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IMPLEMENTATION OF FMEA METHOD IN MAINTENANCE OF SEMI-TRAILER COMBINATION

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Abstract

The paper deals with the proposal of new maintenance system on a semi-trailer combination. Analysis of wear and damage of air brake system components used on the semi-trailer combination based on real experience from practice and creation of the FMEA analysis of the system using software support are presented.

The need for continuous improvement of product quality, reliability and safety arises from product specifications, government regulatory requirements, agency recommendations, legal implications and above all a company's desire to improve its market position and customer satisfaction. These issues require product manufacturers to perform risk analyses that identify and minimize part/system failures throughout the product‘s life cycle. The FMEA methodology is one of the risk analysis techniques recommended by international standards. It is a systematic process to identify potential failures to fulfil the intended function, to identify possible failure causes so the causes can be eliminated, and to locate the failure consequences so the consequences can be reduced.

Key words: FMEA (Failure mode and effect analysis), risk priority number, air brake system of semi-trailer

INTRODUCTION

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. Function of air brake system on semi-trailer is to ensure deceleration, stopping and parking a semi-trailer.

The current maintenance system of trailers is described with focus on the basic air brake system design. Following analysis of wear and damage of air brake system components used on the semi-trailer combination based on real experience from practice and creation of the FMECA analysis have been done [2, 8, 11].

1. RISK ASSESSMENT

For the technical condition diagnosing of machinery, different diagnostic methods are being used. These methods can give different results. We cannot use certain methods for different machines and different operating conditions because the results can often be distorted or misleading.

Risk analysis contributes to improved security. The risk analysis process depends on the experience, knowledge, imagination, creativity and skills of the team (individuals) engaged in this analysis. Only application of these procedures cannot ensure a proper and thorough risk analysis results without teamwork of competent staff [1].

An equally important step is to choose an appropriate risk assessment methods. Risk assessment assesses the seriousness of the estimated magnitude of the risk and the need for its reduction based on the risk analysis.

There are various methods for risk assessment. These methods are used in various steps of risk management processes, or they can also be combined. Risk assessment methods can be divided [9, 17, 19]:

1. according to the valuation method:
   - qualitative,
   - quantitative,
   - semi quantitative.
2. According to sources of information:
   - deductive,
   - inductive.

2. FMEA (Failure Mode and Effect 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. In this case it is a Failure Modes, Effects and

Criticality Analysis - FMECA. The basis for a successful FMEA is a quality concept estimate of possible failures that may occur and their causes. Its main objective is to improve the reliability, safety, and quality evaluation of the product. FMEA is based on certain design level, such as the level of component or subsystem, for which root causes of failures are available. In the beginning it is necessary to create structure of the analysed system, and the basic principle of the method is the breakdown of the elements [3, 10, 20].

The FMEA shall be performed according to the following steps [19]:

1. Describe the product to be analysed, by providing:
   - functional descriptions,
   - interfaces,
   - interrelationships and interdependencies of the items which constitute the product,
   - operational modes,
   - mission phases.
2. Identify all potential failure modes for each item and investigate their effects on the item under analysis and on the product and operation to be studied.
3. Assume that each single item failure is the only failure in the product.
4. Evaluate each failure mode in terms of the worst potential consequences and assign a severity category.
5. Identify failure detection methods.
6. Identify existing preventive or compensating provisions for each failure mode.
7. Provide for identified critical items corrective design or other actions (such as operator actions) necessary to eliminate the failure or to mitigate or to control the risk.
8. Document the analysis and summarize the results and the problems that cannot be solved by the corrective actions.
9. Record all critical items into a dedicated table as an input to the overall project critical item list (CIL).

The FMEA/FMECA is basically a bottom-up analysis considering each single elementary failure mode and assessing its effects up to the boundary of the product or process under analysis. The FMEA/FMECA methodology is not adapted to assess combination of failures within a product or a process [3, 10, 20].

Applying each methodology step, FMEA is presented on the real example of Compressed air system as a part of a semi-trailer EBS system. The semi-trailers serve for transport of large volume goods. According to EEC standards, the most important parameters of semi-trailer combinations are:

- total weight,
- maximum load on each axle,
- total length and width,
- total cargo volume for goods transported.

The main components, described for a 3-axle semi-trailer, are:

- frame, king pin, support fixtures, axles, air brake system, side impact protection, rear bumper, superstructure, floor;
- accessories: spare wheel bracket for spare wheel, water tank, plastic toolbox, retractable step unit.

Air brake system (fig. 2) has direct influence on driving safety in road traffic. The main function of the entire brake system is controlled by EBS. The air brake system consists of two branches – air and electrical (EBS) [4, 5].

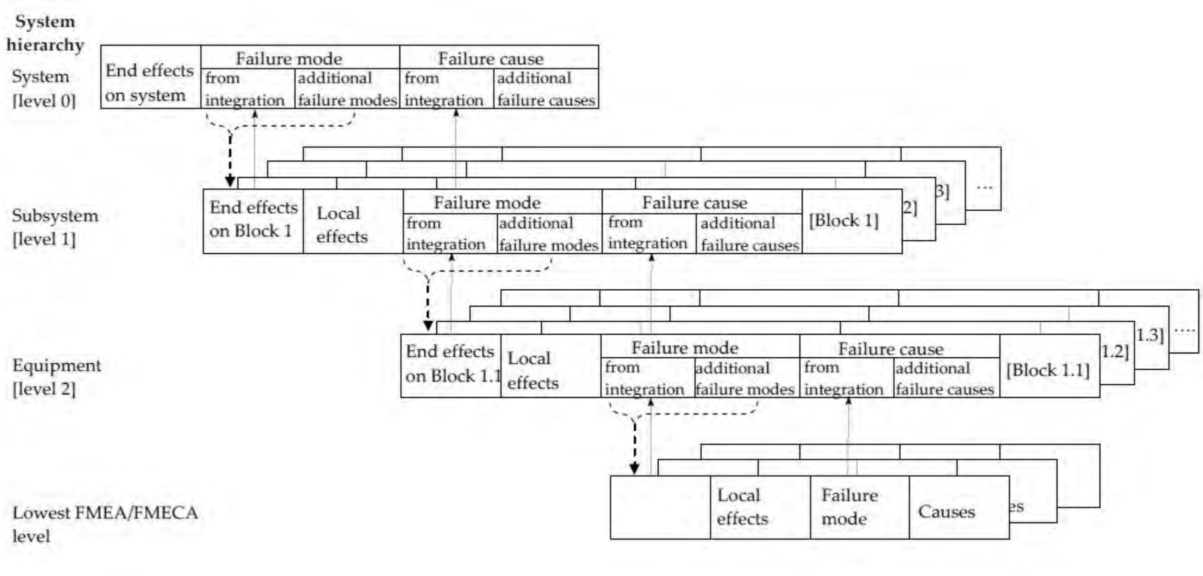
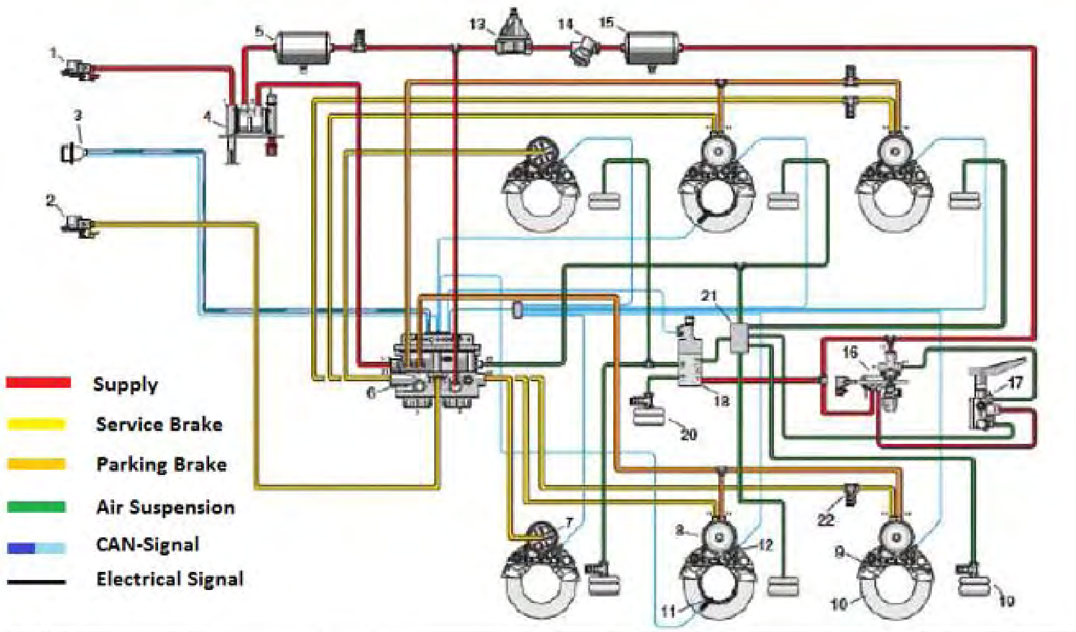


Fig. 1. Graphical representation of integration requirements according EN 16602-30-02:2014 [17]



1	Coupling head with filter (supply)	7	Brake chamber	13	Pressure protection valve	19	Air spring bellows
2	Coupling head with filter(common)	8	Spring brake	14	Line filter	20	Lift bellows
3	EBS connection ISO 7638	9	Air disc brake	15	Air reservoir, suspension	21	Junction block
4	Park/shunt valve with emergency function	10	Brake disc	16	Levelling valve	22	Test connector
5	Air reservoir	11	Sensing ring and speed sensor	17	Raise/lower valve		
6	EBS trailer module	12	Wear sensor	18	Lift axle valve		

Fig. 2. Air brake system

2.1. Creating FMEA structure for compressed air system of the semi-trailer

APIS PRO 6.5 programme was used to develop FMEA analysis of EBS system with analysis of the criticality of nodes, including functional and fault networks. The first step is the creation of a system structure, in this case the structure of the air pressure system of the semitrailer shown in fig. 2. Functions and failures are necessary to be provided for individual elements of the structure. A failure mode is defined as an effect by which the failure of the element is observed. It is important to create a list of all possible or potential failure modes of system, which is the basis of FMEA method – Fig. 3. Then failure networks, or failure interrelations, can be created, that is description of the mutual cause - effect relations in sense of failures – fig. 3.

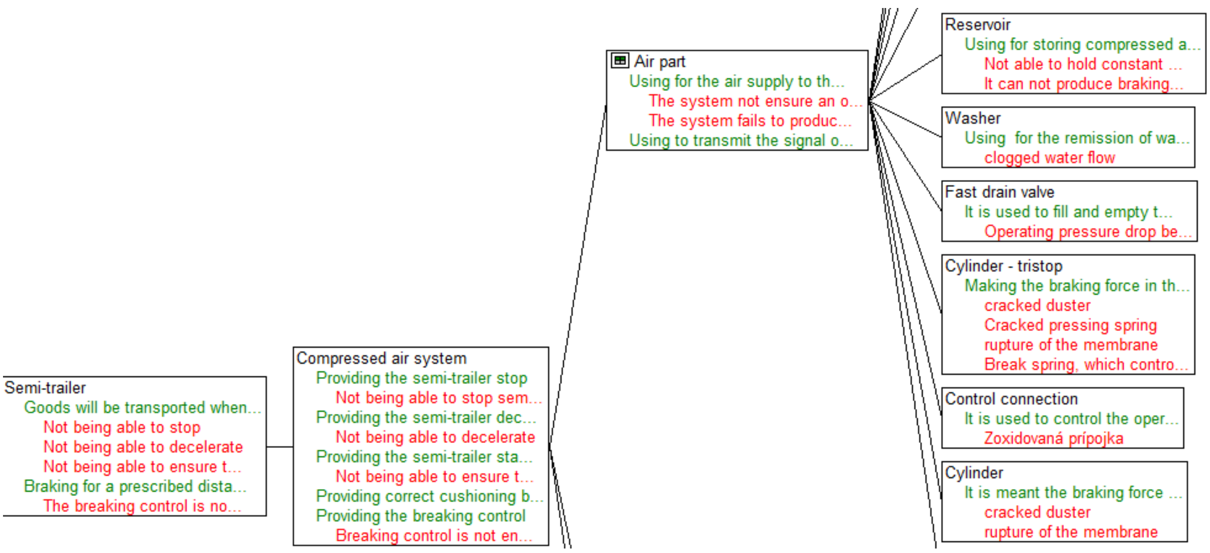


Fig. 3. View of the semi-trailer structure with the structure of functions and failures network

2.2. 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 [3, 7, 10].

$$RPN = S \times O \times D \quad (1)$$

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 failure causes, (10 means, that causes of failure surely happen)

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

Example of risk's form assessment (RPN) is shown in fig. 4.

2.3. Risk values (RPN) of current maintenance system

After making FMECA analysis of Compressed air system and the subsequent compilation of FMEA forms and associated values for each degree of risk factors we need to determine the permissible risk values (RPN), that we are willing to accept and which show that the selected detection measures are sufficient. Acceptable risk value (RPN) will not have any impact on the function of the air pressure system and on the functioning of semi-trailer or on the human safety. Therefore there is no need to perform any preventative measures.

In the case of air pressures system when using the current methods for the detection of failures, the RPN values are in the range 500-80, see figure 5 (shown in red).

These values are not acceptable for use on the road. Therefore it is necessary to reduce the value of all the risks to an acceptable value and also reduce the value of the results of errors to avoid safety consequences (loss of human lives in the worst case) and so that a semi-trailer was in up-state [5, 6].

2.4. Proposal detection and preventive measures

We found that the risk values (RPN) of current maintenance system are very high and also the consequences of disruption caused to the individual components of air pressure system have high values and therefore there must be a change in the current maintenance system.

The change consists of a proposal for new period of planned inspections, using new methods to detect failures of individual components and also the use of preventive measures, therefore replacing the components of air pressure system after a certain number of kilometres travelled. Visual inspection is performed every 45 000 km with a tolerance of +/- 2000 km or after four months from commissioning or since the last inspection on all components of air pressure system. Its purpose is to reveal failures that might occur in the production process, but they appear during operation of the semi-trailer. Its task is, based on more frequent interval by visual

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

inspection, to prevent any unexpected failure which could have consequences on human safety and disable the compressed air system from operation. These inspections can be carried out only by a qualified person in a professional facility. Tightness and functionality test of individual components of air pressure system is done by diagnosing every 90 000 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 failure consequences.

Tightness test is carried out as follows: diagnostic system is connected to the air pressure system and the electronics is activated by switching on from the truck. By this the EBS system becomes active. Then the service brake in the truck is activated so that the whole compressed air system is filled with the operating pressure. In the diagnosis menu the tightness test is selected and the desired time interval is set. Usually it is 120 seconds. Tightness test starts automatically and automatically finds any air leaks throughout the system. If the diagnosis detects pressure drop in any part of the air pressure system then qualified staff is needed to find out where a leak is and replace damaged components.

The increasing number of kilometres travelled leads to more frequent failures of individual components of air pressure system as follows from the analysis of wear and damage. There are 1470 semi-trailers which have been monitored, they have run from 150 000 km to 2 250 000 km, and their failure rate is 32,9. This is the main reason to create appropriate preventive measures. This causes reduction of failures, human safety is not endangered and compressed air system ensures reliable operation of the semi-trailer.

FMECA analysis showed that it is appropriate to change all components of air pressure systems except piping and wiring after elapsed 180 000 km, which is more expensive than original maintenance system, but it minimizes the risk of failure and the consequences associated with them [6, 13, 15].

2.5. RPN evaluation after the introduction of corrective measures

After the introduction of screening and preventive measures to reduce the value of the RPN it is necessary to continue to monitor this indicator.

In fig. 4 we can see the brake cylinder – tristop with the cause of the failure rupture of membranes, where the risk/priority number is after implementation corrective measures.

Fig. 5 shows that there was a significant reduction of the risk values (RPN) with proposed methods for detection, as well as by preventive measures. Risk values (RPN) in the first stage of the planned preventive inspections are moving in the range from 400 to 60.

After applying preventive measures the risk values (RPN) are moving in the range between 80 to 32.

In some cases there were, particularly for wiring, sensors and EBS modulators that risk values RPN in the proposed maintenance system exceeded the original risk values RPN of current maintenance system.

Visual inspection is not sufficient in some cases and cannot detect failures that could occur in the internal part of the individual components of air pressure system [12].

The occurrence of failures of individual components to running 75 000 km is very low, only 2.6, and therefore it can be assumed that running up to 45 000 km this occurrence will be minimal and therefore a proposed visual inspection is sufficient.

Then after riding 90 000 km it is proposed to make more detailed check of the individual components of air pressure system using diagnostics and leak check of individual components and thereby, reducing the risk of RPN values of proposed maintenance system PM to an acceptable value [4, 6].

Effects	S	C	Failure mode	Cause	Preventive action	O	Detection action	D	RPN	R/D
1.1.1.c.1 Semi-trailer is not able to stop {1}	5		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}	1.1.1.1.9.a.1 Cracked duster {1}	Initial state: 23.6.2016					
						10	Visual control every 75 000 km {1}	4	400	
					Revision state: 23.6.2016					
						10	Visual control every 45 000 km {1}	3	(300)	
					Revision state: 23.6.2016					
					replace the brake cylinder every 180000 km {1}	2	Checking for leaks using diagnostics every 90 000 km {1}	2	(40)	

Fig. 5. Value of risk/priority number for brake cylinder

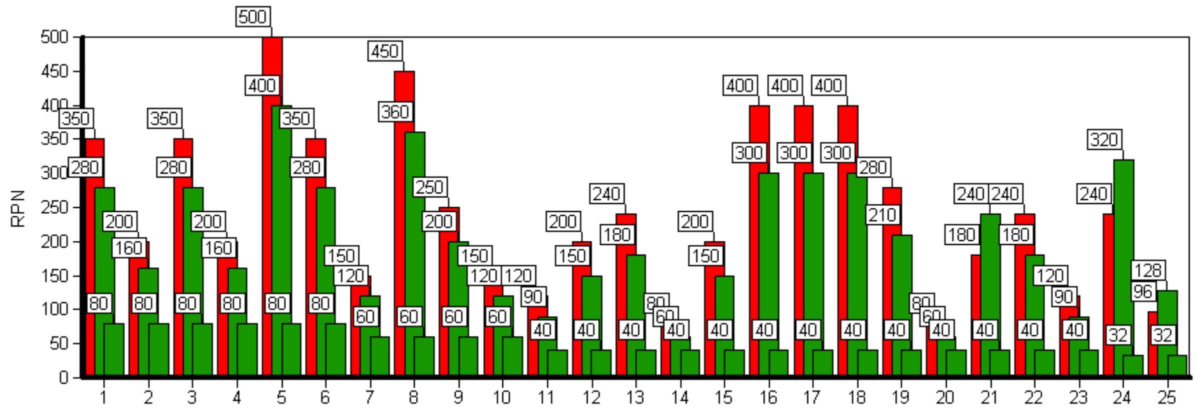


Fig. 6. RPN values for existing and proposed maintenance system [4]

Tab. 1: Elements for the figure 6

No.	The name of component	No.	The name of component
1.	Connecting head - red	14.	Reservoir
2.	Connecting hose	15.	Fast drain valve with two-way braking valve
3.	Connecting head - yellow	16.	Brake cylinder – tristop (cracked compressed spring)
4.	Connecting hose	17.	Brake cylinder – tristop (ruptured membrane)
5.	Brake cylinder – tristop (rupped duster)	18.	Brake cylinder – tristop (cracked spring which operated parking brake)
6.	Brake cylinder		
7.	Washer	19.	Brake cylinder
8.	Pipeline	20.	Reservoir
9.	EBS connector	21.	Wiring
10.	Inspection connection	22.	Air-break valve
11.	Pipe filter	23.	Pipe filter
12.	Fast brake release valve	24.	Sensors
13.	Drivers brake valve	25.	EBS modulator

The subject of this analysis is the change of air pressure system maintenance. Therefore, there are proposed methods for the detection of failures on individual components of air pressure system.

The first method is visual inspection every 45 000 km.

The second method is to use diagnostics every 90000 km to check the tightness and functionality of individual components.

After every 180 000 km exchange of all components of air pressure system will be done except of piping and wiring.

3. CONCLUSION

Nowadays one of the most used vehicles for carrying large numbers of material goods are trucks with semi-trailers. To ensure failure-free operation of the semi-trailer it is very important to ensure compliance with maintenance plans of manufacturers of semi-trailers. Compressed air system appears as one of the systems, in which increased wear and damage of the components occurs caused by functioning and a large number of components.

Compressed air system was selected because the failure of any component in the air pressure system may cause serious safety consequences (loss of human lives), because system is unable to provide stopping or slowing the semi-trailer. Our conclusion are given in the following points:

1. Currently the trailers are using EBS type braking system.
2. Occurrence of failures on individual components of air pressure system is increasing with the number of driven kilometres.
3. Analysis of wear and defective components of air pressure system revealed that the highest failure occurrence is on the brake cylinder - Tristop, sensors, coupling heads, brake cylinders, EBS connector and braking.
4. FMECA analysis of compressed air system showed that the current range of maintenance inspection every 75000 km is unsatisfactory.
5. A new maintenance plan was made and the preventive inspections was planned every 45000 km, 90000 km and 180000 km.

The first level of the preventive 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 purchase 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 90 000 km or will be no later than 8 months from the second inspection. More complex check will be performed with using the proposed methods to detect failures.

The third level of preventive maintenance is proposed for every 180000 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. The replacement of all components of air pressure system is performed with exception of the wiring and piping.

6. The paper proposed a new method of detecting faults on individual components of air pressure systems and to use diagnostics to check the tightness and functionality of individual components.
7. Decreasing of risk values has been shown. Risk values of the current maintenance system are in the range from 500 to 80 and risk values of the proposed maintenance are in the range from 80 to 32 [3, 6].

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