MAINTENANCE SYSTEM OF SEMI-TRAILER AND RISK PRIORITY NUMBER

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Abstract

The new maintenance system of semi-trailer combination as a most used road freight transport means is the subject of interest in this article. The real experiences from practice and creation of the FMEA analysis of the system using software support are the basis of wear and damage analysis of air brake system components used on the semi-trailer combination. The desire to improve market position of the company, customer satisfaction, but also the product specifications, government regulatory requirements, agency recommendations, and legal implications are the grounds for continuous improvement of the product quality, reliability and safety. These reasons push the product manufacturers to perform risk analyses which help them identify and minimize system failures during the life cycle of product. One of the risk analysis techniques recommended by international standards to identify possible failure causes is the FMEA methodology. It helps to locate the failures and reduce their consequences, so that the intended function of the machine is fulfilled.

The wear and damage analysis of individual components of air brake system and creating of the FMECA analysis for semi-trailer combination was presented in this paper. Base on them, new methods to detect failures of components of air systems, preventive measures and set up of a new planned preventive maintenance system for air brakes was designed. The cost of the proposed maintenance system is 2.2 times higher than the cost of the current maintenance system, but it minimizes the failures and their consequences (traffic accidents).

Keywords: maintenance; FMEA; risk priority number; reliability

1. Introduction

Road safety issues are the subject of interest of researchers from different European countries. For example, Cernicky et al., [1, 10] suggested that the implementation of ITS (Intelligent Transport Systems) in a selected part of a communication network should be one of the possibilities to reduce the number of road accidents. Skrúcaný et al., [16, 17] investigated dangers related to heavy goods vehicle transportation under different loads and in varying conditions of operating. One of the investigated aspects was braking

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process of truck tractor with semi-trailer. In [17], the authors examined the impact of additional equipment of a truck tractor with semi-trailer (spoilers and additional covers) on aerodynamic properties by simulation in a wind tunnel. In works [19, 2, 21], authors investigated the vehicle stability properties for different trailer combinations through simulations methods. From this study resulted that the articulated vehicle stability depends on the trailer parameters (e.g., mass, centre of gravity and dimensions) and on the connection to the tractor. Articulated vehicles demonstrated their economic profitability, but as the number of these vehicles grows, it is observed that there is a need to improve their performance in terms of handling and control [11]. Nowadays the towing vehicle itself is not normally a source of instability, because it is controlled by the vehicle stability controller based on the actuation of the friction brakes [20]. On the other hand, the trailer is not generally directly controlled. Lee et al., in work [12], describe a controller for the braking system of the trailer, which is robust with respect to the sensor noise as well as variations in longitudinal velocity and model parameters.

Road safety depends on several factors such as the psychophysical state of man (driver), surroundings (road), and technical condition of the vehicle (systems reliability of means of transport). Drożdziel et al. [5, 6] present selected issues of maintenance and reliability of vehicle safety systems for a vehicle fleet used in a transport company. As presented in the literature, the functioning of the vehicle fleet in a transport company is influenced by many factors, including service and repair costs [6, 14]. The most commonly used means of transport in road freight transport is a semi–trailer combination. This consists of tandem truck or truck with semi-trailer. This type is the most commonly used means of transport and became a subject of interest in the solution of the research in which maintenance of selected parts of semi–trailer combination was solved. The basic vehicle system responsible for road safety is the braking system. The current maintenance system of the basic air brake system is described in this article.

Function of air brake system on semi-trailer is to ensure deceleration, stopping and parking a semi–trailer. Two systems are used in practice, which are anti-block system ABS and electronic braking system EBS. The research was focused only to the electronic braking system EBS.

Information and the real experiences from practice were the basis for the FMECA (Failure Modes, Effects and Criticality Analysis) analysis of the system. Analysis was concentrated on the damage and wear of air brake system components, regarding the semi-trailer combination. Conducted analysis became the basis for the design of a new risk reduction maintenance system. The comparison of the current maintenance system with the proposed new system was performed. Risk priority number (RPN) values resulting from proposed preventive maintenance were used at the new maintenance system whose main objective was to reduce the impact of any failure in any component on the air brake system [18].

2. Analysis of the current state of semi-trailer maintenance

For any vehicle, respectively semi-trailer intended to operate safely, reliably and economically, the principles set out in the maintenance plan must be observed and given sufficient attention. Neglected maintenance and repairs can lead to the failure of one of the trailer parts and thus to serious accidents [13]. In practice, semi-trailers use a maintenance system based on the number of kilometers traveled or during the months of operation determined by each semi-trailer manufacturer for his specific product. The earlier event is always binding.

Individual maintenance interventions are carried out on the following main parts [3, 4]:

1. Frame;
2. Extension;
3. Trailer coupling plate - king pin;
4. Axles;
5. Tires;
6. Air pressure system;
7. Spring system - mechanical and pneumatic suspension;
8. Electrical system;
9. Retractable supports;
10. Additional accessories.

Individual maintenance interventions inspections are carried out as follows:

1. First inspection - 75000 km or 6 months after commissioning;
2. Second inspection - 150000 km or 12 months;
3. Third inspection - 225000 km or 18 months;
4. Fourth inspection - 300000 km or 24 months;
5. Fifth Tour - 375000 km or 30 months;
6. Sixth tour - 425000 km or 36 months.

The wear and damage analysis of the individual components was performed on a sample of 1470 semi-trailers. The total number of semitrailers registered in company is 1961. Of these, 1470 semitrailers were inspected for the air system and 497 were repaired due to an accident or other problem that was not related to the air system.

From the sample of 1470 semi-trailers, 800 semi-trailers already had a failure of the air-pressure system, and 670 semi-trailers were found to be faulty by a service inspection. The number of failures of the air brake system components is shown in Figure 1.

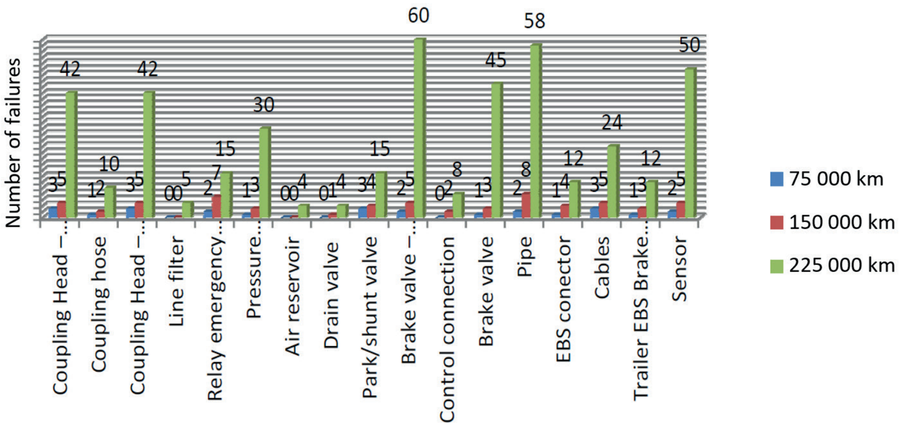

Fig. 1. The number of failures of the components of the air brake system

3. FMEA analysis

FMEA is the inductive method, which evaluates possible equipment failures and their impacts on technological process, which may occur at various levels - at the system, subsystem, or component thereof. It is used to identify the type of failure modes of individual devices and systems. It may be extended to the frequency of failures or probability [7, 8].

The FMEA Analysis of EBS system was done with the analysis of criticality of nodes, including functional and fault networks.

The first step is to create the structure of the air brake system. It is also necessary to establish the elements of the structure and their functions and failures. Then we can create function networks and failure networks (Figure 2). The next step in the FMECA analysis is a risk assessment. Values of probability, severity and detection are entered into FMECA forms.

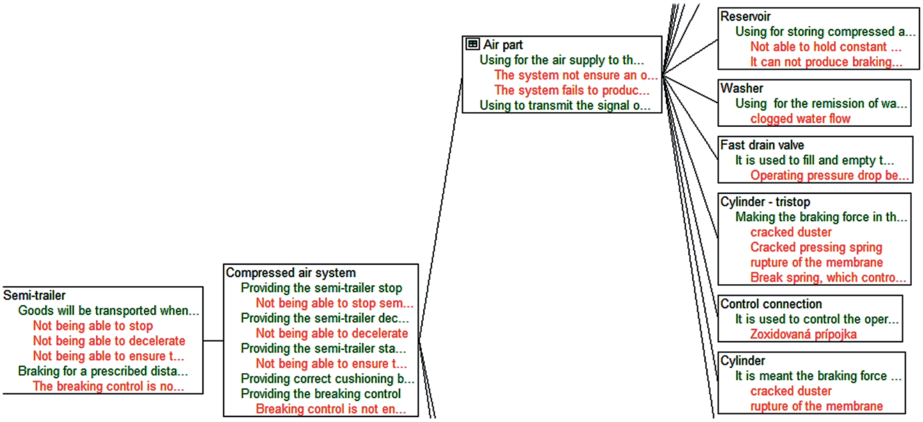

Fig. 2. View of the semi-trailer structure with the structure of functions and failures networks

3.1. Risk evaluation

Creation of FMEA forms is the main task in the third step. Its result is knowledge of the risk of failure creation. To risk assessment of the system at the design and planning step available measures to limit failures occurrence and to improve their detection are assigned.

The measure of this evaluation is an indicator – RPN – Risk priority number, which consists of three factors, where the level of risk is expressed by their mathematical product [7, 15].

$$\mathrm{RPN} = \mathrm{S} \times \mathrm{O} \times \mathrm{D} \tag{1}$$

where:

S – severity – the importance of the seriousness of the occurrence of failure causes, (value is the number between 1 and 10, where 10 is the most important).

O – occurrence – the probability of occurrence of failure causes, (10 means that causes of failure surely happen)

D – detection – the probability of detection of failures´ causes (it is result, where 10 means that we cannot detect the cause of failure).

Example of risk's form assessment (RPN) is shown in Figure 3.

Effects	S	C	Failure mode	Cause	Preventive action	O	Detection action	D	RPN	R/D
APiS Informationstechnologien GmbH					FMEA Design			Number: 1.1.1.1.1 Page:		
Type/Model/Fabrication/Lot: EBS systém				Item code: Revision state:	Responsible: Company:			Created: 23.4.2016		
FMEA/system element: Air supply pipes				Item code: Revision state:	Responsible: Company:			Created: 23.4.2016 Modified: 23.6.2016		
Effects	S	C	Failure mode	Cause	Preventive action	O	Detection action	D	RPN	R/D
System element: Air supply pipes										
Function: Privádza tlak vzduchu z ťažného vozidla v rozmedzí 6,5 až 8,5 baru {1}										
1.1.1.1.a.1 The system not ensure an operating pressure of 6.5 bar to 8.5 bar and the braking pressure in the range from 0 bar to 6.5 bar {1}	10		1.1.1.1.1.a.1 It is unable to produce the desired pressure in the range of 6.5 to 8.5 bar of truck vehicle for trailer {1}	1.1.1.1.1.1.a.1 Ruptured rubber sealing {1}	Initial state: 23.4.2016					
					none {1}	7	Visual check every 75 000 km {1}	5	350	
				1.1.1.1.1.2.a.1 Ruptured hose {1}	Initial state: 23.4.2016					
					none {1}	4	Visual check every 45 000 km {1}	5	200	

Fig. 3. FMEA form of risk assessment for air supply pipes (EBS system)

There are very important factors for the risk assessment of the failure consequences of air brake system level of risk RPN. The level of risk RPN values is normally between 500 to 80, see Figure 4 for air brake system using current methods for the detection of failures. These values are unacceptable for the road traffic. It is necessary to reduce the value of all the risks to an acceptable value and to reduce value of the consequences of failures to prevent possible losses of human lives (the worst case) and a semi-trailer should permanently be in operational state.

RPN values of the current system of maintenance are very high and also the consequences of failures occurring at the individual components of air brake system are of high values, so the current maintenance system should be changed. Proposed change will consist of a new interval of planned preventive inspections, using the new methods for the detection of failures of individual component's, as well as the use of preventive measures, that is exchanging air brake system components after a certain number of kilometres run by a semi-trailer.

4. Proposal of maintenance intervals for air brake system

The number of worn components that may fail increases with the mileage. If the risk values reach a critical level, the consequences of failure of a component may result in severe trailer failure or even loss of human life. The proposed intervals for the service inspections consist of three levels of maintenance interventions, which meet the definition of the preventive maintenance and are intended to reduce the probability of failure or the degradation of the functioning of an item [9].

The first level of the preventative maintenance is proposed for every 45 000 km with a tolerance of +/- 2000 km or will be no later than 4 months from the date of sale or will be no later than 4 months since the previous inspection. Visual inspection is performed only, which is used to detect failures of individual components that could occur in the manufacturing process and will show up within operation after a certain number of kilometres travelled. The second level of the preventative maintenance is proposed for every 75 000 km with a tolerance of +/- 5000 km or will be no later than 8 months from the date of sale or will be no later than 8 months since the second inspection. More complex check will be performed with using the proposed methods to detect failures. This interval is designed by calculating the total cost of the failures consequences that can result from the examined 1470 semi–trailers and costs resulting from service inspections carried out on the same number of vehicles. The third level of the preventive maintenance is proposed for every 180 000 km with a tolerance of +/- 5000 km or will be no later than 16 months from the date of sale or will be no later than 16 months since the third inspection. Exchange of all components of air brake system except air pipes and cables in a professional workplace will be performed.

In the proposed preventive maintenance, two methods to detect failures - visual inspection and checking of tightness and functionality of using diagnostics are proposed. The role of the visual inspection is based on more frequent intervals by visual inspection to avoid unexpected failures that could have consequences in the loss of human life or in removal of the air brake system from operation.

In FMECA analysis, it was found that it is appropriate to change all air brake system components except pipe and cables after running 180 000 km, thus the current maintenance system will be more expensive but minimizes the risk of failures and the consequences associated with them.

As shown in Figure 4, RPN values were significantly reduced by applying the proposed detection methods as well as preventive measures. RPN values for the first stage of the preventive maintenance are in the range from 400 to 60. RPN values range from 80 to 32 when we use preventive measures. The green columns in the picture represent RPN values for individual components and well-defined cause failures when we use the first level of the preventive maintenance.

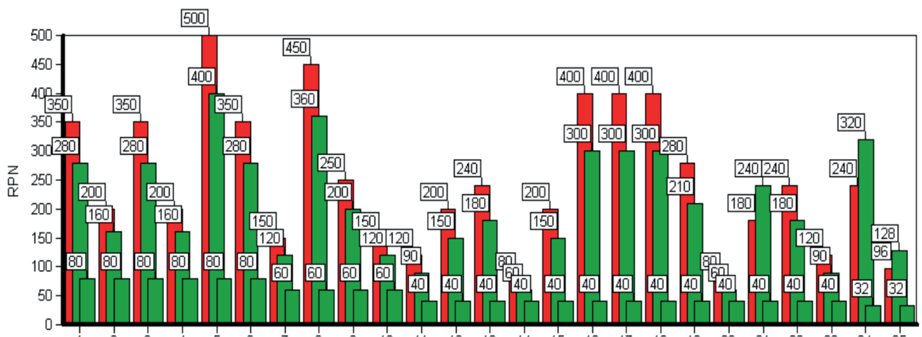

Fig. 4. RPN values for existing and proposed maintenance system

The numbers of 1, 2, 3 etc. represent individual components of air brake system and each numbers have a well-defined cause of failure. For example, number 1 is coupling head and its cause of failure is damaged rubber seal.

5. Conclusions

The paper includes the wear and damage analysis to individual components of the air brake system and creating the FMECA analysis. On this basis the new methods are designed to detect failures of components of air systems, preventive measures and set up a new maintenance system planned preventive maintenance system for air pressure.

The costs of the proposed maintenance system are 2.2 times higher than the costs of the current maintenance system after running 225 000 km. The analysis showed that the current maintenance system has 32.9% probability that after running 225 000 km there will be a failure in one component of air brake system. Consequence of failure was estimated in an average of 40 000 Euro. The increased costs of the proposed maintenance system are justified because there is a minimization of failures and their consequences, and thus there is a potential to save human health and lives.

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7. Nomenclature

ABS – anti-block system

EBS – electronic braking system

FMEA – Failure Modes, Effects Analysis

FMECA - Failure Modes, Effects and Criticality Analysis

RPN – risk priority number

8. References

[1] Cernicky L., Kalasova A.: The application of telematic technologies in Slovakia - the possibility of improving road safety in the Slovak Republic. Scientific Journal of Silesian University of Technology-Series Transport. 2015, 86, 5–11.

[2] Ding N., Shi X., Zhang Y., Chen W., Shi X., Zhang Y., Chen W. Analysis of bifurcation and stability for a tractor semi-trailer in planar motion. Vehicle System Dynamics. 2014, 52 (12), 1729–1751, DOI: 10.1080/00423114.2014.960431.

[3] Dizo J., Blatnicky M.: Use of multibody system dynamics as a tool for the vehicle behaviour diagnostics. Zeszyty Naukowe Instytutu Pojazdow: mechanika, ekologia, bezpieczeństwo, mechatronika. 2015, 3(103), 37–46.

[4] Dizo J., Blatnicky M.: Use of multibody system dynamics as a tool for rail vehicle behaviour diagnostics. Diagnostyka. 2016, 17(2), 9–16.

[5] Drozdziel P., Krzywonos L., Madlenak R., Rybicka I.: Selected aspects of analyses of failure rates of active safety systems in buses. Communications-Scientific Letters of the University of Žilina. 2014, 16, 3, 114–119.

[6] Drozdziel P., Rybicka I., Madlenak R., Andrusiuk A., Siluch D.: The engine set damage assessment in the public transport vehicles. Advances in Science and Technology-Research Journal. 2017, 11(1), 117–127, DOI: 10.12913/22998624/66502.

[7] Grencik J., Poprocky R., Stuchly V., Zvolensky P.: Evolution of maintenance systems of passenger and freight wagons from the ECM certification point of view. Communications-Scientific Letters of the University of Zilina. 2014, 16(3A), 40–47.

[8] Grencik J., Ruman F.: Maintenance and failure consequences costs as a criterion for change of maintenance system - case study. 10th European Conference of Young Research and Scientific Workers, TRANSCOM 2013, 24-26 June 2013, Zilina, Slovakia, 2013, 253–256.

[9] Grencik J., Ruman F.: Proposal of new maintenance scheme of air brake system on semi-trailer combination. Diagnostyka. 2015, 16(2), 11–19.

[10] Kalasova A., Mikulski J., Kubikova A.: The impact of intelligent transport systems on an accident rate of the chosen part of road communication network in the Slovak Republic," in 16th International Conference on Transport Systems Telematics (TST2016), Katowice Ustron, Poland, Mar. 16-19, 2016, Challenge of Transport Telematics, Edited by: Mikulski J., Communications in Computer and Information Science, 2016, 640, 47–58.

[11] Kulkarni A., Nanaware R., Kulkarni A., Garud V.: Synthesis and optimization of steering mechanism of extra-long semi-trailer vehicle. Procedia Structural Integrity. 2019, 14, 158–167, DOI: 10.1016/j.prostr.2019.05.021

[12] Lee E., Kapoor S., Sikder T., He Y.: An optimal robust controller for active trailer differential braking systems of car-trailer combinations. International Journal of Vehicle Systems Modelling and Testing. 2017, 12(1–2), 72–93, DOI: 10.1504/IJVSMT.2017.10008917.

[13] Nieto A.B, Garcia J.L.S.R., Lopez V.D., Sanchez S.S.: Analysis of results obtained on vehicle technical inspection using fBRAKE in Spain and development of a new model for semi-trailers based on Regulation No. 13. International journal of heavy vehicle systems. 2018, 25(2), 163–188, DOI: 10.1504/IJHVS.2018.10011855.

[14] Rybicka I., Drozdziel P., Stopka O., Luptak V.: Methodology to propose a regional transport organization within specific integrated transport system: a case study. Transport Problems. 2018, 13(4), 115–125, DOI: 10.20858/tp.2018.13.4.11.

[15] Saderova J., Bindzar P.: Definition of logistics activities during building of a concreting plant. Carpathian Logistics Congress CLC, 2012.

[16] Skrúcaný T., Gnap J.: The effect of the crosswinds on the stability of the moving vehicles. 6th International Scientific Conference on Dynamic of Civil Engineering and Transport Structures and Wind Engineering. Applied Mechanics and Materials. 2014, 617, 296–301, DOI: 10.4028/www.scientific.net/AMM.617.296.

[17] Skrucany T., Sarkan B., Gnap J.: Influence of aerodynamic trailer devices on drag reduction measured in a wind tunnel. Maintenance and Reliability. 2016, 18(1), 151–154.

[18] Stuchly V., Grencik J.: Calculation of preventive maintenance tasks using RCM method. Euromaintenance 2010, Conference, 12-14.5.2010 - Fiera di Verona - Italy, 207–209.

[19] Van de Molengraft-Luijten M.F.J., Besselink I.J.M., Verschuren R.M.A.F., Nijmeijer H.: Analysis of the lateral dynamic behaviour of articulated commercial vehicles. Vehicle System Dynamics. 2012, 50(1), 169–189, DOI: 10.1080/00423114.2012.676650.

[20] Zanchetta M., Tavernini D., Sorniotto A., Gruber P., Lenzo B., Ferrara A., et al.: Trailer control through vehicle yaw moment control: Theoretical analysis and experimental assessment. Mechatronics. 2019, 64, 102282, DOI: 10.1016/j.mechatronics.2019.102282.

[21] Zong C.F., Zhu T.J., Wang C., Liu H.Z.: Multi-objective stability control algorithm of heavy tractor semi-trailer based on differential braking. Chinese journal of mechanical engineering. 2012, 25(1), 88–97, DOI: 10.3901/CJME.2012.01.088.