diesel locomotive; diesel engine; mileage; freight turnover;
fuel consumption; failure; probability; probability density

Gintaras GELUMBICKAS, Gediminas VAIČIŪNAS*
Vilnius Gediminas Technical University, Faculty of Transport Engineering
Railway Transport Engineering Division
Basanaviciaus st. 28, Vilnius, Lithuania
**Corresponding author*. E-mail: vaic@vgtu.lt

RESEARCH ON THE INFLUENCE OF OPERATIONAL FACTORS ON THE NUMBER OF FAILURES OF DIESEL LOCOMOTIVES' ENGINES

Summary. Having replaced the diesel locomotives operated in Lithuanian railways by new ones, part of old diesel locomotives (21 units) were renovated. They were equipped with new diesel engines made in Kolomna (Russia). These diesel locomotives are used as reserve locomotives or for carrying small scope freight on local routes. After a few years from their renovation diesel engines as well as the locomotives started to fail. Failures happened to be repeated. The article analyses these locomotives' failure patterns such as number distribution of engine failures according to locomotive mileage, distribution of engine failures according to diesel locomotive turnover, distribution of engine failure number according to consumed fuel. It suggested to regard the density of engine failure probability according to consumed fuel as one of the indicators of engine reliability.

BADANIA WPŁYWU CZYNNIKÓW OPERACYJNYCH NA LICZBĘ AWARII SILNIKÓW SPALINOWYCH LOKOMOTYW

Streszczenie. Po zastąpieniu lokomotyw spalinowych pracujących w kolejach litewskich przez nowe cześć ze starych lokomotyw spalinowych (21 jednostek) zostało odnowionych. Wyposażono je w nowe silniki spalinowe wyprodukowane w Kołomnie (Rosja). Te lokomotywy spalinowe są używane jako lokomotywy rezerwowe lub do przewozu małego zakresu towarowego po trasach lokalnych. Po kilku latach od ich renowacji silniki spalinowe oraz lokomotywy zaczęły się psuć. Awarie zaczęły się powtarzać. Artykuł przedstawia awarie tych lokomotyw, rozkład liczby awarii silnika zgodnie z przebiegiem lokomotywy, dystrybucję awarii silnika według przebiegu lokomotywy spalinowej, rozkład liczby awarii silnika zgodnie ze zużytym paliwem. Sugeruje się wzięcie pod uwagę gęstości prawdopodobieństwa awarii silnika, zgodnie ze zużytym paliwem, jako jednego ze wskaźników niezawodności silnika.

1. INTRODUCTION

The research carried out is based on the main diesel locomotives of Lithuania. Since 2008 Lithuanian diesel locomotive fleet, which mainly consisted of diesel locomotives 2M62 left from Soviet Union time was almost fully replaced by Siemens locomotives ER20CF made in Germany [5]. The remaining part of 2M62 locomotives were either utilized or renovated [6]. The locomotives whose bodywork, brake system and other equipment remained in good condition were renewed by installing them with new engines. 21 of 2M62 series locomotives were installed diesel engine made in Kolomna and series of locomotives became 2M62K (“K” meaning “Kolomna”) [2]. The following diesel locomotives are used as reserve locomotives or for carrying small scope freight on local routes. After a few years from their renovation diesel engines as well as the locomotives started to fail. Failures happened to be repeated. Therefore, there was a need to analyze the failure regularities.

2. CONTENT OF RESEARCH FOR RELIABILITY INDICATORS

Forecasting diesel engine failures for locomotives and estimating costs for their elimination, firstly, number of faults dependency on the factors that influence them was determined. The following research has 2 aims: identify the diesel locomotives whose engine failure determining factors have the highest influence and which of these factors’ influence is the easiest to predict. The following dependencies have been analyzed: distribution of total engine failure number according to average weight of rolling stock, distribution of engine failure number according to comparative fuel consumption, distribution of locomotives and their engine failure number according to engine age, distribution of engine failures according to locomotive mileage with a new engine, distribution of failures according to turnover, distribution of engine failure number according to consumed fuel. The possibility to associate analyzed measures with probability density of locomotives and their engines’ maintenance and failure was examined.

3. STATISTICAL DATA RESEARCH

Statistical failure data for diesel locomotives was started to collect from the beginning of their operation after the new engines were installed. The distribution of locomotives’ failure number according to mileage with new engine is illustrated in figure [1].

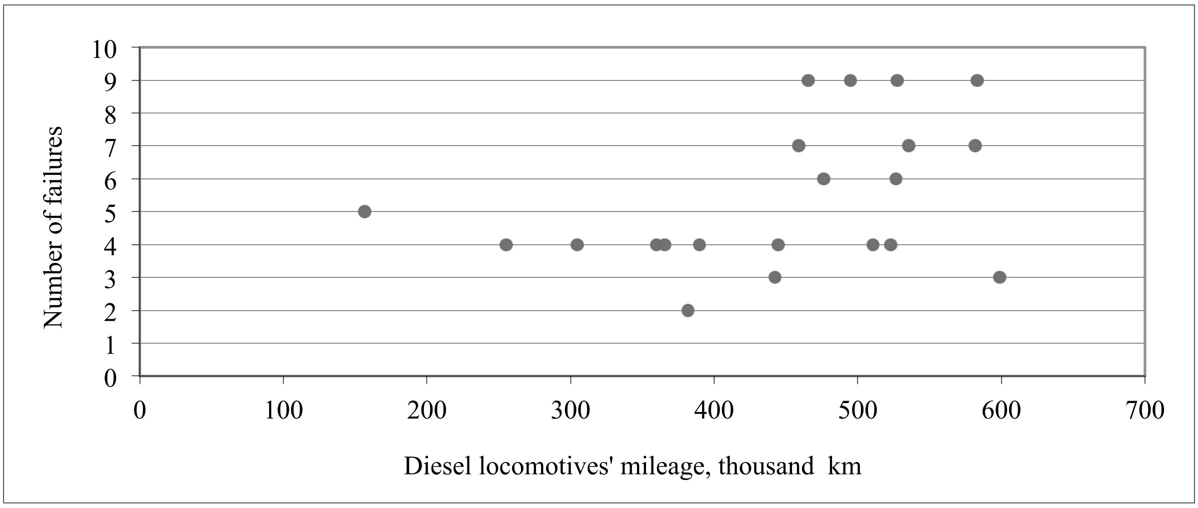

Fig. 1. Distribution of diesel locomotives’ failures according to mileage with a new engine
Rys. 1. Rozkład awarii lokomotyw spalinowych zgodnie z przebiegiem w nowym silniku

It should be noticed that in pic. 1 one-dot represents one diesel locomotive. Distribution of diesel locomotives’ failures according to mileage with a new engine has regularity. Until mileage of 400–450 thousand km the highest number of locomotives’ failures does not exceed 5 failures a year. This number increases up to 9 when 450 thousand mileages are reached. It is evident that when 450 thousand km is reached the highest number of locomotives’ failures almost doubles.

As the number of diesel locomotives is known (21 units) the function of failure free operation density (according to mileage) can be made. This probability in point i is calculated based on formula:

$$P_i = 1 - \frac{\sum N_{fi}}{\sum N_{ti}}, \tag{1}$$

here: N_{fi} – total number of failures during i mileage interval, N_{ti} – the number of locomotives operated during the research.

Goods locomotives differ from other vehicles (e.g. cars) because their mileage not often reflects their actual run-in. The weight of trains ranges from 1 to 6 or more thousand tons. The weight of researched locomotives' tracked trains was about 4–5 thousand tons. In order to describe run-in of diesel locomotives their freight turnover (measured by ton kilometers) needs to be examined. The distribution of diesel locomotives' failure number according to annual turnover is illustrated in fig. 2.

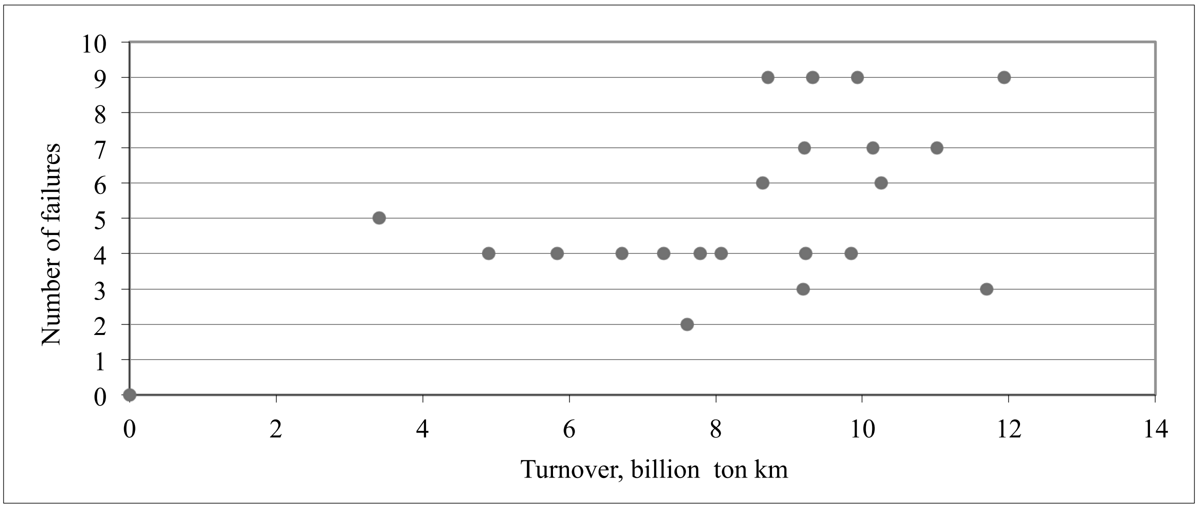

Fig. 2. The distribution of diesel locomotives' failure number according to annual turnover
Rys. 2. Rozkład liczby awarii lokomotyw spalinowych według rocznego przebiegu

Regularity in fig. 2 is almost identical to distribution of failure number according to mileage. The number failures of locomotives with turnover of less than 8 bill. ton km. is 4–5 failures per locomotive a year, for the ones with turnover of over 8 bill ton km. failure number increases from 3 to 9 failures per locomotive a year (average about 6–7). According to freight turnover in ton km. density function of diesel locomotive failure free operation probability can be made. Formula (1) can be used; however, instead of mileage in km freight turnover in ton km should be used. As failure number dependencies on mileage and on freight turnover are analogical, therefore, failure free operation changes of density probability will be analogical. The idea was raised during the research to analyze dependency of failure number on other parameters of locomotive's run-in, which would more exactly define energetic run-in of the engine (such as operational time in hours or fuel consumption in tons. Due to peculiarities of account system relation of failure number with locomotives' operation time in hours failed. However, fuel accounting is often strictly controlled. Therefore, the data on diesel locomotives' fuel consumption exist and they are easy to relate with failure number. Distribution of locomotives' failure number according to annual fuel consumption is illustrated in fig. 3.

Locomotives' failure number according to fuel consumed distributes similarly like according to mileage and freight turnover. Failure number for diesel locomotives, which consume up to 2 thousand tons of fuel a year is until 5, later this number increases to 9 failures per locomotive a year. Fault free operation probability density function here can also be made based on slightly corrected (1) formula. However the research takes interest into the reliability of the engine. As not all the failures of diesel locomotives are related to engine failures, this allows to expect higher failure free operation and its higher density.

Distribution of engine failures number according to locomotives' mileage with new engines is illustrated in fig. 4.

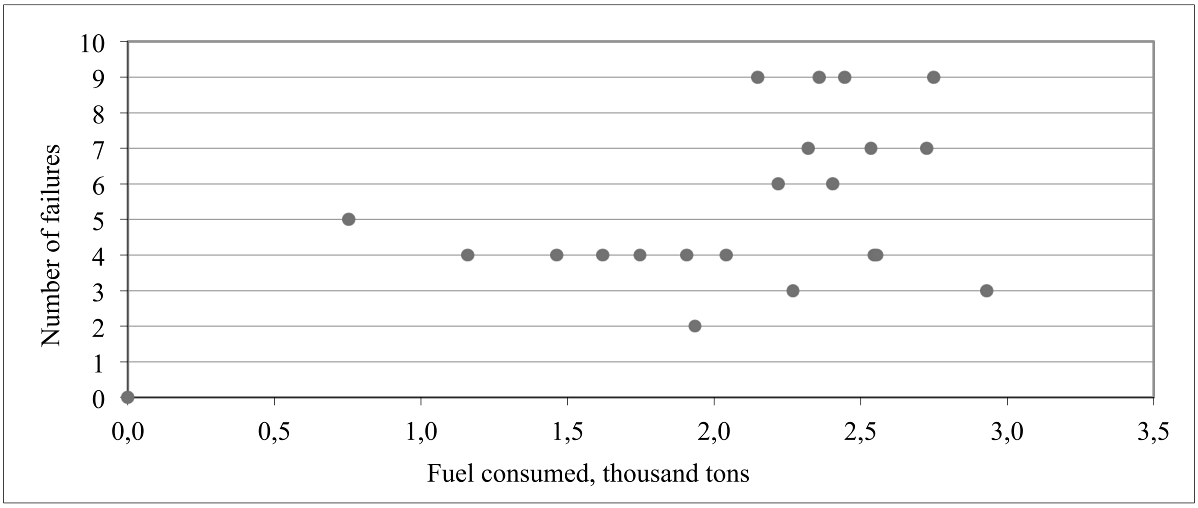

Fig. 3. Distribution of locomotives' failure number according to annual fuel consumption
Rys. 3. Rozkład awarii lokomotyw zgodnie z rocznym zużyciem paliwa

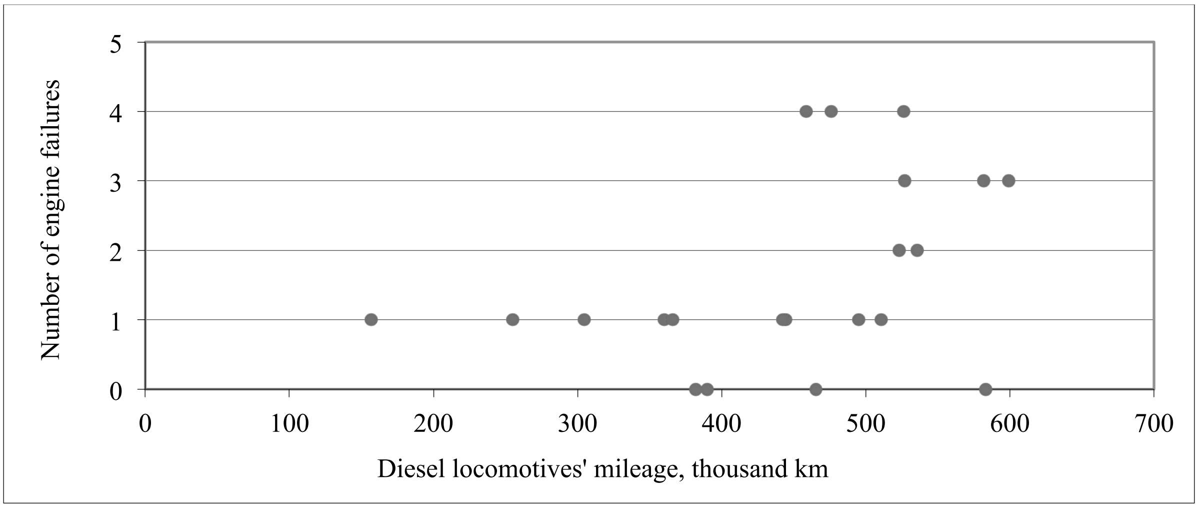

Fig. 4. Distribution of engine failures number according to locomotives' mileage with new engines
Rys. 4. Rozkład liczby awarii silnika zgodnie z przebiegiem lokomotyw z nowymi silnikami

Fig. 4 illustrates the relation of failure number with mileage of locomotives (with new engines). Until the mileage of 400 thousand engine failure number reaches only 1 per year. The figure increases to 4 after the mileage of 450 thousand km. The dependency matches the dependency in pic. 1 however numbers here are twice lower. It is because pic. 4 analyses failure numbers not for all the diesel locomotive, but only for its engine. Later the same order of analysis is being applied as analyzing the dependencies of locomotives' failure number. Distribution of the number of engine failures according to locomotives' turnover is illustrated in fig. 5.

Fig. 5 correlates with fig. 2. Locomotives with annual freight turnover up to 8 billion ton kilometers have failure number of about 1 per year. The locomotives with freight turnover over 8 billion ton kilometers have higher annual engine failure rate from 1 to 4. Based on data of pictures 4 and 5, locomotive engine failure free operation density dependencies can be made (using the structure of (1) formula). Number of failures has to be associated with the parameters that describe the run-in of locomotive engines, such as run-in by hours or by consumed fuel. Distribution of number of engine failures according to consumed fuel is illustrated in fig. 6.

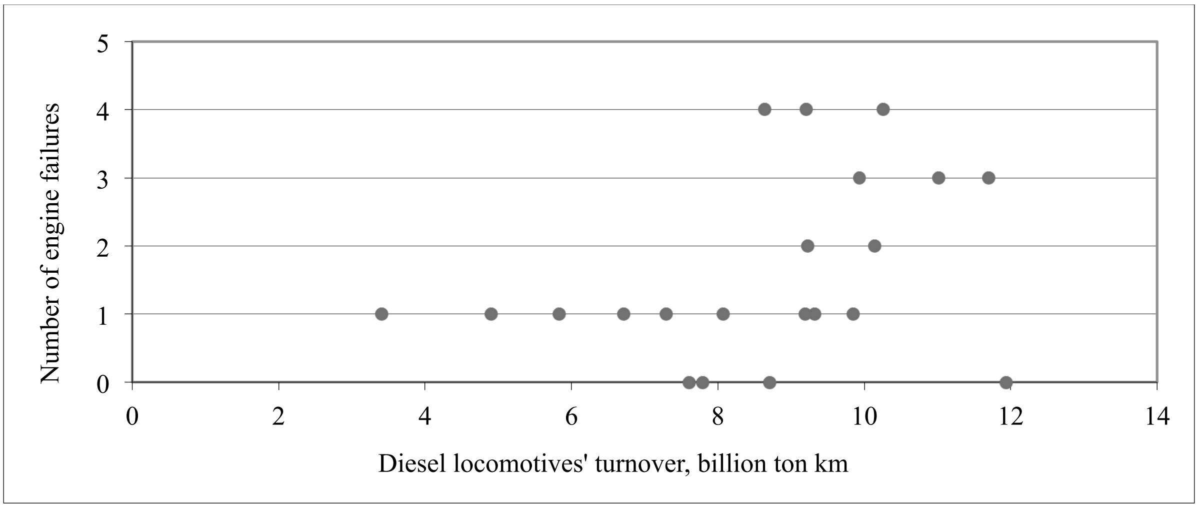

Fig. 5. Distribution of the number of engine failures according to locomotives' turnover
Rys. 5. Rozkład liczby awarii silnika zgodnie z obrotem lokomotyw

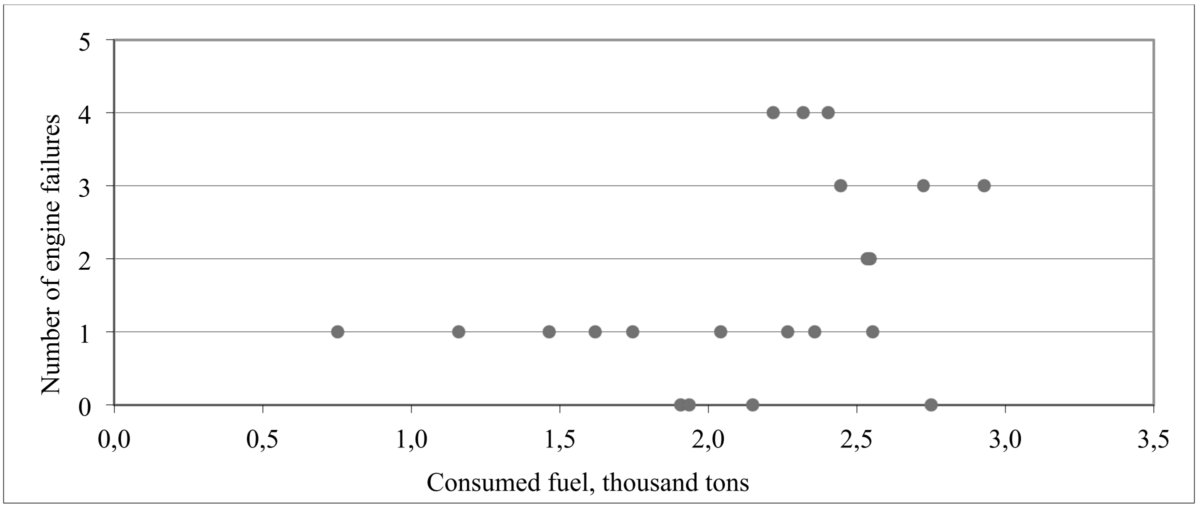

Fig. 6. Distribution of number of engine failures according to consumed fuel
Rys. 6. Rozkład liczby awarii silnika zgodnie ze zużyciem paliwa

It is evident that the regularity in fig. 6 is almost the same as the regularities in pictures 4 and 5. Diesel locomotives that consume over 2 000 tons of fuel a year have a failure rate of 4 per locomotive a year.

To summarize the regularities of pictures 1–6, a good inter-correlation of locomotives' mileage by km, freight turnover ton km and consumed fuel can be seen, because failure rate regularities according to all these factors are equal. Therefore, engine failure part compared to total number of failures has to be similar or slightly vary. However, this needs to be changed. Fig. 7 illustrates the dependency of engine failure percentage on locomotives' annual mileage.

Analyzing the distribution of engine failure percentage compared to the total number of diesel locomotive failures according to locomotives' mileage, engine failures until the mileage of 350 thousand km account for less than 30% of all locomotive failures. After the mileage of 350 thousand, the figure increases to 70%, in some cases up to 100%. Considering the nature of previous dependencies, other dependencies (from ton km or from fuel consumption) can be expected to be similar. The percentage of engine failures compared to total number of locomotive failures according to locomotive turnover is illustrated in fig. 8.

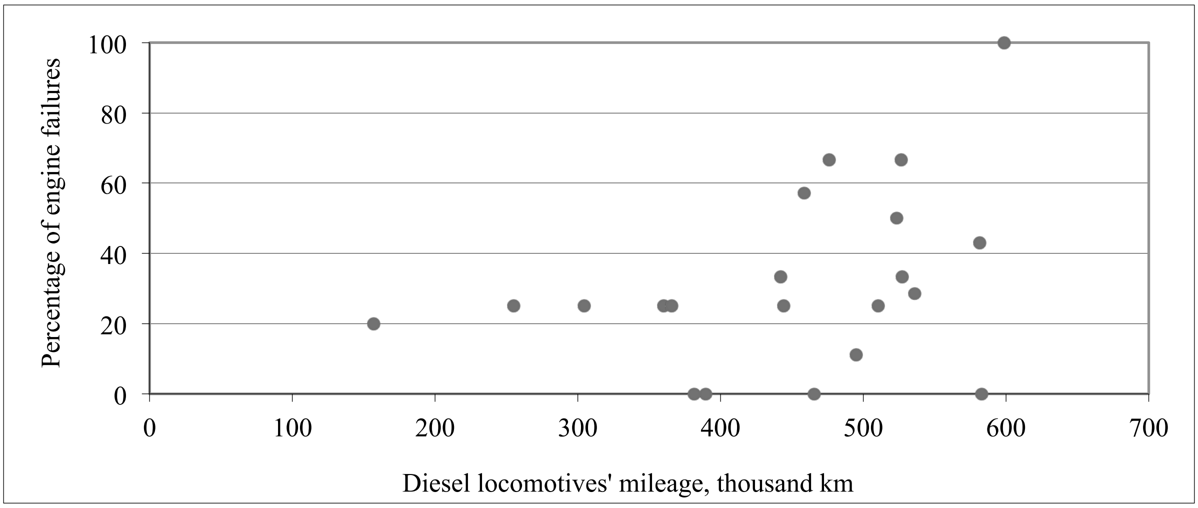

Fig. 7. The dependency of engine failure percentage on locomotives' annual mileage
Rys. 7. Zależność procentowa awarii silnika w rocznym przebiegu lokomotyw

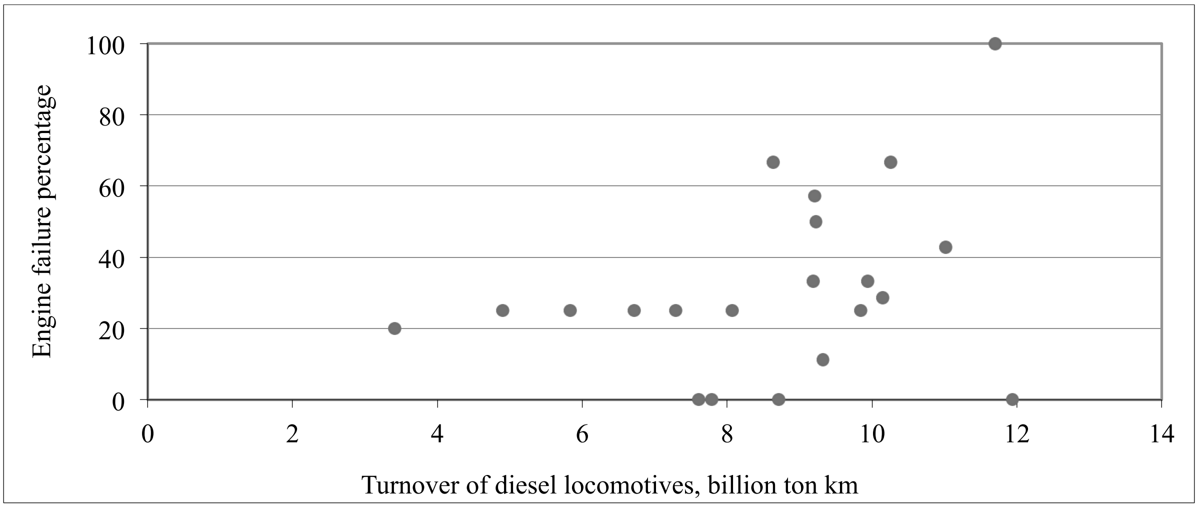

Fig. 8. The percentage of engine failures compared to total number of locomotive failures according to locomotive turnover
Rys. 8. Procentowe porównanie awarii silnika z całkowitą liczbą awarii lokomotywy zgodnie z przebiegiem

Engine failure percentage (from locomotive failure number) of diesel locomotives with freight turnover over 8 billion ton km is several times higher than those of locomotives with freight turnover until 8 billion ton km. Fig. 9 illustrates engine failure percentage from total locomotive failure number according to consumed fuel.

The highest percentage of engine failures when 2 000 tons of consumed fuel is reached increases from 30% to 70% or 100%.

As the number of locomotive failures and their engine failure number changes according to mileage, turnover and consumed fuel, so there is good correlation between mileage, turnover and fuel consumption. It means that locomotive operational conditions in this respect are similar: mileage corresponds to certain turnover and respective fuel consumption. Consequently, it would be correct to understand distribution of failure stream (either of locomotives or their engines) according to the mentioned factors as the failure number change of an average statistical diesel locomotive when these factors change. In this case the average number of failures should be used. Based on this average number, failure free operational probability and its density in respect to all these three factors can be calculated. When reliability of engines is examined, the dependence of engine failure probability on consumed fuel proves to be significant. Consumed fuel reflects the work performed by an engine (the work here is understood as physical value). The change of engine failure probability density according to consumed fuel is illustrated in pic. 10. Probability density is calculated by formula [4]:

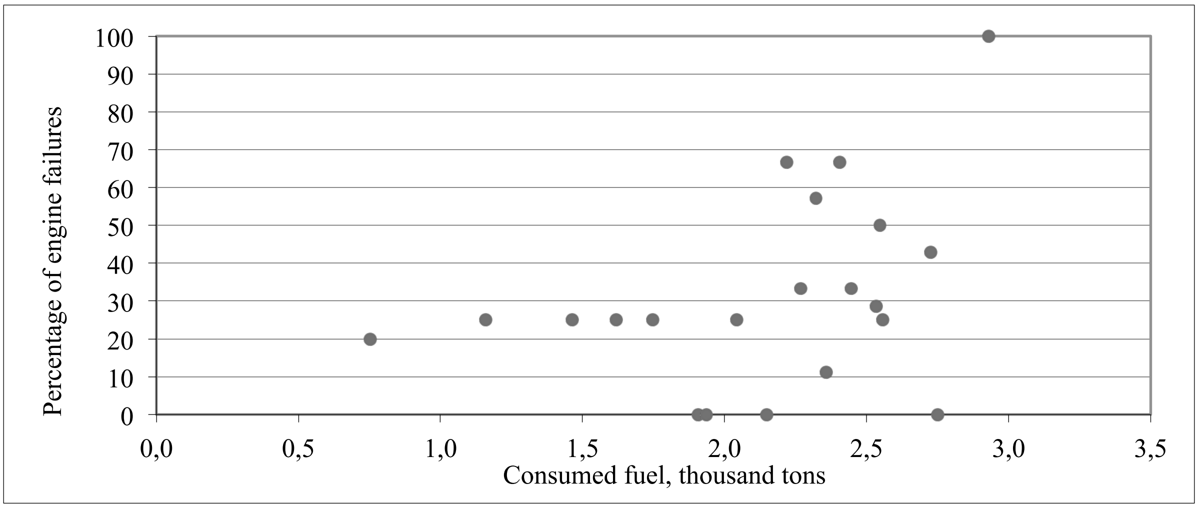

Fig. 9. Engine failure percentage from total locomotive failure number according to consumed fuel
Rys. 9. Procentowe awarie silnika w całkowitej liczbie awarii zgodnie ze zużytym paliwem

$$P_i = \frac{\sum N_{fi}}{\sum N_{ti} \cdot \Delta G_{fuel}}, \quad (2)$$

here: ΔG_{fuel} – consumed fuel during researched operational interval, t.

Density of engine failure probability is measured by t^{-1}.

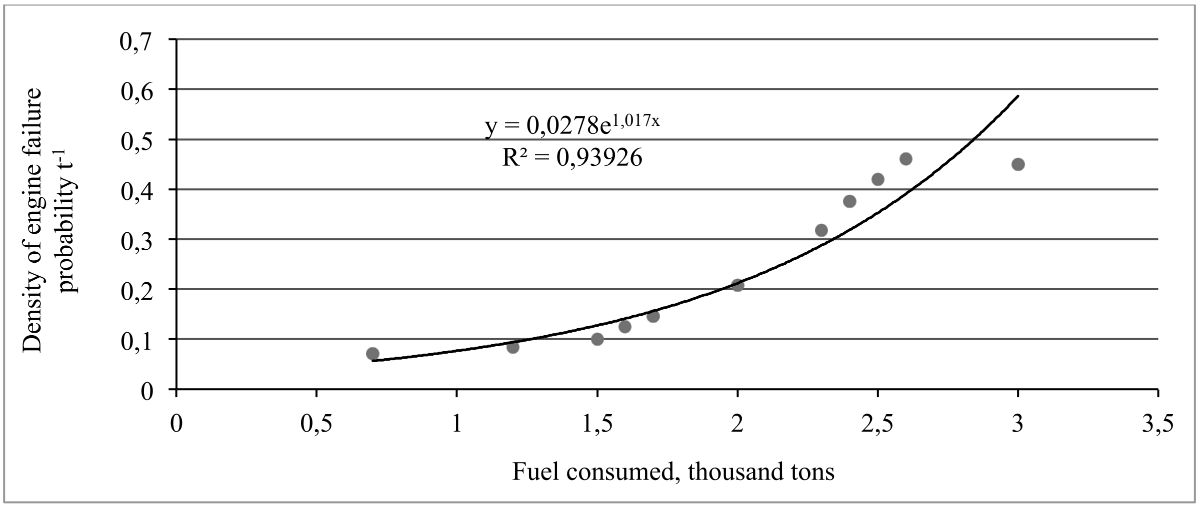

Fig. 10. The change of engine failure probability density according to consumed fuel
Rys. 10. Zmiana gęstości prawdopodobieństwa awarii silnika zgodnie ze zużytym paliwem

When integrating the change function of engine failure probability density according to consumed fuel, engine failure probability in the researched interval of consumed fuel can be calculated [4]:

$$P = \int_{G_{fuel\_1}}^{G_{fuel\_2}} p_i \cdot dG_{fuel} \,. \qquad (3)$$

The space under the curve in graph 10 shows engine failure probability. The density of engine failure probability according to consumed fuel can be regarded as one of the indicators of engine reliability. This indicator according to its mathematical structure can be regarded as reliability indicator and defines reliability of an engine according to physical meaning.

4. CONCLUSIONS

1. Having examined possible influence of various factors on the number of engine failures, it is evident that the factor that has crucial influence is the **run-in** of an engine. It can be expressed by the age of an engine (e.g. years), by mileage of a diesel locomotive (with a new engine), by turnover or by consumed fuel.
2. As the number of locomotive failures and their engine failure number changes according to mileage, turnover and consumed fuel, it seems that operational conditions of diesel locomotives in this respect are similar: mileage corresponds to certain turnover and respective fuel consumption.
3. If operational conditions of diesel locomotives are similar, it is totally correct to perceive the distribution of failure source according to mileage, turnover and consumed fuel as the change of failure number of a statistical diesel locomotive when these factors change.
4. The density of engine failure probability according to consumed fuel can be regarded as one of the indicators of engine reliability. This indicator according to its mathematical structure can be regarded as reliability indicator and defines reliability of an engine according to physical meaning.

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