FMECA OF BRAKE SYSTEM'S ELEMENTS OF LIGHT COMMERCIAL VEHICLES

Dobrivoje Ćatić[1]*, Ph.D, Full professor, Jasna Glišović*[2]*, Ph.D, Assistant professor, Jasmina Blagojević*[3]*, Ph.D, student, Sandra Veličković*[4]*, Ph.D, student, Marko Delić*[5]*, Ph.D, student*

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INTRODUCTION

According to IEC standard [1], Failure Modes and Effects Analysis (FMEA) is a method for analysis of technical systems reliability. FMEA was developed for USA military purposes as a technique for assessment of reliability through determination of effects of different failure modes of technical systems. This method dates from November 9th, 1949, as an official document [2]. Application of FMEA in automotive industry projects followed no sooner than in the second half of the 1980's and it was related with introduction of quality regulations Q-101 by American Ford Company.

FMEA is a procedure for evaluation of reliability of a technical system that may be applied in all phases of its lifetime. FMEA is generally an inductive method. It is based on consideration of all potential failures of constitutive parts of the system and effects they have on the system. Criticality Analysis (CA) is a procedure for evaluation of criticality rating for all constitutive parts, where, by criticality, a relative measure of item's failure modes influence on reliable and safe operation of the system is meant. Joint FMEA and CA analysis are called Failure modes, effects and criticality analysis - FMECA. According to previous considerations, application of FMECA based on exploitation data is founded on the assumption that the intensity of all failure modes of system elements is constant, which is valid for electronic systems [3]. This assumption considerably simplifies the procedure for criticality assessment. However, application of this methodology in cases when failure intensity is a function of time may lead to distortion of real picture of elements' criticality. A proposal for procedure of quantitative FMECA of machine system's elements, originating from modification of the existing method, is given in paper [4].

For the safety of people and vehicles in traffic, the brake system of motor vehicles has a special significance. Performing detailed analysis of the causes and failure modes of the observed object requires knowledge of the structure, functioning modes and the relationship among the constituent elements. The significance of the braking system of the motor vehicle for the safety of people in traffic requires a detailed analysis of the constituent components in terms of occurrence of the failure. Based on exploitation data, using the method FMECA, the determination of the critical elements of the light commercial vehicle's braking system, which have restrictive influence on the reliable and safe operation of the

[1] *corresponding author:Dobrivoje Ćatić, Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, Kragujevac, caticd@kg.ac.rs*
[2] *Jasna Glišović, Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, Kragujevac, jaca@kg.ac.rs*
[3] *Jasmina Blagojević, Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, Kragujevac, jasminamikovic89@gmail.com*
[4] *Sandra Veličković, Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, Kragujevac, sandravelickovic89@gmail.com*
[5] *Marko Delić, Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, Kragujevac, delicmarko@gmail.com*

system is made in this paper.

IMPORTANCE, ROLE AND STRUCTURE OF THE BRAKING SYSTEM

An important part of the motor vehicle technology relates to braking. The ability of a vehicle to decelerate is one of the primary components of the preventive-active safety. Speed of the motor vehicle in certain traffic conditions, as well as the maximum speed on the open road, depends on the efficiency of the braking devices and the possibility of stopping a motor vehicle in the shortest possible distance. Vehicle with better braking performances may develop in service a higher average speed. Therefore, the braking characteristics of the vehicle can be considered an important part of the overall dynamic characteristics of the vehicle.

Braking system is a typical example of a complex system of motor vehicles, whose structure is determined by a complex objective function and certain current international and national regulations on the safety of vehicles in traffic. The main subsystems of the braking system are: service brake, secondary brake, parking brake and an additional brake or retarder. The basic structure of the braking system of motor vehicles is schematically shown in Figure 1 [5].

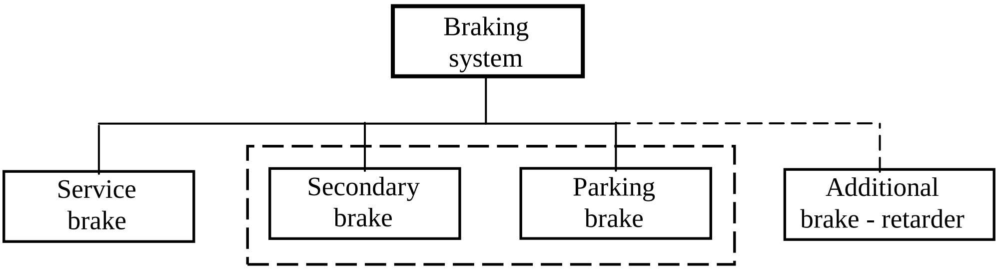

Figure 1: *The structure of the braking system of a motor vehicle*

The term "brake" in the names of individual subsystems has conditionally i.e. adopted meaning. In this case, it involves the entire subsystem with the specific purpose (for service, secondary, parking or additional braking), not just brake as the executive mechanical device of the braking system, as well as each subsystem individually.

Service brake takes over performing the most important tasks of the braking system, i.e. braking with the maximum deceleration (in case of emergency) and all mild, short braking under normal moving conditions.

The secondary or emergency brake is introduced solely to increase the security of the vehicle in traffic, i.e. in order to achieve higher reliability of the braking system. Its mission is to provide an opportunity for braking the vehicle in case if there is a failure in the service brake subsystem.

Parking brake has a task to provide permanent braking-holding the vehicle in place, so-called the parking brake. In addition, it is used for starting the vehicle on a hill. If this brake is design so that it can be also activated during the movement of vehicles, which is commonly the case, the parking brake can takes over tasks of the secondary-emergency brake. In this case, the emergency and parking brake are one same subsystem, which is showed in the block diagram in Figure 1.

Additional brake or retarder has a task to provide slightly, prolonged braking while vehicle moving on longer downs, with the goal of moving vehicles approximately with constant speed. Mandatory presence of the additional brake is prescribed only for vehicles with greater total mass, as indicated in Figure 1 with the dashed line.

Subsystems of the braking system are structurally design basically in the same way, and they include the same functional components: command, transmission mechanism and brakes.

Command is used to activate the appropriate subsystem of service, secondary and other brakes. Each subsystem must have its own command placed so that the driver can easily activate it.

Transmission mechanism has the task to transmit the impulse from the command to the executive devices-the brakes and thereby provides the necessary deceleration i.e. braking of the vehicle.

Brakes are the executive devices of the braking system, by which their objectives are realized. Therefore, their importance within the braking system is especially pronounced. Basically, the brakes are friction mechanisms, which convert the vehicle's kinetic energy into heat [10].

A complete failure of the braking system, due to the complexity of the structure, is rarely occurred. The largest number of failure modes of the constituent elements leads to a partial failure of this system. In the reference [6] by using Fault tree analisys method, a detailed analysis of potential failure modes of the braking system's elements of light commercial vehicles is performed. In this way, it was recorded the highest number of failure modes of elements that directly or indirectly lead to a reduction in performance of the braking system of motor vehicles.

QUANTITATIVE FMECA PROCEDURE FOR MACHINE SYSTEMS' ELEMENTS

Within the reference [6], the procedure of quantitative FMECA of mechanical system's elements is explained, which was created by modifying the existing procedure, taking into account the specificity of mechanical system's elements in terms of failure intensity. The modified version of the quantitative FMECA given in the paper consists of the following steps:

1. Determination of criticality $C_{ij}^{(k)}$ of failure mode *j* of element *i* is to be done by categories of failure effects *k* (*k* = 1, 2, 3, 4), using:

$$C_{ij}^{(k)} = \frac{\alpha_{ij} \cdot \beta_{ij}^{(k)} \cdot t_i}{t_{sri}}, \tag{1}$$

where α_{ij} is a relative rate (frequency measure) of failure mode *j* of element *i* ($0 \le \alpha_{ij} \le 1$, $\sum_j \alpha_{ij} = 1$), $\beta_{ij}^{(k)}$ is conditional probability that failure mode *j* of element *i* will cause category *k* failure effect according to the adopted classification (values are taken from Table 1, according to recommendations from [1, 3], t_i is operating time of element *i* and t_{sri} is mean operating time until failure of element *i* occurs.

***Table 1**: Values of conditional probabilities*

Degree of occurrence of the *k*-th failure effect category	$\beta_{ij}^{(k)}$ [-]
Certain event	1
Probable event	0.1 ... 1
Most probably would not happen	0 ... 0.1
Practically doesn't happen	0

Calculated values of $C_{ij}^{(k)}$ apart from being the starting point for determination of other quantitative properties of element's criticality, they make it possible to rank the element's failure modes according to effects in order to evaluate the most critical system's failure modes from the aspect of reliability and safety.

2. Determination of failure criticality of element *i*, which causes the *k*-th category of failure effects [7]:

$$C_i^{(k)} = \sum_j C_{ij}^{(k)} . \tag{2}$$

Calculation of $C_i^{(k)}$ enables the isolation of the most important elements whose failures lead to certain categories of effects.

3. Determination of criticality of the *k*-th category of the system's effects, by summation of criticalities of all elements failure modes for the specified effect category:

$$C_p = \sum_i \sum_j C_{ij}^{(k)} . \tag{3}$$

Calculated values of C_k are statistical indicators of the representation rating of the individual category of effects.

4. Determination of "absolute criticality" of element *i* according to [6]:

$$C_i = a_I \cdot C_i^{(I)} + a_{II} \cdot C_i^{(II)} + a_{III} \cdot C_i^{(III)} + a_{IV} \cdot C_i^{(IV)}, \tag{4}$$

where a_k is "weight" of the *k*-th (*k* = 1, 2, 3, 4) category of effects (values may be determined using subjective evaluation of effect's "weight" for each case, from the interval between 0 and 1) and $C_i^{(k)}$ is the *i*-th element criticality for the *k*-th category of effects.

By ranking obtained values C_i it can, in a direct way, be evaluating the degree of criticality of system elements from the aspect of durability and security with no complicated analysis.

A computer program for quantitative FMECA of mechanical systems' elements, according to the procedure described above, is established and will be used in future work.

ANALYSIS OF THE CRITICALITY DEGREE OF BRAKE'S ELEMENTS

Quantitative FMECA of braking system's elements of light commercial vehicles is conducted for detailed failure analysis of this system and obtaining information based on which the critical elements of the system, in terms of durability, and safety will be determined.

The basis of this analysis is a complex set of data, which is usually formed in the shape of the table. The process of collecting the data required for quantitative FMECA of the braking system's elements was conducted in the following steps [6]:

1. structural decomposition of the system (In the first step, based on the manufacturer's documentation [8], the structural decomposition of the braking system, the identification and encoding of constituent units are made.);
2. the adoption of structural level for conduction of quantitative FMECA procedure;
3. identification of all failure modes of elements;
4. determination of relative participation of individual elements' failure modes;
5. category definition of final failure effects;
6. categorization of element's failure modes according to effects and determination of conditional probabilities of final effects;
7. determination of mean operating time until element failure occurs and
8. calculation of the total operation time of elements.

Forming of input files for the program of quantitative FMECA of mechanical systems' elements was performed based on the data, which one part is shown in Table 2. To calculate the elements absolute criticality in accordance with (3), the following weighting factors of effect categories are adopted: $a_I = 1{,}00$; $a_{II} = 0{,}70$; $a_{III} = 0{,}30$ and $a_{IV} = 0{,}05$. Weighting factors were adopted by subjective assessment of the experts from the subject area.

By processing of the acquired data given in Table 2, by using the computer program for quantitative analysis of the criticality of the mechanical system elements, the results are obtained for: criticality of elements' failure modes without taking into account the effects (Table 3), criticality of elements with taking into account the effects (Table 4), criticality of final failure effects (Table 5) and absolute criticality of elements (Table 6).

To assess the criticality degree of units' failure modes (parts and assemblies of the braking system), it is considered a total of 35 different structural units and a total of 96 their failure modes. Output list of the program for the criticality degree of units' failure modes regardless of the effects contains the ranked failure modes according to criticality. Since the units' failure modes are sorted according to criticality in descending series, the first part of this list is an interesting for the analysis. Therefore, and due to limited space in the paper, Table 3 shows the initial part of the output list of the program.

In the braking system, as opposed to steering system [9], based on Table 3, one can observes greater uniformity of criticality of units' failure modes. The most critical failure mode of brake system's units, regardless of the result, is the wear of the shoe's brake lining with the category of effects of *k*.2 and criticality of $0.5677 \cdot 10^{-3}$. This should be assumed due to the extremely difficult operating conditions (high sliding speed, high operating temperature and large contact pressure). In the second is increased clearance of bearing bushings of brake command with criticality of $0.3996 \cdot 10^{-3}$, but the category of effects is *k*.4. In the third is the wear of walking surface of the command's rubber cover, also with the effects of *k*.4. Nonhermetic master cylinder is in fourth in the category of effects *k*.1. In the fifth is nonhermetic wheel brake cylinder. Nonhermetic cylinders occur due to wear of rubber sealing rings. Wear speed of the sealing rings depends on the external cylinder sealing i.e. on prevention the ingress of abrasive and corrosive impurities in the interior of the cylinders, then on the quality of the oil, working motion of the pistons, operating temperatures, etc.

Failure modes of drum occupy high places, too. Wear of the drum is in the sixth in order of criticality, and scratched working surface of drum is in eighth place. However, from twentieth place, the criticality of failure modes is over a hundred times smaller than the criticality of most critical failure modes.

Based on Table 4, for effect *k*.1 highest criticality have units whose failures lead to complete failure of service or parking brake (master cylinder, rear and front cable of the parking brake), or to the failure of one line in parallel connection of service brake (wheel brake cylinder, pipes and connectors of hydraulic installation, etc.).

Based on Table 5, the representation of units' failure modes with an effect's category *k*.3 with 2.10% is negligible compared to the other categories of effects. Failure modes with effects *k*.4, regardless of representation, because of the severity of effects, are not prevailed to the determination of the most critical unit in the braking system. Failure modes of units with the ultimate effects *k*.1 and *k*.2 are remained for consideration. The question is whether they are more important units' failure modes with a category of effect *k*.2 and the relative representation of 46.39%, or failure modes with the category of effect *k*.1 and relative representation of 18.98%. The dilemma can be resolved by calculating the absolute criticality of units. Table 6 contains the units that are ranked according to the absolute criticality. Based on this table, the biggest criticality has the brake shoe lining. Further follow: the master cylinder, wheel brake cylinder, drum, depressor, etc.

***Table 2**: Basics of the FMECA procedure for elements of the light commercial vehicle's braking system*

Element's name	Elem. code	Failure mode	Failure mode code	Rel. rate α_{ij} [-]	Loss prob. β_{ij} [-]	Final effect	t_{sr} [h] x10^3
Pedal of brake command	51111	Breakage of connection parts	N.32	0.003	0.4	*k*.1	14.96
Rubber cover of pedal	51112	Slipping off from the pedal	N.29	0.1	1.0	*k*.4	2.32
		Wear of step on surface	N.77	0.9	0.6	*k*.4	
Bearing bushing	51113	Increased clearance	N.35	0.995	1.0	*k*.4	2.49
		Get jammed	N.36	0.005	0.4	*k*.2	
Return spring of pedal	51101	Spring crack	N.06	0.1	0.6	*k*.2	13.67
		Insufficient elasticity	N.15	0.001	0.3	*k*.2	
		Fallout of spring	N.29	0.002	0.6	*k*.2	
Pull rod of piston pump	51102	Deformation	N.02	0.001	0.2	*k*.2	12.08
		Fork crack	N.06	0.001	0.7	*k*.1	
		Coil damage	N.07	0.03	0.4	*k*.2	
		Misalignment	N.62	0.2	0.8	*k*.2	
Reservoir for fluid	51201	Porosity	N.81	0.002	0.4	*k*.3	14.97
Flexible pipe of the reservoir	51202	A loose connection	N.31	0.06	0.7	*k*.3	13.93
		Broken pipe clamps	N.32	0.01	0.8	*k*.3	
		Pipe porosity	N.81	0.002	0.2	*k*.3	
Master brake cylinder	51210	Loose connection with body	N.31	0.001	0.2	*k*.3	3.31
		Pistons get jammed	N.36	0.02	1.0	*k*.1	
		Nonhermetic	N.58	0.9785	0.6	*k*.1	
		Body porosity	N.81	0.0005	0.3	*k*.3	
Brake booster	51220	Blocking	N.13	0.02	1.0	*k*.2	14.10
		Ineffective	N.30	0.005	1.0	*k*.2	
		Insufficient press. connect. elements	N.31	0.001	0.4	*k*.3	
		Nonhermetic	N.58	0.04	1.0	*k*.2	
Braking regulator	51240	Damage to the coil of plug	N.07	0.004	0.8	*k*.3	14.78
		Damage to seals	N.37	0.01	0.4	*k*.1	
		Body porosity	N.81	0.002	0.2	*k*.3	

***Table 3**: Criticality of elements' failure modes without taking into account the effects*

No.	Code	Element's name	Failure mode	Eff. name	α [-]	β [-]	t_{sr} [h]	t_i [h]	Criticality $C_{ij}^{(k)}$ [-]
1	51312	Shoe lining	Wear of the lining	*k*.2	0.8800	1.0	1.550E+03	1	0.5677E-03
2	51113	Bearing bushing	Increased clearance	*k*.4	0.9950	1.0	2.490E+04	1	0.3996E-03
3	51112	Rubber cover of pedal	Wear of the step on surface	*k*.4	0.9000	0.6	2.320E+03	1	0.2328E-03
4	51210	Master brake cylinder	Nonhermetic	*k*.1	0.9785	0.6	3.310E+03	1	0.1774E-03
5	51250	Wheel brake cylinder	Nonhermetic	*k*.1	0.8595	0.5	3.090E+03	1	0.1391E-03
6	51306	Drum	Wear of the work surface	*k*.2	0.5750	1.0	4.230E+03	1	0.1359E-03
7	51230	Depressor	Insufficient efficiency	*k*.2	0.9980	1.0	8.320E+03	1	0.1200E-03
8	51306	Drum	Scratched working surface	*k*.2	0.4000	0.7	4.230E+03	1	0.6619E-04
9	51112	Rubber cover of pedal	Slipping off from the pedal	*k*.4	0.1000	1.0	2.320E+03	1	0.4310E-04
10	51250	Wheel brake cylinder	Damage of the outlet valve	*k*.3	0.1200	1.0	3.090E+03	1	0.3883E-04
11	52204	Rear cable with cover	Lining get jammed	*k*.1	0.3000	0.6	8.140E+03	1	0.2211E-04
12	51102	Pull rod of piston pump	Misalignment	*k*.2	0.2000	0.8	1.208E+04	1	0.1325E-04
13	52201	Front cable with cover	Lining get jammed	*k*.1	0.2000	0.6	1.003E+04	1	0.1196E-04
14	51208	Other pipes and connectors	Cracking	*k*.1	0.2000	1.0	1.285E+04	1	0.1167E-04
15	51204	Pipes of servo commands (pneumatic)	Tube cracking	*k*.2	0.1500	1.0	1.306E+04	1	0.1149E-04
16	52204	Rear cable with cover	Cable stretching	*k*.2	0.2000	0.4	8.140E+03	1	0.9828E-05
17	52201	Front cable with cover	Cable stretching	*k*.2	0.2000	0.4	1.003E+04	1	0.7976E-05
18	51312	Shoe lining	Contamination of lining	*k*.2	0.0100	1.0	1.550E+03	1	0.6452E-05
19	51210	Master brake cylinder	Pistons get jammed	*k*.1	0.0200	1.0	3.310E+03	1	0.6042E-05
20	51250	Wheel brake cylinder	Pistons get jammed	*k*.1	0.0200	0.8	3.090E+03	1	0.5178E-05

Table 4: *Criticality of elements with taking into account the effects*

a) Criticality by effects *k*.1

No.	Code	Element's name	$C_i^{(k)}$ [-]
1	51210	Master brake cylinder	0.1834E-03
2	51250	Wheel brake cylinder	0.1443E-03
3	52204	Rear cable with cover	0.2703E-04
4	52201	Front cable with cover	0.1396E-04
5	51208	Other pipes and connectors of hydraulic install.	0.1261E-04
6	51312	Shoe lining	0.6452E-05
7	51206	Flexible pipes of hydraulic installation	0.3988E-05
8	51306	Drum	0.9456E-06
9	52202	Wheel with a fork	0.5277E-06
10	52206	Lever mechanism of the parking brake on the wheel	0.3362E-06
11	51240	Braking regulator	0.2706E-06

b) Criticality by effects *k*.2

No.	Code	Element's name	$C_i^{(k)}$ [-]
1	51312	Shoe lining	0.5794E-03
2	51306	Drum	0.2050E-03
3	51230	Depressor	0.1202E-03
4	51102	Pull rod of piston pump	0.1425E-04
5	51204	Pipes of servo commands (pneumatic)	0.1167E-04
6	52204	Rear cable with cover	0.9828E-05
7	52201	Front cable with cover	0.7976E-05
8	51220	Brake booster	0.4610E-05
9	51101	Return spring of pedal	0.4499E-05
10	51241	Regulator command	0.1434E-05

c) Criticality by effects *k*.3

No.	Code	Element's name	$C_i^{(k)}$ [-]
1	51250	Wheel brake cylinder	0.3887E-04
2	51202	Flexible pipe of reservoir	0.3618E-05
3	52205	Bracket of cable's cover	0.2683E-06
4	51240	Braking regulator	0.2436E-06
5	51205	One-way valve	0.2038E-06

d) Criticality by effects *k*.4

No.	Code	Element's name	$C_i^{(k)}$ [-]
1	51113	Bearing bushing	0.3996E-03
2	51112	Rubber cover of pedal	0.2759E-03
3	52111	Parking brake lever	0.3349E-06

***Table 5:** Criticality of final failure effects*

No.	Final effect	C_k [-]	Rel. crit. %
1	*k*.2	0.9640E-03	46.39
2	*k*.4	0.6759E-05	32.53
3	*k*.1	0.3943E-03	18.98
4	*k*.3	0.4369E-05	2.10

***Table 6:** Absolute criticality of elements*

No.	Code	Element's name	C_i [-]
1	51312	Brake lining	0.4120E-03
2	51210	Master brake cylinder	0.1834E-03
3	51250	Wheel brake cylinder	0.1559E-03
4	51306	Drum	0.1444E-03
5	51230	Depressor	0.8413E-04
6	52204	Rear cable with cover	0.3391E-04
7	51113	Bearing bushing	0.2054E-04
8	52201	Front cable with cover	0.1954E-04
9	51112	Rubber cover of pedal	0.1379E-04
10	51208	Other pipes and connectors of hydraulic install.	0.1265E-04
11	51102	Pull rod of piston pump	0.1004E-04
12	51204	Pipes of servo commands (pneumatic)	0.8168E-05
13	51206	Flexible pipes of hydraulic installation	0.4032E-05
14	51220	Brake booster	0.3235E-05

For purposes of separation of a small number of relevant units from a large number of less significant, the Pareto analysis of the absolute criticality of brake system's unit is performed. Figure 2 shows the percentage share of the top ten most critical units of the brake system. Criticality of the remaining 25 units is only 3.2%.

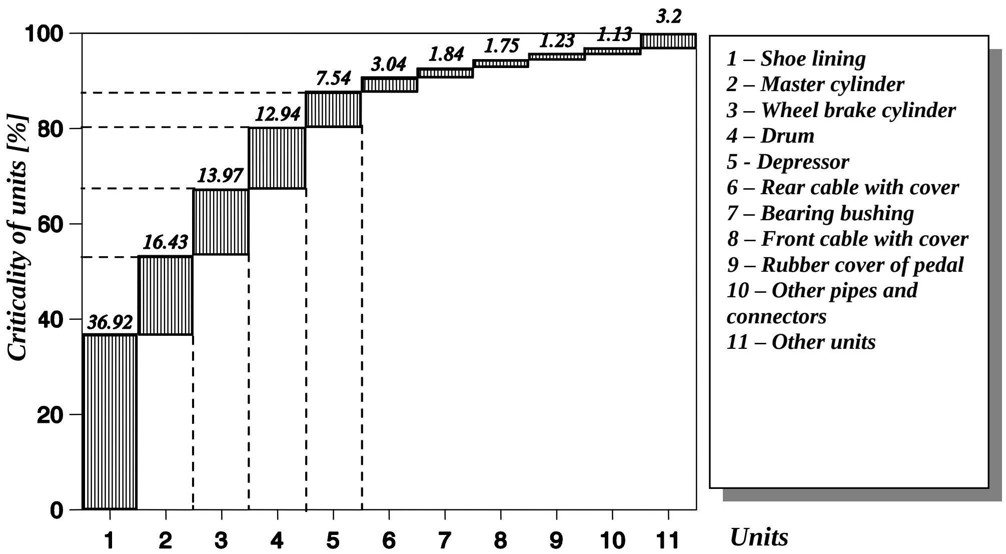

***Figure 2:** Pareto analysis of the absolute criticality degree of whole brake system*

Based on the above analysis, the brake shoe lining is undoubtedly the most critical unit (element) of the braking system of the considered type of vehicle. A group of units according to the sequence shown in Figure 2 then follows.

CONCLUSION

By analysis of failure mode, effects and criticality analysis of machine systems' elements, based on data from exploitation, we get a range of information necessary for detailed knowledge of the system from the point of failure. In the case that there is data on medium operation time until failure and the relative frequencies of certain modes of failure of elements, or can be assessed by applying the quantitative analysis of modes, effects and criticality of failure may be made ranking of failure modes of elements by degree of criticality. Calculation of criticality failure modes of elements of mechanical systems and their ranking by degree of criticality is important because it points to the elements and their failure modes in which a criticality is the greatest. Analysis of the causes of critical failure modes of elements can be determined directions of undertaking concrete measures to minimize or completely eliminate the causes of failure, or lower the effects of failure. Thus increases the reliability of critical elements, and thus the reliability, dependability and quality of the entire system.

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REFERENCES

[1] IEC 60812. *Analysis techniques for system reliability - Procedure for failure mode and effects analysis (FMEA)*, 2nd ed., Geneva, International Electromechanical Commission, 2006.

[2] Stamatis D.H.: *Failure mode and effect analysis*, 2nd ed., American Society for Quality, Milwaukee, Wisconsin, 2003.

[3] Mtain Inc. *Reliability, maintainability, logistics support, engineering services, reliability failure modes, effects and criticality analysis*, from *http://www.mtain.com/relia/relfmeca.htm*, Accessed: 08.06.2010.

[4] Catic D., Jeremic B., Djordjevic Z., Miloradovic N.: *Criticality analysis of the elements of the light commercial vehicle's steering tie-rod joint*, Strojniški vestnik - Journal of Mechanical Engineering, Ljubljana, Slovenia, Vol. 57, No 6, p. 495-502, 2011.

[5] Todorović J.: *Braking of motor vehicle*, Institute for textbooks and teaching aids, Beograd, 1988.

[6] Ćatić D.: *Development and application of reliability theory methods*, Faculty of Mechanical Engineering, Kragujevac, 2005.

[7] Dhillon B. S.: *Design reliability, fundamentals and applications*, Department of Mechanical Engineering, University of Ottawa, Ottawa, Ontario, Canada, CRC Press LLC, 1999.

[8] Service manuals, "*Zastava Iveco trucks*", Kragujevac, 1991.

[9] Catic D., Ivanovic G., Jeremić B., Lakic Globocki G.: *Criticality analysis of elements of automobile's steering system*, Journal of the Balkan Tribological Association, Bulgaria, Vol. 17, No 1, 2011.

[10] Glišović, J.: *Vehicles design-A methodical collection of problems with theory excerpts*, Faculty of Engineering, University of Kragujevac, Kragujevac, 2014.