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OPERATIONAL RELIABILITY OF FIRE APPLIANCES ON MERCEDES-BENZ CHASSIS WITH BRIGADES OF FIRE RESCUE SERVICE OF THE MORAVIAN-SILESIA REGION

This paper is focused on the evaluation of data obtained from operational records of fire appliances for the period 2010 - 2013 with emphasis on fire appliances built on Mercedes-Benz chassis. These vehicles are operated by the professional units of Fire Rescue Service of the Moravian-Silesian Region. The data recorded in electronic form in operational records were analysed. The primary result of this analysis was the selection of repairs after failure. Failure severity with regard to the functional reliability of fire appliances was used as selection criterion. Subsequently the assessment of the reliability was performed by setting selected characteristics from a group of complex reliability indicators.

Keywords: Operational reliability, fire appliance, service, failure, repair.

1. Introduction

Detailed calculation results of selected reliability characteristics for fire fighting vehicles built on Mercedes-Benz (MB) chassis are presented in this paper. The results emerged from the evaluation of primary data on the operation of these vehicles. This paper follows the previous publication which evaluates the operation and maintenance of MB chassis fire fighting vehicles [1]; it also extends previous researches in this area conducted in 2010 [2] by adding vehicles built on Econic chassis to the observed group. The results of the analysis of operational characteristics will not be discussed in detail hereafter, but the final selected values will be given only for providing an overview of vehicle utilization.

2. Characteristics of observed fire fighting vehicles

The Moravian-Silesian Region, which has an area of 5.4 thousand km² and a population of about 1.2 million, is in terms of organization of fire brigades divided into 6 regional departments, with a total of 22 fire stations. Seven fire fighting vehicles on MB Econic chassis are placed at six fire stations in the regional department of Ostrava. Eleven fire fighting vehicles on MB Atego chassis are located at the regional departments outside of Ostrava. The MB Atego vehicles represent the standard intervention vehicles, namely first and second response vehicles; crew size of 6, 2500l water tank, middle weight category with mixed chassis

4x4 suitable for unpaved roads [3 and 4]. MB Econic vehicles represent the exclusively urban intervention fire fighting vehicles; crew size of 6, 2700l water tank, chassis 4x2, heavy weight category [4].

The MB Atego vehicles had the *average annual mileage* of 4864 km, the MB Econic vehicles were comparable with 4352 km. The *share of machine work in place* in motohours was 50% on an average for the MB Atego vehicles, whereas for the MB Econic vehicles, it was only 28% on an average. When comparing the response activity with other activities, the difference is bigger. In the case of the MB Atego vehicles, response actions form 64% in comparison with the MB Econic vehicles with 70%. The absolute numbers of repairs per vehicle regardless of failure severity per four years of observation were on an average 14 failures per MB Atego vehicle and up to 20 failures on MB Econic vehicle [1].

As the observed vehicles have different chassis bases, each chassis class will be evaluated separately in the following text. The *age of the vehicle* is the second most important criterion that is used for the division of vehicles in calculations while assessing reliability. According to this criterion, the MB Atego vehicles are divided into two groups:

- *vehicles under 10 years of age* - 7 vehicles; the average age is 7.1 years,
- *vehicles over 10 years of age* - 4 vehicles; the average age is 10.3 years.

The MB Econic vehicles were not divided into the age groups; they are new vehicles that were put into service between 2010 and 2013.

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3. Partial indicators of reliability characteristics

Statistical data on maintenance and repairs [4] were provided to evaluate the failure rate of the observed vehicles. The data were divided into three groups, *repairs after a failure* (both on the chassis base and on the fire bodywork), *preventive maintenance* (inspection, testing, scheduled inspections, state technical inspections, emissions) and *repair after damage* (during the intervention, after a traffic accident). The results of analyses of operating characteristics in absolute values were published in [1]. Assessment of failure severity preceded the calculations of reliability characteristics. Criteria according to the FMEA method [3] were used for this. Insignificant failures were excluded from the group of failures. Results of calculations of selected reliability indicators following from the analysis of repairs after the failure will be presented in the following text. They are as follows:

- *reliability,*
- *availability,*
- *mean time between failures,*
- *failure rate.*

4. Methods and results

Reliability can be generally characterized as a property of the object consisting in the ability to perform required functions under defined conditions in a defined time period [5]. The so-called test plan method [6] was chosen for failure flow analysis [7 and 8] to evaluate this indicator. By this method, mean times to failure can be determined for a small group of products. The test plan censored by time-to-failure, so called “*t - plan*”, was used for failure rate evaluation. The duration of the test is the limit and the number of detected failures is a random variable. The assumption of the test is that the products are repaired after a failure. The accumulated working time of the vehicle T_{AKU} is a time variable representing the course of the test. T_{AKU} is the total time during which all products were in operation. The accumulated working time for the chosen *t - plan* is calculated according to the following equation:

$$T_{AKU} = \sum(\tau - \sum \theta) + (n - r) \cdot \tau_0 \tag{1}$$

where:

τ_0 test time, from the beginning to the r_0 -th failure,

n number of tested products,

r number of fault units,

θ_i time needed to repair the *i*-th product during the test interval.

The calculation of the accumulated working time according to equation (1) was conducted for four values of the test time: 20, 40, 60 and 80 hours. These intervals, after calculating by the average speed of 50 km/h, represent the mileages of 1000, 2000, 3000 and 4000 km. In standard practice, indicators related only

to the 1000 km mileage interval are used. The decision to use four intervals was based on operating vehicle loads stated in vehicle characteristics. The reason for this decision was to cover a longer time period of use of response fire appliances. The results of the calculations of accumulated operating time on an average per vehicle, both in hours and in kilometres, are provided in Table 1. The average speed of 50 km/h was used for the calculation.

Results of accumulated working time calculations Table 1

T_{AKU}	MB Atego				MB Eonic			
τ_0 [h] - test time	20	40	60	80	20	40	60	80
T_{AKU} per vehicle [h]	19.2	38.7	57.4	76.0	19.7	37.1	49.2	62.1
T_{AKU} per vehicle [km]	959	1936	2868	3800	986	1855	2459	3105

Mean Time Between Failures (MTBF) is the most frequently used indicator in practice for assessing the reliability of repairable systems. It is the mean operating time between two consecutive failures. The indicator is determined as the sample mean of the measured operating times according to [7 and 8]:

$$T_s^* = \frac{1}{n} \sum_{i=1}^n t_i \tag{2}$$

where:

t_i the *i*-th vehicle operation time during the reporting period,

n the number of vehicles included in the test.

In the calculation, all monitored vehicles are included, i.e. both vehicles with failures and those without failures during the reporting period. The results of calculations for the observed vehicles are given in Table 2.

Results of “Mean Time Between Failures” Calculations Table 2

MTBF	MB Atego				MB Eonic			
τ_0 [h] - test time	20	40	60	80	20	40	60	80
T_s^* [h]	15.5	28.9	39.7	46.9	19.7	37.1	49.2	62.1
T_s^* [km]	777	1443	1984	2345	986	1855	2459	3105

For the sake of completion, the distribution of the resulting values of T_s^* at the division of MB Atego vehicles into the age groups is shown in Fig. 1. The expected fact that the interval between repairs shortens for vehicles over 10 years of age is confirmed here. This group of vehicles is approaching the decline stage in its life cycle.

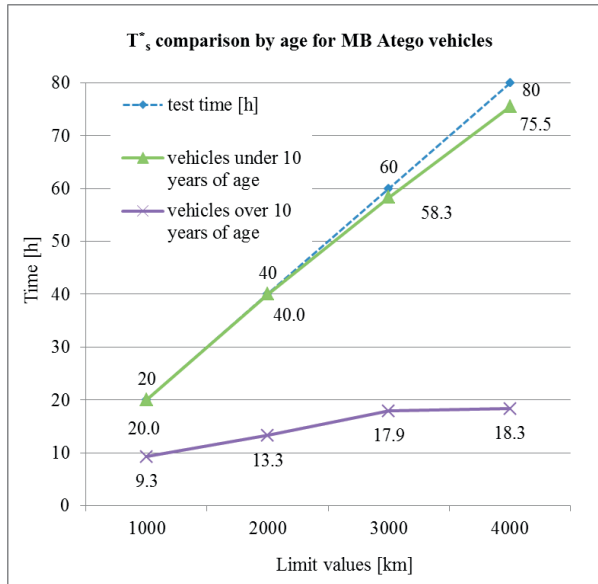


Fig. 1 T_s^* comparison by vehicle age

Failure rate depends on the life cycle stage of the technical system. In the normal use of the product, where the exponential law distribution of time-between-failures is valid approximately, it is possible to consider the T_s^* value as constant [7 and 8]. This property was already tested in the previous study of the failure rate of MB Atego vehicles in 2006-2009 and is given in [2]. Then, the variable has a simple meaning, i.e. the average number of hours (or mileage in km) per failure. Thus equation (3) is valid for calculating the failure rate λ :

$$\lambda = \frac{1}{T_s^*} \tag{3}$$

The results of failure rate calculations for all vehicles regardless of age and separately for the two age groups of vehicles are given in Table 3.

Failure rate of Mercedes-Benz vehicles Table 3

Failure rate	MB Atego				MB Econic			
	20	40	60	80	20	40	60	80
τ_0 [h] - test time	20	40	60	80	20	40	60	80
vehicles in total	0.0644	0.0347	0.0252	0.0213	0.0507	0.0269	0.0203	0.0161
vehicles under 10 years of age	0.0500	0.0250	0.0171	0.0133				
vehicles over 10 years of age	0.1077	0.0754	0.0558	0.0545				

Availability is the ability of an object to perform the required functions under given conditions at a given time interval while ensuring the desired ambient conditions. This state of the object can be characterized by a number of complex indicators of

reliability. Availability coefficient K_p defined by equation (4) was used in our calculations at this stage of research [7]:

$$K_p = \frac{\sum_{j=1}^n t_{pj}}{\sum_{j=1}^n t_{pj} + \sum_{i=1}^n t_{oi}} \tag{4}$$

where:

$\sum t_{pj}$ the sum of times of failure-free operation,

$\sum t_{oi}$ the sum of service time during the period under review.

Calculation results for the defined periods of testing are shown in Fig. 2 where it can be seen that the assessment of fire appliances merely within one small interval of 1000 km is not the best predicative indicator.

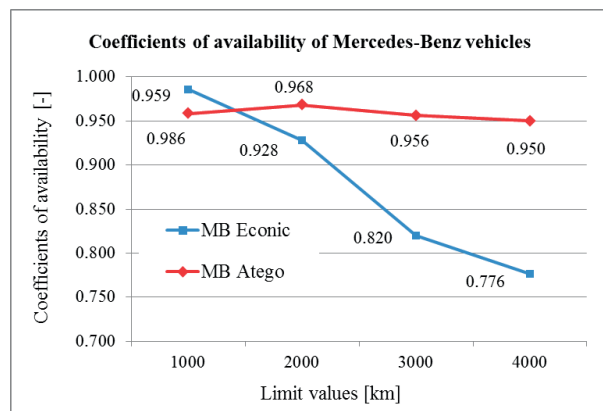


Fig. 2 Coefficient of availability of Mercedes-Benz vehicles

5. Discussion

The ongoing research is focused on the processing of data and the comparison of operation of fire appliances built on Mercedes-Benz, MAN, TATRA and Renault chassis. It is a case of a group of 75 vehicles located in the Moravian-Silesian, South Moravian and Zlin Regions.

The results may be distorted by the fact that the observed vehicles are not identical but only similar. The vehicles are in operation for various periods and have different workloads. First response vehicles, water tenders and backup vehicles are considered here. This fact should always be taken into account. It is necessary to observe vehicles in appropriately selected groups with similar characteristics.

Nevertheless, it is possible to form at least an approximate idea from the results of research by comparing the operation and the reliability of fire appliances built on different chassis. The comparison of appliances operating in urban agglomerations, such as Brno and Ostrava, will have other predictive value of results than the comparison of appliances in territories outside of these urban agglomerations.

Achieving the ideal state of input data for the calculation of reliability of vehicles of the Fire Rescue Service of the Czech Republic seems to be, owing to the current *composition* of fire appliances from the point of view of models of individual vehicles and manufacturers of fire bodyworks, virtually impossible. Another factor affecting the results is the relatively rapid *development* both of chassis bases of fire fighting vehicles and especially of the design of fire bodyworks from the manual control of pump unit, through electro-pneumatic control up to the electronic systems of control in the fire bodywork via CAN (Controller Area Network) bus to control almost the entire vehicle, including the chassis base. These electronic control systems significantly influence the resulting functional reliability of the vehicle.

6. Conclusion

Summarized calculation results for the *accumulated working time* T_{AKU} as characteristic of vehicle reliability are shown in Fig. 3. TATRA vehicles in the South Moravian Region win in the results, while TATRA vehicles from the Zlin Region are at the other end of the results. The reason may be prosaic. The age of five vehicles in the observed group of 11 vehicles is 25 years. The MB Eonic vehicles are at the very end of reliability. It should be noted here that the MB Eonic vehicle is a development prototype, which is in the phase shortly after the startup stage on its lifecycle curve. More attention will be given to these vehicles in further research. Vehicles on MAN TGM chassis occupy together with MB Atego vehicles the imaginary second position. The mentioned vehicles have almost the same value of this parameter and their curves in the graph coincide. They differ only in the order of units of kilometres.

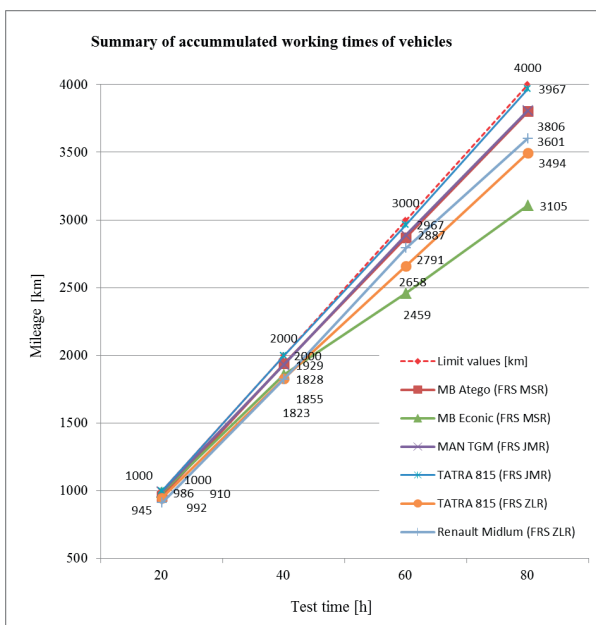


Fig. 3 Summarized results of accumulated working time calculation

The results of calculation of the *reliability coefficient* K_p for all groups of monitored fire fighting vehicles are summarized in Fig. 4. The assumption made at the beginning of calculations that the time of 1000 km test is insufficient is confirmed here. The differences between the new MB Eonic vehicles and the previously acquired appliances already begin to show themselves in the next interval (2000 km = 40 h). These differences deepen in longer periods of observation.

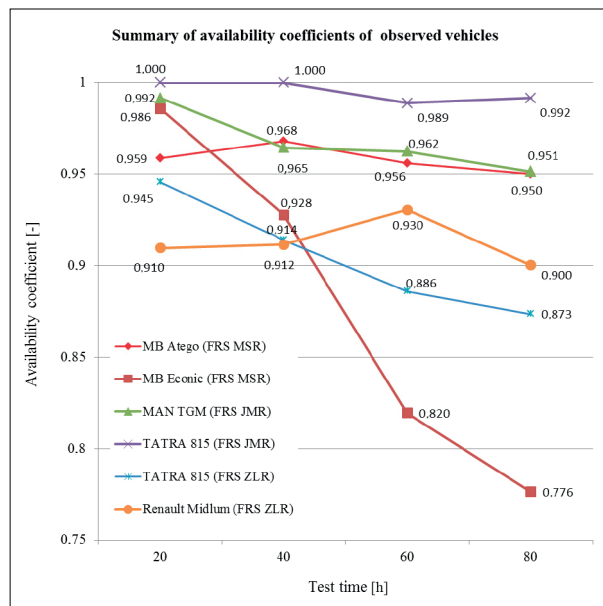


Fig. 4 Summarized results of availability coefficient calculation

The next stage of processing of operational data on observed vehicles is to calculate the partial indicators of maintainability and reparability of observed fire appliances and to complete this research.

Acknowledgements

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