ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1217257

CHARACTERISTIC FEATURES OF THE RELATION BETWEEN MOTOR TRUCK MILEAGE AND ENGINE CUBIC CAPACITY

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Abstract

The motor vehicle operation process results in a growth in the vehicle mileage and the rate of this growth is usually characterized by specifying the value of this mileage (in km) calculated per a time unit (month, year, etc.). In this paper, the relation between the specific mileage (km per a time unit) of a motor truck and the engine capacity category has been analysed. Results of calculations based on the observation of the mileage of over 3 600 motor trucks of more than 3 500 kg gross vehicle mass (GVM) have been presented.

In the analysis, intervals of equal width were adopted in which the mileage values (in km) were grouped. The percentage of the vehicles whose monthly mileage values belonged to the i^{th} interval was calculated. The resulting set of k discrete values of the percentage of the vehicles with predefined mileage was approximated by a polynomial. The approximation functions are polynomials of the fifth or sixth degree. The curves representing such functions very well describe the distribution of values of the mileage of motor vehicles with engines of over 10000 cm^3 capacity.

A characteristic feature of the calculated distributions of vehicle mileage values is the fact that the location of the areas of predominating mileage values strongly depend on the engine capacity. The highest values of the monthly mileage of motor trucks with engines of up to 5 000 cm^3 capacity do not exceed 9 500 km and increase to 12 500 km for trucks with engines whose capacity exceeds 12 000 cm^3. Based on the profiles of the approximation functions, it has been found that the mileage values corresponding to the first mode of these functions decline with increasing engine capacity values. Simultaneously, a decrease can be observed in the percentage of the vehicles with short mileage with a growth in the engine capacity values. Conversely, the motor truck mileage values corresponding to the second mode of the approximation functions markedly increase with growing engine capacity values. An increase can also be seen in the percentage of the trucks with long mileage in the group of vehicles with engines of over 10000 cm^3 capacity.

Keywords: *motor trucks, mileage, engine capacity*

1. Introduction

A consequence of the high rate of growth in the road transport of goods is intensive development of the fleet of motor trucks. The basic directions of this development include:

– raising the efficiency of transport facilities,
– reducing the energy consumption during road transport,
– improving the safety in road transport.

The measures of these indicators are often considered in relation to the mileage (specified in km) of the motor vehicles because the mileage is a quantitative measure of the vehicle presence in the road traffic and in the transport of goods. The motor vehicle mileage values are a basis for the planning of transport activities and for the cost estimation. The vehicle mileage is considered from the point of view of insurance risk [5, 8], exhaust emissions [4, 7, 14], or vehicle operation costs [12]. In this field, works dealing with the operation of motor cars predominate [4, 5, 7, 12]. Participation of motor trucks in the road traffic does not only mean the fulfilment of transport tasks. Negative effects of the development of road transport of goods are also considered, which include external costs, i.e. exhaust emission effects and high fatality of road accidents [1, 10].

In this study, a vehicle group has been analysed that includes motor trucks of more than 3 500 kg gross vehicle mass (GVM), referred to as heavy goods vehicles (HGV). The analysis does not cover special vehicles.

The objective of this work was to characterize and to estimate in quantitative terms the distribution of the vehicle mileage value (in kilometres) depending on the vehicle engine capacity. In this estimation, several categories of the capacity of automotive engines were to be taken into account. Based on the data collected, answers were sought to several current questions:
– What specific mileage values (in kilometres) predominate now in the operation of motor vehicles?
– Do these mileage values depend on the vehicle engine capacity?

The motor vehicle operation process results in a growth in the number of kilometres travelled. An analysis of this process should be based on the results of observation of a large number of vehicles.

The basic unit of time account adopted in this work is a month and the vehicle mileage is specified in kilometres per month (km/m). Such a period is taken as a basis for the analysis of work efficiency at transport companies and, as well, in specialist business studies and reports [6] and in scientific research [8, 12].

According to report [11], motor trucks more than 20 years old practically cannot be met on roads and their share in the goods transport work is 0.5 percent. Publication [2] presents results of observation of 500 motor trucks in respect of their roadworthiness. These observations show that motor vehicles with short operation period predominate in the road traffic; in the group of vehicles of more than 3 500 kg GVM, the vehicles 10 and more years old were found to make as little as 11 % of the total.

Motor trucks are selected according to the transport tasks planned. There are many factors of considerable importance for the vehicle selection, such as load capacity, unladen mass, fuel consumption, or engine capacity. They are interrelated and, in the manufacturer's product setting-up process, a change in one of them may affect the values of the others. The further analysis has been done with making use of the fact that the engine capacity is one of the parameters that have an impact on the power output and fuel consumption and, indirectly, on the transport capabilities of the vehicle [3, 9].

2. Calculation method and characterization of the dataset

The vehicle mileage values (in kilometres) were collected on the grounds of many information sources in the years 2010-2014. Over 3 600 vehicles were taken into consideration, which had been operated for not more than 20 years.

At the analysis of the dataset, k intervals were adopted, in which the monthly mileage (PM) values (in kilometres per month, i.e. [km/m]) were grouped: 0-999 km/m, 1 000-1 999 km/m, 2 000-2 999 km/m, and so on, up to 14 999 km/m, with the interval width being treated as approximately equal to 1 000 km/m.

Intervals about 500 km/m wide, i.e. 0-499 km/m, 500-999 km/m, 1 000 -1 499 km/m, 1 500-1 999 km/m, 2 000-2 499 km/m, and so on, were also considered. The selection of the interval width should facilitate the revealing of characteristic features (properties) of the distribution of the PM values. This leads to a compromise, because:
– an increase in the interval width results in a reduction in the number of the intervals, i.e. in a reduction in the vehicle groups,
– a reduction in the interval width results in a growth in the number of the intervals and causes the PM values to be dispersed among more vehicle groups.

The percentage of the number of vehicles whose monthly mileage values belonged to the i^{th} interval was calculated as follows:

$$p_i = \frac{n_i}{\sum_1^k n_i} 100\%, \tag{1}$$

where:
n_i – number of vehicles whose monthly mileage values belonged to the i[th] interval.

Based on the dataset, the mean monthly mileage value was calculated for each i[th] interval and denoted by L_i. Then, the PL_i value, i.e. the value of the averaged mileage of the vehicles classified in the i[th] interval, was calculated as follows:

$$PL_i = 0.01\, L_i\, p_i . \tag{2}$$

The set of k values of the percentage p_i (*PM*) was approximated by a function:

$$y = f_a(x), \tag{3}$$

where x corresponds to the PM values and y corresponds to the percentage of the vehicles whose monthly mileage values are equal to the specific PM value. The approximation function f_a is here a polynomial whose coefficients were determined with the use of the least square method. The characteristic values of the following function were also determined:

$$y_i = f_a(PS_i), \tag{4}$$

where:
PS_i – median of the i[th] interval.

As an example: for the 1 000-1 999 km/m interval, we have PS_i = 1 499.5 km/m. In this interval, 291 vehicles were classified and the mean value of their monthly mileage is L_i = 1 519 km/m. The quality of the approximation was assessed on the grounds of the coefficient of determination R^2 and the difference:

$$\Delta p = \frac{1}{k}\sum_{i=1}^{k}(y_i - p_i). \tag{5}$$

At the stage of assessment of the quality of the calculation results obtained, the following mean value estimators were also used:

$$\overline{p} = \frac{1}{k}\sum_{i=1}^{k} p_i \;, \qquad \overline{y} = \frac{1}{k}\sum_{i=1}^{k} y_i, \tag{6}$$

$$\overline{L} = \frac{1}{k}\sum_{i=1}^{k} L_i \;, \qquad \overline{PL} = \frac{1}{k}\sum_{i=1}^{k} PL_i. \tag{7}$$

These values were separately calculated for each category of engine capacity. Table 1 shows brief characteristics of about twenty motor truck makes and models taken as an example from among those covered by the dataset under analysis. For some of these vehicles, the data presented apply to truck-tractor versions as well.

Tab. 1. Motor trucks present in the Polish market, GVM exceeding 3 500 kg

Engine capacity category [cm^3]	Motor truck makes and models	GVM [kg]	Engine capacity [cm^3]
2 000-4 999	MERCEDES-BENZ 508 D, 515 CDI Sprinter, 814, Atego; IVECO EUROCARGO; MAN M2000, TGL	4 600; 5 000; 6 000; 7 500; 10 000; 12 000	2 148; 3 908, 3 920; 4 249; 4 250; 4 580
5 000-9 999	IVECO EUROCARGO, Stralis, ML, ML180; MERCEDES BENZ 1114…1320, Atego 2; MAN TGL; VOLVO FL, FE, FM	8 000; 12 000; 13 000; 16 000; 18 000; 20 000	5 880; 5 958; 6 374; 6 871; 7 146; 9 364; 9 603
10 000-11 999	MAN TGA, TGX, TGS; SCANIA 114, 124, R380, 124/420, 124/470, R420; R480; RENAULT Premium, Premium Route; MERCEDES BENZ Actros, Axor	18 000; 18 600; 19 000; 25 000; 26 000	10 300; 10 308; 10 318; 10 518; 10 520; 10 600; 10 635; 10 640; 10 837; 11 100; 11 116; 11 700; 11 705; 11 946; 11 967
Over 12 000	VOLVO FH12, FH16, FH400, FH440, FH480, FH500; DAF XF95, XF 105; SCANIA R440, R480, G440; RENAULT Magnum; MAN F2000, TG, TGA; IVECO Stralis	18 000; 18 100; 18 600; 19 000; 26 000	12 100; 12 130; 12 771; 12 777; 12 780; 12 580; 12 740; 12 777; 12 780; 12 816; 12 880; 12 882; 12 895; 12 902

Results of grouping the mileage values and calculation of the percentage distribution of the vehicles among $k = 16$ mileage intervals have been shown in Fig. 1.

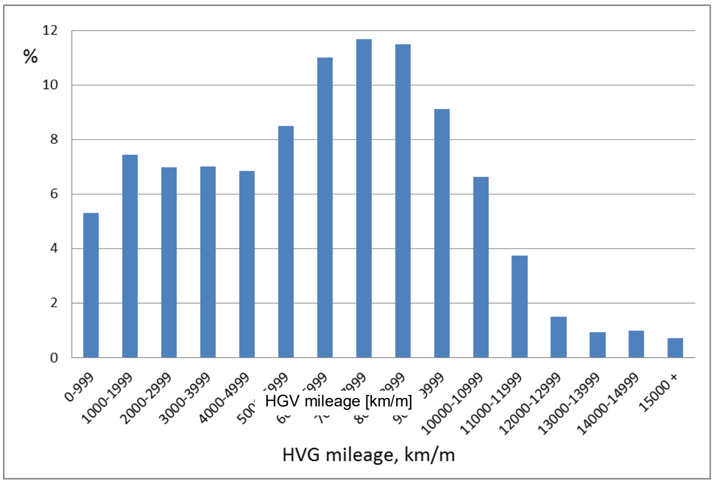

Fig. 1. Percentage vehicle distribution among successive monthly mileage (PM) intervals

The percentage distribution presented in Fig. 1 shows that the PM values are chiefly concentrated within the range of 6 000-8 999 km/m, where as many as 34.19 % vehicles taken together have been classified. The greatest number, i.e. 456 vehicles, fell inside the 7 000-7 999 km/m interval. The mean number of vehicles per one interval 1 000 km/m wide is 244 motor trucks. The mean PM value on the whole dataset is 6 521.9 km/m. The number of vehicles whose monthly mileage exceeded 15 000 km/m was also determined; it made 0.72 % of the total and was the smallest one among those determined for all the mileage intervals.

3. Engine capacity versus monthly mileage

The relation between the mean monthly mileage of a vehicle and the engine capacity, being the subject matter of this analysis, is a generalization, which helps to systematize the monthly vehicle mileage values by assigning them to a few categories and subcategories of engine capacity. With this end in view, the set of heavy goods vehicles (HGVs) under consideration was divided into subcategories, depending on their engine capacity values (in cm^3), i.e. 2 000-2 999 cm^3, 3 000-3 999 cm^3, 4 000-4 999 cm^3, and so on. Then, the number of the vehicles counted in each subcategory was determined. For the subcategories where 100 or more HGVs were counted, the mean values *L* and standard deviation values *STD* of the monthly mileage were calculated. The mean mileage values thus determined are represented by points in Fig. 2. These points provide a basis for establishing a model of the relation between the monthly mileage of an HGV and the capacity of its engine. This relation was represented by a linear model:

$$L = 0.3813V + 2374.8 \text{ [km/m]}, \tag{8}$$

where:
V – engine capacity value within the range of 2 000-12 999 cm^3.

The value of the coefficient of determination of this regression function is high, amounting to $R^2 = 0.9704$.

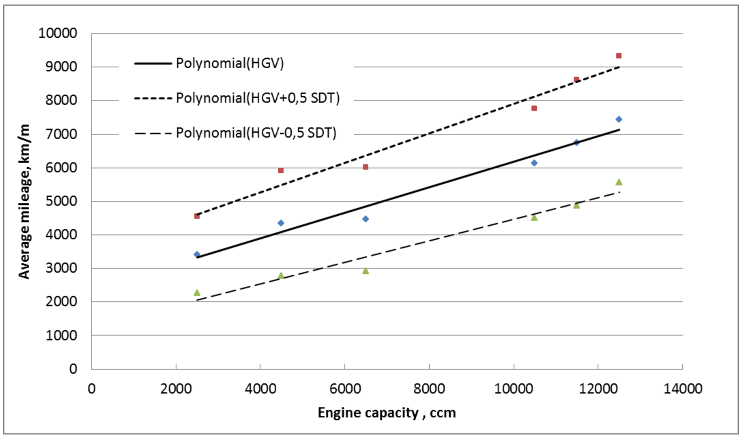

Fig. 2. Relation between engine capacity and vehicle mileage

The configuration of points in the graph in Fig. 2 facilitated the separation of several engine capacity categories, denoted as follows:

S2 – HGVs with engines of capacity within the range of 2 000-4 999 cm^3,
S5 – HGVs with engines of capacity within the range of 5 000-9 999 cm^3,
S10 – HGVs with engines of capacity within the range of 10 000-11 999 cm^3,
S12 – HGVs with engines of capacity equal to or exceeding 12 000 cm^3.

The dataset was divided into four categories as defined above and the data in each category were arranged in ascending order of the vehicle mileage values. The numerical series thus obtained were subjected to a further analysis. For each category, calculations were carried out to determine the percentages p_i of the numbers of vehicles whose PM (monthly mileage) values belonged to individual intervals, according to equation (1). The mileage classification presented in Fig. 3 has been based on intervals whose width was 500 km/m.

Individual bars in the graphs in Fig. 3 show the percentage distribution of the numbers of vehicles according to the monthly vehicle mileage values. An attempt was also made to formulate a computational description of this distribution with the use of the approximation function (3) for each engine capacity category. The approximation function models adopted have been presented in

Table 2. The curves representing the approximation functions in Fig. 3 were selected according to the criterion of the maximum value of the coefficient of determination R^2.

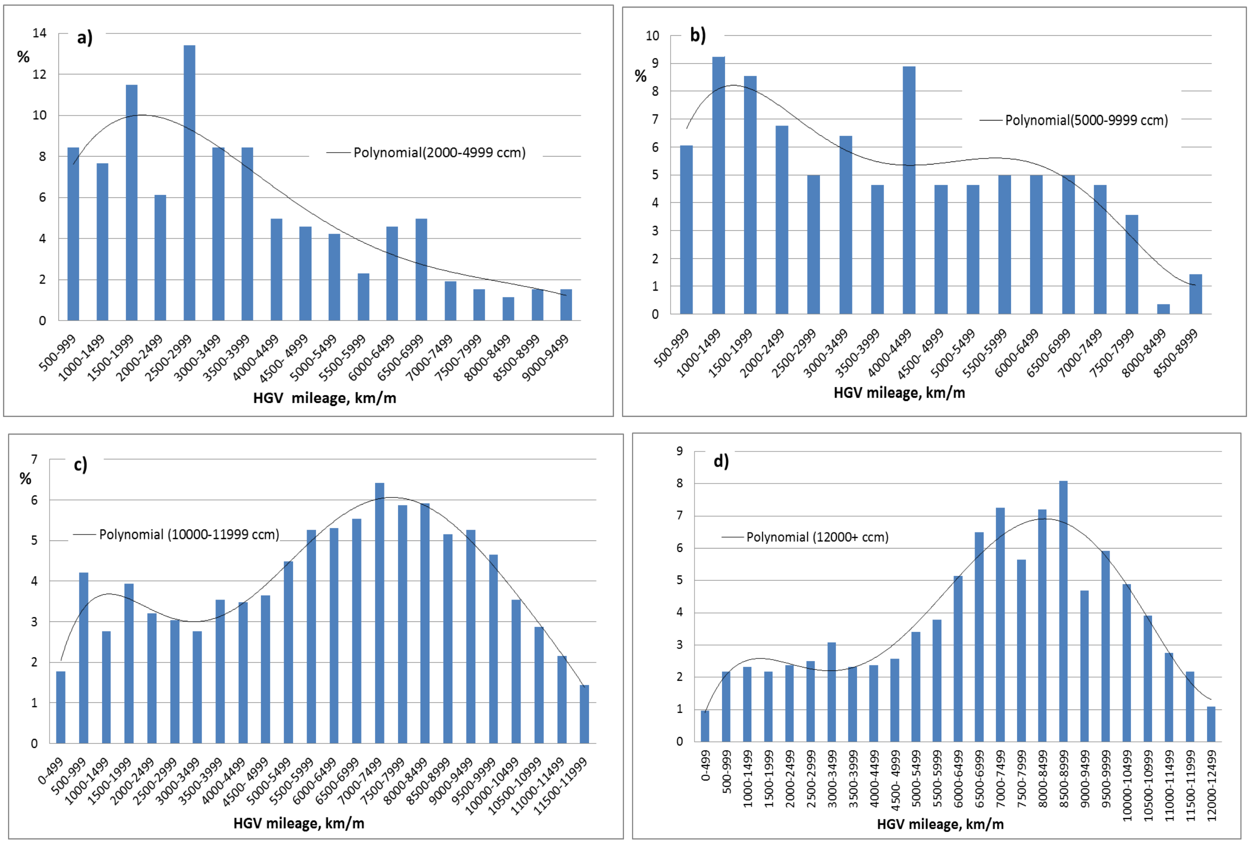

Fig. 3. Distribution of the percentage p_i of the numbers of vehicles among individual monthly mileage intervals: a) vehicles of category S2; b) vehicles of category S5; c) vehicles of category S10; d) vehicles of category S12

Tab. 2. Models of the distribution of the monthly vehicle mileage values: x – monthly mileage [km/m]; y – percentage of the vehicles

Engine capacity category	Equation representing the model of the distribution of the monthly vehicle mileage values	R^2	PM range [km/m]
S2	$y = 1E\text{-}18x^5 - 4E\text{-}14x^4 + 6E\text{-}10x^3 - 4E\text{-}06x^2 + 0.0096x + 2.4419$	0,7722	750-9 500
S5	$y = 1E\text{-}17x^5 - 2E\text{-}13x^4 + 2E\text{-}09x^3 - 9E\text{-}06x^2 + 0.0151x - 0.4075$	0,7314	750-9 000
S10	$y = -2E\text{-}22x^6 + 9E\text{-}18x^5 - 1E\text{-}13x^4 + 1E\text{-}09x^3 - 4E\text{-}06x^2 + 0.0056x + 0.8818$	0,9364	250-12 000
S12	$y = 2E\text{-}18x^5 - 5E\text{-}14x^4 + 6E\text{-}10x^3 - 2E\text{-}06x^2 + 0.0042x + 0.0253$	0,9061	250-12 500

The approximation functions are polynomials of the fifth or sixth degree. The curves that represent such functions well (for categories S2 and S5) and very well (for categories S10 and S12) describe the percentage distribution of the vehicle mileage values within the PM range having been determined. This range has been specified in Table 2 and it covers all the distribution values that exceed 1 %.

4. Analysis of calculation results

A characteristic feature of the calculated distributions is the diversified location of the areas of predominating monthly vehicle mileage values, depending on the category of engine capacity.

One or two such areas may be marked out and their widths have been given in Table 3, based on the profile of the curve representing the approximation function for every category of engine capacity.

Tab. 3. Areas of predominating monthly vehicle mileage values PM and percentage p_i of the vehicles of individual categories

	Mode in the area of low monthly mileage values		Mode in the area of high monthly mileage values	
Engine capacity category	Range of the predominating monthly mileage values [km/m]	Percentage p_i of vehicles falling in the range of the predominating monthly mileage values [%]	Range of the predominating monthly mileage values [km/m]	Percentage p_i of vehicles falling in the range of the predominating monthly mileage values [%]
S2	1 000-2 999	38.70	Mode does not exist	
S5	1 000-2 499	24.56	5 000-6 499	14.59
S10	1 000-2 499	9.91	6 500-8 499	23.75
S12	Mode not very well visible		7 000-9 499	32.88

In the group of HGVs with engines classified in category S2, there is a significant number of vehicles (38.70 %), for which the monthly mileage values are relatively low (1 000-2 999 km/m). They may be the vehicles used for local goods distribution jobs, with daily mileage of 50-150 km. In this category, a subgroup can be noticed (making 9.58 %, visible in the bar graph only), whose monthly mileage values fall within the range of 6 000-6 999 km/m. This subgroup may consist of, say, vehicles operated by courier companies or vehicles used for express deliveries of low-mass parcels, e.g. for the transport of medicines, perishable food, flowers, etc. For the vehicles belonging to category S5, two ranges of the predominating monthly mileage values were marked out, i.e. 1 000-2 499 km/m and 5 000-6 499 km/m. The mode within the range of low PM values covers a wide group of vehicles, i.e. 24.56 % of the total number of vehicles of this category. In contrast, the noticeable range of the monthly mileage values corresponding to the second mode covers a relatively low number (14.59 %) of vehicles of this category.

In category S10, there are 9.91 % of vehicles whose monthly mileage values fall within the range of 1 000-2 499 km/m. In other words, this range of low monthly mileage values covers a relatively low number of vehicles. On the other hand, the group of vehicles for which the monthly mileage values (PM) are within the range of 6 500-8 499 km/m is well visible (it makes 23.75 % of the total). In category S12, the group of vehicles whose monthly mileage values are low, i.e. of up to 2 000 km/m, is quite small (7.64 % of the total). The vehicles belonging to the group that predominates in this category of engine capacity (making 32.88 % of all the vehicles) achieves monthly mileage values within the range of 7 000-9 499 km/m.

With increasing engine capacity, a decrease can be observed in the number of vehicles with low monthly mileage values while the number of vehicles with high monthly mileage values is growing (Table 4). The monthly vehicle mileage values increase with growing engine capacity. The biggest mileages of the S2 category vehicles reach a level of 9 500 km/m, which rises to 12 500 km/m for vehicles of the S12 category.

Tab. 4. Percentage of the vehicles whose monthly vehicle mileage values PM do not exceed 1 000 km/m or are higher than 10 000 km/m

Category	Percentage of the vehicles whose PM values do not exceed 1 000 km/m	Percentage of the vehicles whose PM values exceed 10 000 km/m
S2	8.43	2.68
S5	10.32	2.49
S10	5.98	10.19
S12	3.15	14.64

Characteristic changes in the distributions of the monthly mileage values have been shown in Fig. 4, with making use of the extreme values of the function that approximates the percentage distribution of the vehicles among successive intervals of the PM values.

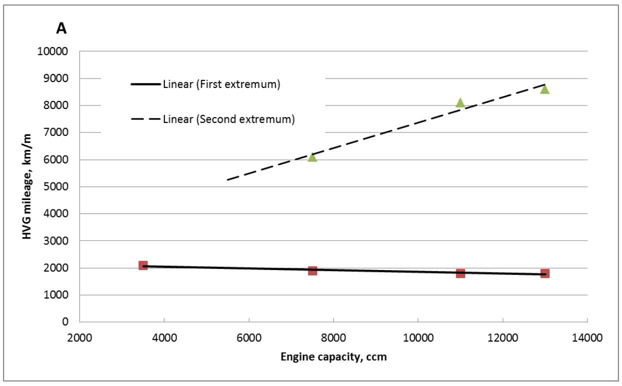

Fig. 4a. Relation between the predominating monthly vehicle mileage values and the vehicle engine capacity values, determined from the approximation functions (Table 2)

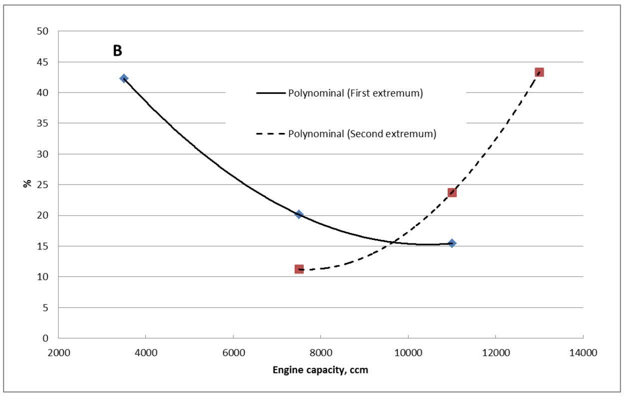

Fig. 4b. Relation between the percentage p_i of the vehicles with predominating monthly mileage values, according to Table 3, and the vehicle engine capacity values

Based on the profiles of the approximation functions, the following findings have been formulated:

– The monthly mileage (PM) values corresponding to the first mode of the approximation functions slightly decline with increasing engine capacity values (Fig. 4a). Simultaneously, a decrease can be observed in the percentage of the vehicles with short mileage with a growth in the engine capacity values (Fig. 4b, solid line).

– The PM values corresponding to the second mode of the approximation functions markedly increase with growing engine capacity values (Fig. 4a). An increase can also be seen in the percentage of the trucks with long mileage in the groups of vehicles of categories S10 and S12 (Fig. 4b, dotted line).

Tab. 5. Summary of the mean values

Category	Mean value $\overline{L}$ [km]	Mean value $\overline{PL}$, based on p_i [km]	Mean value $\overline{p}$, from the percentage [%]	Mean value $\overline{y}$, from the model of the regression function [%]	Mean value of the difference between the model and the actual percentage, Δp [%]
S2	3838	3767	5.407	5.453	0.046
S5	4132	4156	5.275	5.243	−0.032
S10	6515	6472	4.137	4.030	−0.107
S12	7411	7330	3.812	3.810	−0.003

The assessment of the quality of results of the statistical calculations and approximation has been based on the following indicators:

– consistency of the mean value of vehicle mileage $\overline{L}$ and $\overline{\overline{PL}}$,
– consistency of the mean value from the percentage distribution $\overline{p}$ and $\overline{y}$,
– difference between characteristic values Δp.

High consistency of the mean value of vehicle mileage $\overline{L}$ and $\overline{\overline{PL}}$ has been achieved. In this summary, the $\overline{L}$ values are somewhat higher than the $\overline{\overline{PL}}$ values because the $\overline{\overline{PL}}$ calculations were done with disregarding the mileage values the percentage of which was below 1 %. The conspicuous high degree of consistency of the $\overline{p}$ and $\overline{y}$ values and the very low Δp values indicate that the approximation functions having been formulated adequately represent the percentage distribution of the monthly vehicle mileage values for all the engine capacity categories.

5. Recapitulation and conclusions

The distribution of the numbers of kilometres travelled by heavy goods vehicles (HGVs) during a one-month vehicle operation period was analysed. The calculations were based on a set of mileage values collected for over 3 600 motor trucks of more than 3 500 kg gross vehicle mass (GVM). In the analysis, intervals of equal width were adopted in which the mileage values (in km) were grouped. The percentage of the vehicles whose monthly mileage values PM belonged to the i^{th} interval was calculated. The resulting set of k discrete values of the percentage of the vehicles with predefined mileage was approximated by a polynomial of the fifth or sixth degree.

A characteristic feature of the calculated distributions of vehicle mileage values is the fact that the location of the areas of predominating mileage values depends on the engine capacity categories. The shape of the curves representing the approximation functions identifies one or two such areas and their widths have been specified in Table 3 for each category of engine capacity. Based on this, the following findings have been formulated:

– In the group of HGVs with engines of up to 5 000 cm^3 capacity, as many as 38.70 % of the vehicles travel 1 000-2 999 km a month.
– In the same category, a subgroup can be noticed (9.58 %), in which the vehicles travel 6 000-6 999 km a month, e.g. as being operated by courier companies or being used for express deliveries of low-mass parcels.
– In the category of HGVs with engines of 10 000-11 999 cm^3 capacity, the group of vehicles monthly travelling 6 500-8 499 km predominates, making 23.75 % of the total.
– In the category of HGVs with engines of more than 12 000 cm^3 capacity, the vehicles constituting the predominating group (32.88 %) monthly travel 7 000-9 499 km.

The differentiation between the values of mileage of heavy goods vehicles by taking into account the engine capacity categories of specific vehicles shows that the information about the mean mileage value for the vehicles thus grouped is not sufficient because of different areas of predominating mileage values and different rate of occurrence of such values in the said areas.

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