. More precisely, behaviours and characteristics of repaired laminated springs almost completely satisfy the demands of the design and exploitation. Of course, in this statement should be taken into account that these laminated springs are already used and that their life-cycle is slightly lower compared to the completely new laminated springs. Therefore, in consideration of application of this solution in practice, it is necessary to conduct techno-economic analysis of its feasibility in specific case. However, practical application of this solution in Fbd wagons for coal transportation in thermal power plant "Nikola Tesla" in Obrenovac, Serbia, has enabled the enormous reduction of costs of maintenance of these wagons. This has enormously increased the efficiency of railway transportation of coal from mining basin to the thermal power plant.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Garg V K, Dukkipati R V. *Dynamics of Railway Vehicle Systems*. New York: Academic Press, 1984.

[2] Huichuan Fan, Xiukun Wei, Limin Jia, Yong Qin. *Fault detection of railway vehicle suspension systems*. Computer Science and Education (ICCSE), 5th Int. Conference on Computer Science and Education, 2010, 1264–1269.

[3] Hayashi Yusuke, Tsunashima Hitoshi, Marumo Yoshitaka. *Fault Detection of Railway Vehicle Suspension Systems Using Multiple-Model Approach*. Journal of Mechanical Systems for Transportation and Logistics, 2008, Vol. 1, Iss. 1, 88–99.

[4] Petrović D, Bižić M. *Improvement of suspension system of Fbd wagons for coal transportation*. Engineering Failure Analysis, 2012, Volume 25: 89 – 96.

[5] *Identification of the causes of the fractures of main leafs of laminated springs on the Fbd wagon*. Study, Test Center of Wagon Factory Kraljevo; 1983. [in Serbian]

DATABASE TO SUPPORT OPTIMIZATION OF ROLLING STOCK MAINTENANCE IN SERBIAN RAILWAYS

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***Abstract** – Timely detection of technical irregularities and avoiding subsequent damage to rolling stock vehicles offers many advantages in daily railway transport: increased security, avoiding traffic disturbances, reducing expenses due to avoiding accidents, extension of revision and wagon maintenance deadlines, optimization of rolling stock maintenance. The first step in the process of monitoring and optimizing rolling stock maintenance procedures is to install the checkpoints for dynamic control of wagons' technical state. The second step is to process and analyze data collected from monitoring equipment. In this work we describe the database developed for the purpose of storing and analyzing data collected from the measuring equipment. The information system consists of a relational database, numerous queries, forms, and reports. Generated queries, forms and reports in the IS can provide useful input parameters for the process of optimizing maintenance of railway stock.*

Keywords – Rolling stock, dynamic monitoring, measuring equipment, database, maintenance.

1. INTRODUCTION

Regular and safe functioning of railway transport depends on flawless organization, but also on the technical state of rolling stock and infrastructure. Besides increasing safety level and avoiding traffic disturbances, an important contributing factor for decreasing total transportation expenses is timely maintenance of railway stock. Transport cost is decreased by avoiding traffic accidents, delaying wagon revision and maintenance deadlines, and optimizing rolling stock maintenance. For these reasons Serbian railways decided to install measuring stations for dynamic control of rolling stock technical state. Such a system should enable detection of overheated axle bearings, flat surfaces on rolling wheels' garland points, excess weight by axle, excess of loading gauge railway vehicles etc. Measuring stations should integrate measuring equipment and automatic control of aforementioned variables. Measuring are expected to be done on the track, during train operation.

In this paper we describe the development of database to store information collected from the measuring checkpoints. Besides organizing collected information, the database allows for generating numerous useful queries. Continuous monitoring of source data from measuring stations and analyzing results of predefined queries are expected to contribute to optimization of rolling stock maintenance.

The remaining sections of the paper are organized as follows: the second section describes devices and measuring equipment integrated into measuring checkpoints, and details the way they operate. The third section details the design and structure of the database, with description of some queries that can be generated over it. We conclude with the analysis of possibilities and benefits of using developed database.

2. DIAGNOSTIC SYSTEM OF BATAJNICA MEASUREMENT STATION

The pilot project, measurement checkpoint **Batajnica**, contains devices for detecting overheated bearings of axle boxes and locked brakes with label TK99, as well as devices for dynamic measurement of train weight and detection of flat surfaces of garland

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points (dynamic balance) G-2000. [1]. Measurement checkpoint is installed on the left side of the double track railway line *Beograd-Šid* at km 22+908. Checkpoint has an internal part (module 1), and an external part which is integrated into the track (modules 2, 3, 4 and 5), as illustrated in Figure 1.

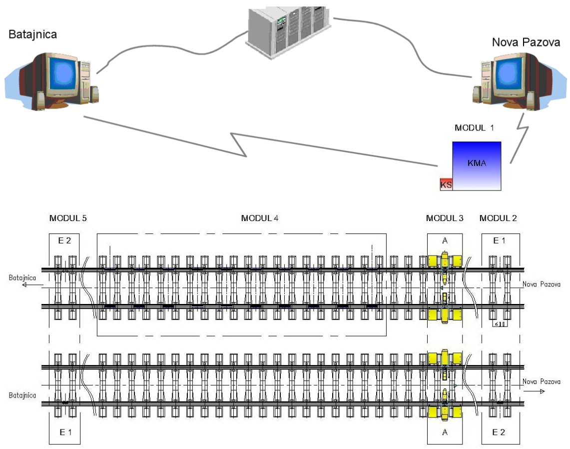

Fig.1. The scheme of the Batajnica measurement checkpoint

The internal part of Batajnica measurement checkpoint for dynamic control of technical state of rolling stock has an electronic equipment rack for management, industrial personal PC for processing of measurement data, modem to forward data to a remote user, and a module for uninterruptible power supply.

Modules 2 and 5 are identical, and have a sensoring device for counting wheels - axle boxes **RSR180** (segments E1 and E2 in Figure 1).

Module 3 contains devices for detecting overheated bearings of axle boxes and locked brakes labelled **TK99** [2] and is installed on both tracks, it also contains central sensor for counting wheels – axle boxes RSR180 (Figure 2). Function of the central sensor for counting wheels - axle boxes (labelled with the letter A on Figures 1 and 2) is to activate the device for detecting overheated bearings of axle boxes and locked brakes, to read and store measured data in a given moment.

TK99 device registers temperature of the case of axle bearing boxes, by applying sensors installed at the left-hand and the right-hand side of the track (*NOA*); wheel's part, by applying sensors installed within the track (*FOA*) and brake disk, by applying sensors installed within the track (*SOA*).

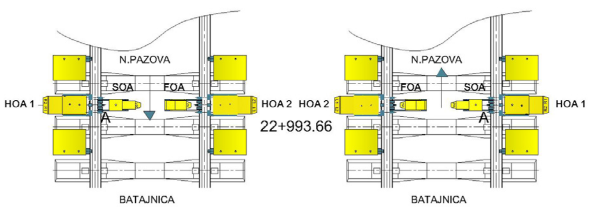

Fig. 2: Module 3 of the Batajnica measurement checkpoint

Module 4 contains G-2000 device for detecting and registering flat surfaces on a wheel [3]. Measuring tape, as well as sensors, are central elements that measure deflection of the rail due to the force by which the wheel sits on the rail [5]. Sensors are installed on the track, between railway sleepers, at axle distance of 1.2m. The total of 10 pairs of sensors are installed on the track. A computer connected to measuring tapes, receives measurement data when the train crosses the measurement checkpoint; the appropriate software detects flat surfaces and calculates axle loads of every wheel of the axle boxes. Cables which connect sensors of the device for detecting and registering flat surfaces on a wheel are installed on the external side of the track to the point where a device TK99 for detecting overheated bearings of the axle boxes and locked brakes is situated. From this point onwards, the cables are put inside plastic protective pipes, and forwarder below gravel to a cable chamber and the internal part of the measurement checkpoint.

Batajnica measurement checkpoint is equipped with an industrial PC whose purpose is to store, process, and display information collected from measurement devices. To display measured data and to report on irregularities, a Windows application paired with the equipment and developed by the manufacturer of the equipment is used. For every train crossing the measurement checkpoint data collected from different measurement devices are displayed [1]. When an irregularity in train crossing the measurement checkpoint is detected, the application emits the sound alarm and visually displays registered irregularities. In such a way, the functioning of the measurement checkpoint directly contributes to increasing security level of railway traffic on the line no 5. However, the existing application does not allow generating new queries over measured data; for optimization, a periodic more complex analysis of data measured on the checkpoint should be enabled [4]. Since the existing application does not allow for such data analysis, in this paper we describe the design and application of such a database. In the future, this database could be also used for accepting an processing information collected from different measuring checkpoints.

2.1 Database structure

The basic principle when designing a database was to accurately and consistently model the measurement checkpoint and physical properties it measures on one side, while at the same time enable development of new queries, if needed. Based on information already displayed by the existing Windows application, we developed a relational data model, and subsequently formed a relational database SERBIAN RAILWAYS ROLLING STOCK DIAGNOSTICS. Database is created by using relational DBMS Microsoft Access 2013; entity-relationship diagram of the database is illustrated in Figure 3.

The basic entities of the relational data model are: railway, device, measurement equipment, train, and alarm. Given the fact that different measurement equipment generates different information about the train that is crossing over it, a real-world train entity can be modelled by two relational entities: TRAIN and TRAIN – GRD. Similarly, the real-world alarm entity (irregularity warnings)can be modelled by as many as three relational entities: *ALARM*, *ALARM – GRD* and *ALARM – GRD – FLAT SPOTS*. The mentioned entities model different types of alarms, generated by different devices. Following are descriptions of database table structures, that illustrate mentioned differences between similar entities.

RAILWAY entity models the real-word entity of the same name from the Serbian railway network. Its purpose is to enable the analysis of the registered irregularities of the technical state of the rolling stock from the viewpoint of the railway in which the irregularity was discovered. Basic attributes of this entity are: railway number and railway name, the same used by Serbian railways.

DEVICE entity models different device types found on the track. Devices contain different measurement equipment and allow for measuring certain parameters of the rolling stock' technical state. This table serves for analyzing registered irregularities of the rolling stock technical state from track and kilometer position viewpoint on the track where the irregularity was discovered. Such analysis could identify track sections on which irregularities are registeres more frequently respect to the others, if such sections exist.

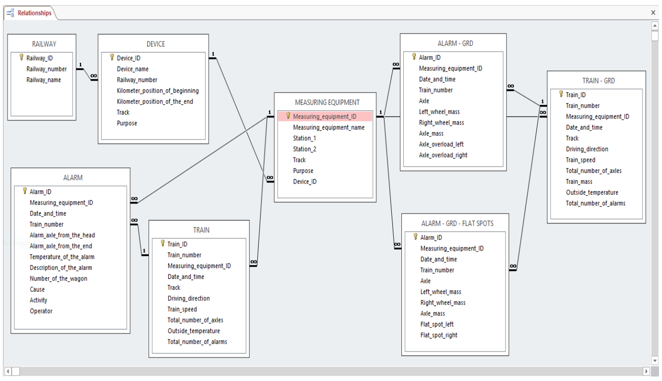

Fig. 3: Entity-relationship diagram of the SR rolling stock diagnostics database

MEASURING EQUPMENT entity models different types of measuring equipment, such as:

Equipment for detecting overheated bearings of axle boxes (*HOA*), which measures temperature of axle boxes bearings;

Equipment for detecting of locking of axle boxes in breaking (*FOA*), which measures the temperature of the wheel body 2 cm above upper level of the rail;

Equipment for detecting overheated disk brakes (*SOA*), which measures the temperature of disk brakes;

Equipment for detecting car and axle weight (*GRD*), which measures the force that wheel acts on the rail on the rail-wheel contact and detects flat spots on wheel, if there are such.

Train entity models trains which cross over measuring equipment for overheating detection (HOA, FOA, SOA). Important attributes of this entity are: number, date and time of the train, track, driving direction, train speed, and outside temperature. *TRAIN – GRD* entity models trains which cross over equipment for measuring car and axle weight and identifying flat spots on the wheel, if there are such (GRD). *TRAIN – GRD* entity has the entity total train weight, which is missing in the entity *TRAIN*.

Alarm axle is the ordinal number of the axle where the irregular temperature was measured; temperature of the alarm is the measured temperature of axle box bearings, wheel or disk brake which activated the alarm. The alarm description attribute specifies the type of measurement: HOA, FOA or SOA, and the type of overheating: warm or hot. Every instance of the *ALARM* entity is related to a single instance of the *TRAIN* entity, and a single instance of *MEASURING EQUIPMENT* entity, so that for every warning we know the train that caused it and the measuring equipment which measured the irregular values.

ALARM – GRD entity models alarms, i.e. warnings generated by measurements of axle loads. The important attributes of this entity are: date and time, axle, left wheel mass, right wheel mass, axle mass, axle overload left and axle overload right. Every instance of *ALARM – GRD* entity is related to a single instance of the *TRAIN – GRD* entity and a single instance of the *MEASURING EQUIPMENT* entity. *ALARM – GRD – FLAT SPOTS* entity models alarms – warnings, generated by detection of flat spots on wheels. The important attributes of this entity are: date and time, axle, flat spot left and flat spot right. Every instance of the *ALARM – GRD – FLAT SPOTS* entity is related to a single instance of the *TRAIN – GRD* entity and a single instance of the *MEASURING EQUIPMENT* entity.

2.2 Predefined Database Queries

Purpose of the *SERBIAN RAILWAYS ROLLING STOCK DIAGNOSTICS* database is to make data collected from measuring checkpoints available for further use and processing. The usefulness of this database becomes clear only when queries over it are generated. Figures 4 to 7 illustrate the result of execution of four selected queries over this database: generating the list of all measurement devices, grouped by railways and tracks, creating the list of all alarms caused by different types of overheating of axle boxes, displaying the list of all trains detected by the device for measuring axle loads, and generating the list of all alarms grouped by the alarm type and cars where alarms are detected. The total number of queries generated is unlimited: queries can be added, modified, and deleted according to current needs.

Devices for diagnostics of rolling stock

Railway_number	Track	Device_name	Kilometer_position_of_beginning	Kilometer_position_of_the_end	Purpose
5	1	E2-TK99	22+951,66	22+951,66	Device for detection of overheated axle bearing and blocked brake
5	1	G-2000	22+979,86	22+990,66	Device for detection of overloaded wheels and flat spots
5	1	A-RSR180	22+993,66	22+993,66	The device of axle counters
5	1	E1-TK99	23+035,66	23+035,66	Device for detection of overheated axle bearing and blocked brake
5	2	E1-TK99	22+951,66	22+951,66	Device for detection of overheated axle bearing and blocked brake
5	2	A-RSR180	22+993,66	22+993,66	The device of axle counters
5	2	E2-TK99	23+035,66	23+035,66	Device for detection of overheated axle bearing and blocked brake

Record: 1 of 7 No Filter Search

Fig. 4: Result of the query Devices for diagnostics of rolling stock

List of alarms

Measuring_equipment_name	Train_	Track	Driving_direction	Alarm_axle_from_the_head	Alarm_axle_from_the_end	Temperature	Description_of_the_alarm
Batajnica 1	125	1	2	4	7	213	HOA - the difference in temperature - right
Batajnica 1	125	1	2	6	5	267	HOA - the difference in temperature - left
Batajnica 1	126	1	2	6	19	215	HOA - the difference in temperature - left
Batajnica 1	126	1	2	8	17	243	HOA - the difference in temperature - left
Batajnica 3	129	1	2	14	11	209	SOA - overheat
Batajnica 3	129	1	2	10	15	256	SOA - overheat
Batajnica 3	129	1	2	12	13	224	SOA - overheat

Record: 1 of 7 No Filter Search

Fig. 5: Result of the query List of alarms

List of trains - GRD

Railway	Device	Measuring_	Train_numb	Date_and_time	Track	Driving_direction	Train_speed	Total_number_of_axles	Train_mass	Total_number_of_alarms
5	G-2000	102	125	12.10.2012. 11:00:09	1	2	115	10	98,56	0
5	G-2000	102	126	12.10.2012. 10:56:59	1	2	116	24	221,58	1
5	G-2000	102	127	12.10.2012. 10:52:37	1	2	98	72	906,56	1
5	G-2000	102	128	12.10.2012. 10:54:21	1	2	129	10	125,78	1
5	G-2000	102	129	12.10.2012. 10:39:12	1	2	129	24	320,15	0
5	G-2000	102	130	12.10.2012. 10:26:39	1	2	78	72	889,14	1

Record: 1 of 6 No Filter Search

Fig. 6: Result of the query List of trains – GRD

List of alarms by type and number of wagons

Description_of_the_alarm	Number_of_the_wagon	Date_and_time	Train_number	Temperature_of_the_alarm
HOA - the difference in temperature - left	50 80 2173 225 1	23.11.2012. 10:50:13	1	267
HOA - the difference in temperature - left	50 80 2173 225 1	28.10.2012. 10:58:45	2	235
HOA - the difference in temperature - left	50 80 2173 225 1	12.10.2012. 10:56:39	2	243
HOA - the difference in temperature - left	50 80 2134 234 3	30.10.2012. 10:54:23	2	215
HOA - the difference in temperature - left	50 80 2134 234 3	29.10.2012. 10:55:45	2	222
HOA - the difference in temperature - right	50 80 2173 225 1	12.11.2012. 10:54:12	1	213
SOA - overheat	50 81 2312 124 2	25.10.2012. 10:13:23	5	256
SOA - overheat	50 81 2312 124 2	23.10.2012. 10:15:24	5	209
SOA - overheat	50 81 2312 124 2	12.10.2012. 10:17:50	5	224

Record: 1 of 9 No Filter Search

Fig. 7: Result of the query List of alarms by type and number of wagons

Total number of alarms by type and number of wagons

Alarm description	Number of wagon	Total number of alarms
HOA - the difference in temperat		
	50 80 2134 234 3	
		2
	50 80 2173 225 1	
		3
HOA - the difference in temperat		
	50 80 2173 225 1	
		1
SOA - overheat		
	50 81 2312 124 2	
		3

Fig. 8: Total number of alarms by type and number of wagons: a report

Many reports and forms are also generated over this database, and these can be modified according to current needs. Reports are a very powerful tool for grouping and sorting records, as well as displaying selected data in a printer-friendly manner. Report in Figure 8 displays the total number of alarms of a certain type and for a certain wagon number. The report from Figure 8 allows for easy identification of cars with the highest number of alarms. For every car, the report displays all related alarms, with information on date and time of the alarm, train number and alarm temperature. Alarm temperature refers to the temperature of a certain part of the axle boxes on which the irregularity is registered.

3. CONCLUSION

Installation of measuring checkpoints for dynamic control of rolling stock technical state will increase reliability level and quality of service. Serbian railways will become a part of modern European transportation system, and Batajnica measuring checkpoint is one of the first efforts in this direction. Preliminary results show that the new system is able to identify 75% of the causes for excluding cars from the Serbian railway traffic [1]. Presented database allows for multicriteria analysis of railways rolling stock technical state. Using database queries, reports and charts does not require any particular informatics knowledge; moreover, the fact that it is designed in widely used MS Access DBMS (a part of MS Office package) means that it does not require new licenses and software installations. The next logical step for extending this work will be to design an application as a front-end interface to a database.

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REFERENCES

[1] Karner, J., Maly, T., Schöbel, A., *TK99 - the Austrian solution for hot box detection*, Proceedings of XIII Scientific-Expert Conference on Railways, pp. 57-60, 09-10 October 2008, Niš.

[2] Đorđević, Ž., Karner, J., Schöbel, A., Mirković, S., *Batajnica checkpoint for wayside train monitoring*, Proceedings of XIV Scientific-Expert Conference on Railways, pp. 189-192, 07-08 October 2010, Niš.

[3] LeDosquet, G., Pawellek, F., Müller-Boruttau, F., Lasca: *Automatic monitoring of the running quality of railway vehicles*, RTR No. 2, 2007, pp. 34-39.

[4] Radosavljević, A., Đorđević, Ž., Mirković, S., *Concept for Wayside Train Monitoring At Serbian Railways - Pilot Project Batajnica*, RTR Special, 2011, pp. 6-11.

[5] Schöbel, A., Karner, J., *Components for wayside train observation in Austria*, Proceedings of XII Scientific-Expert Conference on Railways, pp. 25-27, 19-20 October 2006, Niš.

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FIRST RESULTS OF THE CHANGE OF THE CRITERIA FOR REGULAR REPAIRS OF SERIES 441 TRACTION VEHICLES

Dragan B. RAJKOVIĆ [1]

Abstract *– During 2012 and 2013, locomotives from the series 441 (and series 461 and 444) were, according to the kilometer criterion, supposed to be withdrawn from traffick. By the Decision of the Executive Board of Serbian Railways JSC, tentative extension of running interval for 200000 km was performed. After two years of locomotives follow up, number of defects on 100000 km, that have occurred at the time of running of the extension of interval for regular repairs. First three out of five locomotives from the series 441 in which the extension of running interval was applied also run the kilometer that was added to the initial interval and tolerance. Comparison of the number of defects on 100000 km for series 441has been made, as well as the analysis of defects, comment of the defect trend and comparison of the mean of defects for the series for the period of last 10 years. Series 461 and 444 have been analised too.*

Keywords – Interval for regular repairs, Regulation book 241, locomotive series 441.

1. INTRODUCTION

Executive Board of SERBIAN RAILWAYS JSC made a Decision on change of interval for exploitation of traction vehicles after the expiration of kilometer criterion defined in Regulation book 241, in order to check condition of parts, joints of devices and vehicle's aggregate regarding wear-out and damages, with an aim to change intervals of certain types of regular maintenance. The Decision has been made based on provisions of the Article 5 of Regulation book 241, which envisage that:

1. Systemic examinations and controls should be performed in order to determine condition of the parts, joints, devices and aggregates regarding wear-out and damages, as well as because of replacement of that condition with time. These examinations and controls enable obtaining certain data used to determine cycles and intervals for performing follow up examinations and regular repairs.
2. Examinations and controls are organized by Railroad transport organizations and Association of YR, in cooperation with workshops responsible for the maintenance of vehicles in question, when needed, and especially on the occasion of:
   - performing first regular repairs on the new type of vehicle for YR,
   - determining new follow up examination or new regular repair,
   - change of intervals for some types of regular maintenance,
   - change of existing scope of works for certain types of regular maintenance.

1.1 Object of maintenance interval change

Reached Decision referred to series of traction vehicles 441, 444, 461, 661, 644, 666, 812/814 and 710. In this paper we will only speak about series 441 and only mention series 444 and 461 in review.

Intervals for maintenance of series 441 and 461 are defined by Regulation book 241 (medium repair/main repair) 600000/1200000±15% km for all vehicles of this series which were not modified according to the modification program, and 80000/1600000±15% km on vehicles on which modifications were performed according to the modification program, and series 444 had maintenance intervals 1000000±15% km.

New intervals for performing, according to the decision of the Executive Board of ZELEZNICE SRBIJE JSC have been change so that intervals are increased for 200000 km.

1.2 Manner of locomotive follow up

Five locomotives from each series have been selected for tentative extension. Locomotives that were selected were the ones which were close to the end of eligible kilometer limit with tolerance. Locomotives with numbers 701, 702, 704, 312, 522 were selected from the series 441. From series 461 locomotives with numbers 006, 002, 139, 153, 122

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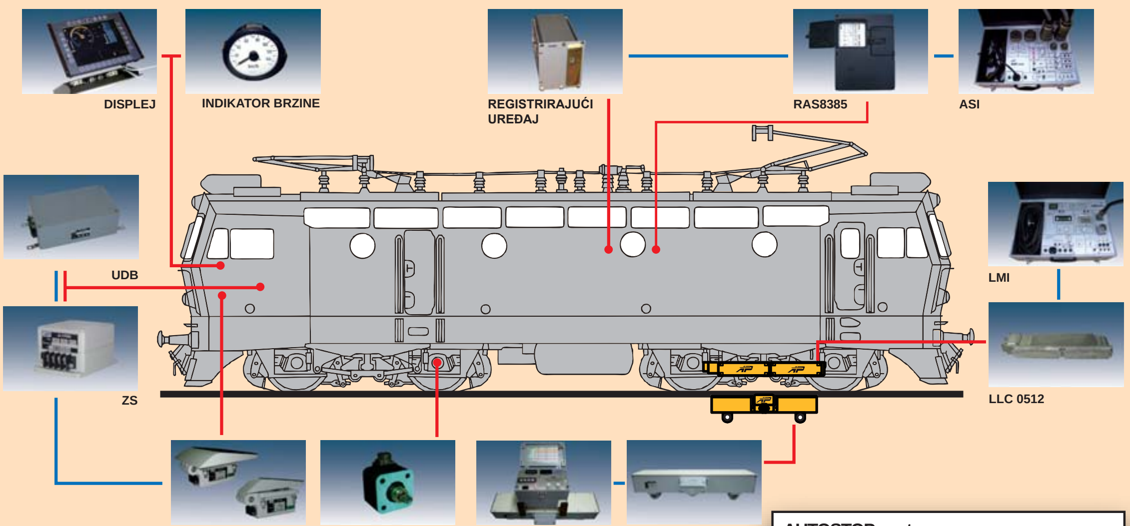
SIGNALNO-SIGURNOSNI UREĐAJI

VOZILA

SIGURNOSNI UREĐAJI ZA VOZILA



Sustav budnosti (SIFA):
Unificirani digitani budnik - **UDB**
Zvučni trotonski signalizator - **ZS**
Nožni prekidač - široki **UP1-D** i uski **UP1**

Izrada projekata sustava za različita vozila

AUTOSTOP sustav:
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Lokomotivski magnet- **LLC0512**
Pružni magnet- **PM500 i PM1020**
ASI - uređaj za testiranje RAS8385
PMI, LMI - ispitni uređaji za magnete

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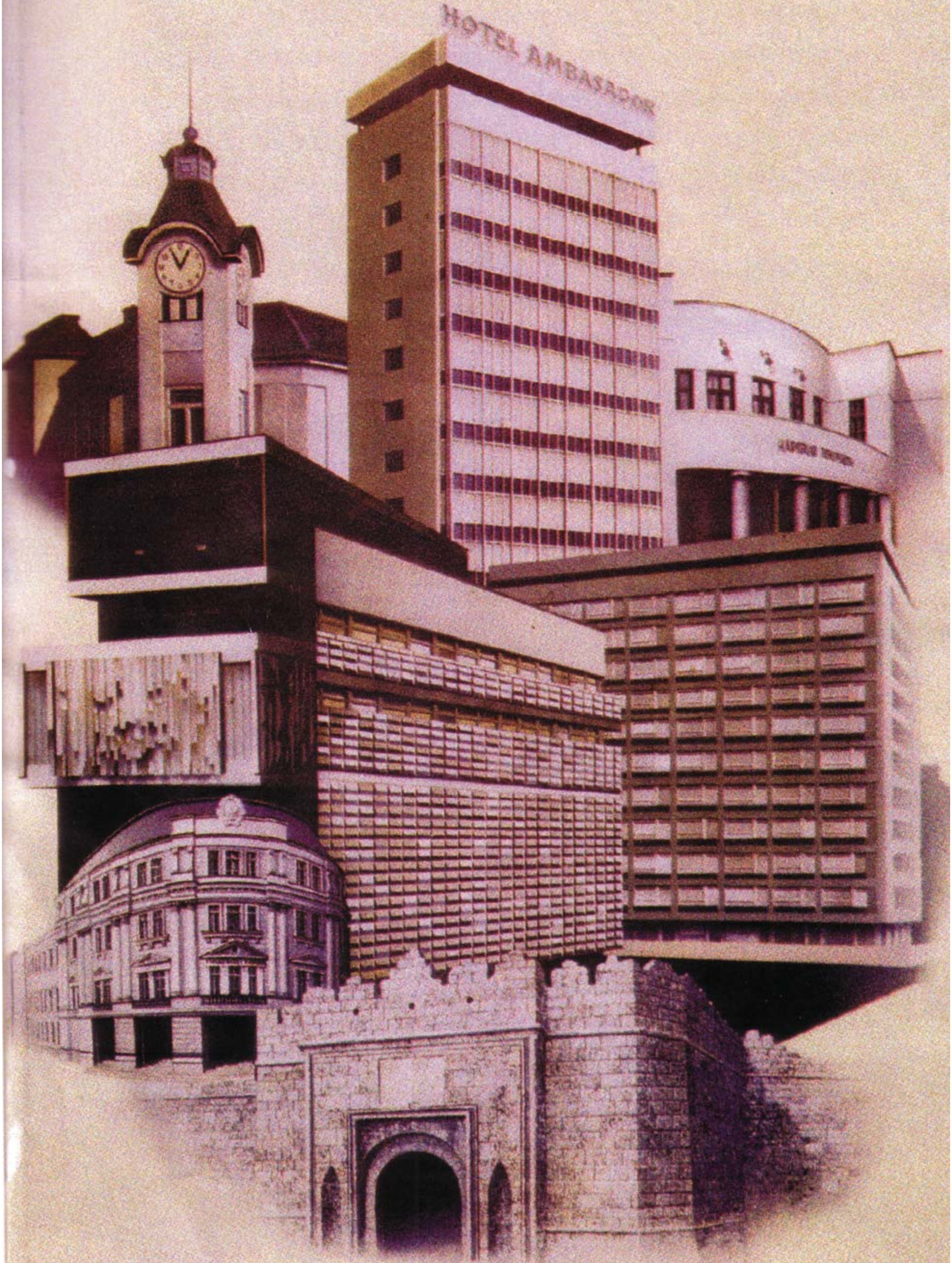
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