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INTENSITY OF MOTOR TRUCKS OPERATION VERSUS VEHICLES' AGE, IN SEVERAL CATEGORIES OF ENGINE CUBIC CAPACITY

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Abstract

Changes in the vehicle operation process, which take place with vehicle's age, have been analysed on the grounds of data collected for over 3 000 motor trucks of more than 3 500 kg gross vehicle mass (GVM), being now in use in Poland. The analysis has covered a 20-year vehicle operation period (referred to as "service life planned"); the distance travelled by a vehicle during this period has been called "target mileage" (expressed in kilometres). As a measure of the intensity of vehicle operation, the "monthly mileage" has been adopted. The monthly mileage values specified in the article strongly depend on the category of engine cubic capacity. Some important characteristics of the mileage growth process, noticed in the recent years along with an intensive development of the road transport, have been presented. The vehicle mileage growth process has been shown for four categories of engine cubic capacity, on the grounds of regression lines based on a polynomial model.

The vehicles with engines of more than 10 000 cm^3 capacity reach more than 1/3 (i.e. 34.7-36.6%) of their target mileage for the first 60 months of operation, while covering only 2-5.3% of this target mileage during the last two years of their 20-year service life planned. During the first 5 years, the intensity of operation of vehicles belonging to this engine capacity category is four to five times as high as that determined for the last 5 years of the 20-year vehicle operation period under analysis. Calculations carried out have shown that the dataset under analysis includes vehicle categories where 90% of the target mileage is reached as early as after 69-70% of the service life planned. This shows that motor vehicles having been used for a short time predominate in the road transport of goods in Poland and that there is an interrelation between the rates of changes in the vehicle operation intensity and the engine capacity.

Keywords: *motor vehicle operation management, motor truck mileage, intensity of vehicle operation*

1. Introduction

Motor trucks are usually in service for many years. During this time, changes take place in the intensity of vehicle operation and in the scope of the transport jobs performed. The changes are introduced in result of analysing actual vehicle operation costs, reliability, and performance characteristics. Simultaneously, new vehicle models appearing in the market are often characterized by more favourable technical parameters and their operation costs may be lower in comparison with those of the older generations. As a measure of the vehicle operation intensity, the distance travelled by the vehicle during a time unit (month, year, etc.), referred to as "specific mileage" (given in km per a time unit), has been generally adopted. The vehicle operation intensity indicators may be used to manage the motor vehicle fleet and to optimize the fleet operation and maintenance costs. Detailed and up-to-date information about the intensity of operation of motor trucks is not easily available. The numerical data provided in [6] show the highest values of the specific mileage recorded in the second year of vehicle operation. In the next years, the specific mileage values decline and the average rate of this decline in the period of 5 years from the achieving of the peak value of the specific mileage is 5.9% in relation to the mileage recorded in the second year of vehicle operation. In the subsequent years, the vehicle operation intensity declines at gradually lowering rates.

The impact of age on the intensity of operation of motor trucks has also been shown by the research results published in 2006 [12], from which the following specific mileage values can be learnt:

- for age of up to 6 years, the mileage, on the average, is 6 515 kilometres per month (km/m),
- for age of above 16 years, the mileage, on the average, is 2 375 km/m.

According to data reported in [4] and concerning the situation prevailing in Poland in 2006, as much as 24.5% of the vehicles being then in use and classified in the category of heavy goods vehicles (HGV), i.e. motor trucks, including tractor-semitrailer units, with gross vehicle mass (GVM) exceeding 3 500 kg, were not more than 10 years old and performed as much as 76.5% of the total goods transport work done by all the vehicles of this category. The data published in [3], collected during mandatory periodical inspections of 500 motor trucks at Vehicle Testing Stations (VTS), revealed that 89.4% of the vehicles of this category being in use in 2011 were up to 9 years old and the other 10.6% had been operated for 10 or more years.

There are many publications (e.g. [1, 3, 4, 6, 8, 10, 12] where a confirmation may be found that vehicles operated for quite a short time predominate in the transport of goods by road. In many cases, such data are based on the observation of quite a small number of vehicles. However, there is a lack of more detailed information on e.g. the relationship between the specific and total mileage and the engine capacity of vehicles.

The objective of this work is to estimate the changes that take place in the intensity of operation of motor trucks with increasing vehicle operation time, in relation to the vehicle engine capacity. With this objective in view, the HGV mileage values were analysed, without special vehicles being taken into account. In the calculations, several categories of the cubic capacity of vehicle engines were discerned; they have been denoted as follows:

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

The intensity of vehicle operation has an impact on the values of the indicators that characterize the transport system. The knowledge of the indicator values makes it possible to manage the vehicle fleet e.g. by making use of forecasting information such as the target mileage planed and the current-to-target mileage ratio as well as the time of cost-effective use of a specific vehicle [2, 7, 9, 11].

2. Characterization of the dataset

The problem was explored on the grounds of data collected about the motor vehicles being currently operated in Poland. The data were collected in the years 2012-2015 from post-accident documentation of motor trucks or from records of mandatory periodical motor truck inspections carried out at Vehicle Testing Stations (VTS). Detailed identification of the vehicle data was done with the use of catalogues [5]; in a synthetic form, the vehicle data have been presented in Tab. 1. More than 3 000 vehicles in total were taken into account. Results of the initial stage of an analysis of a part of these data have been given in [8], where the relation between specific mileage and engine capacity of motor trucks was examined.

In this article, time is specified in months, which have been adopted as the basic time unit, and the specific vehicle mileage, i.e. monthly mileage in this case, expressed in kilometres per month [km/m], has been denoted by *PM*. The dataset, divided into categories, was arranged in the order of increasing vehicle operation time. The numerical series thus obtained were divided, depending on needs, into 12-month intervals of vehicle operation time. For each interval, the corresponding number of vehicles was determined. For the intervals where at least 50 motor vehicles were grouped, the mean mileage values L_i were calculated.

Tab. 1. Motor trucks in the vehicle set under analysis

Make, model	Engine capacity [cm^3]	GVM [tons]	Make, model	Engine capacity [cm^3]	GVM [tons]
Iveco Turbo Daily	2 499-2 798	4.2-6.0	Volvo FL	5 480-9 600	8.6-18.0
Mercedes-Benz Sprinter/508D	2 299-3 498	4.6-5.0	Mercedes-Benz Actros/184x/185x	11 946-16 000	18.0-32.0
Renault Mascott/B90	2 445-2 953	5.0-6.5	MAN F2000/F90	11 967-18 273	17.0-26.0
Iveco E. Cargo	5 861-7 685	7.5-15.0	Renault Magnum	11 900-16 400	18.0-26.0
Scania 94/P93/P92	8 475-9 000	17.0-26.0	Volvo FM/F16	12 130-16 120	17.0-35.0

In the analysis, the following notation has been adopted:

L_i, P_i – mean total and monthly mileage of the vehicles of the i^{th} interval of vehicle operation time,

P_{sr} – mean value of the monthly mileage, calculated for the total vehicle operation time,

L_{20} – total vehicle mileage after 20 years of vehicle operation,

i – number identifying a consecutive 12-month interval (period) of vehicle operation time, defined as follows: $i = 1$ for 7-18 months, $i = 2$ for 19-30 months, $i = 3$ for 31-42 months, $i = 20$ for 235-246 months,

k_i – number of the vehicles, whose operation time fell within the i^{th} interval,

L_{ik} – mileage of the k^{th} vehicle in the i^{th} interval of vehicle operation time.

The vehicles that had been operated for less than 6 months and for more than 246 months were not taken into account in the dataset. The analysis carried out covered a 20-year vehicle operation period. The total mileage achieved by a vehicle at the end of this period has been called "target mileage".

3. Analysis of the intensity of vehicle operation

3.1. Characterization of the process of growth in the mileage of a motor truck

The intensity of motor vehicle operation changes with vehicle age. An important factor having an impact on these changes is the appearance of vehicle models with new engineering solutions having been introduced. This results in gradual replacement of vehicle fleet by transport companies.

The general nature of the process of growth in vehicle mileage with the years of vehicle operation is known, but interest is aroused by the specific features of this process that have emerged in the recent years with an intensive development of road transport, wide range of vehicles offered in the primary and secondary market, and tough competition between transport companies. The following issues were subjected to the analysis:

– rate of growth in the mileage with vehicle operation years,
– relation between the vehicle mileage growth process and the engine capacity category.

These issues were explored in four engine capacity categories adopted previously.

The vehicle mileage growth process has been shown in Fig. 1 for four categories of engine cubic capacity, on the grounds of regression lines based on a polynomial model:

$$L_R = f(x), \tag{1}$$

where x is the number of months of vehicle operation.

The calculations were made with using the L_i values; the regression function curves are characterized by high values of the coefficient of determination, i.e. $R^2 = 0.94\text{-}0.99$.

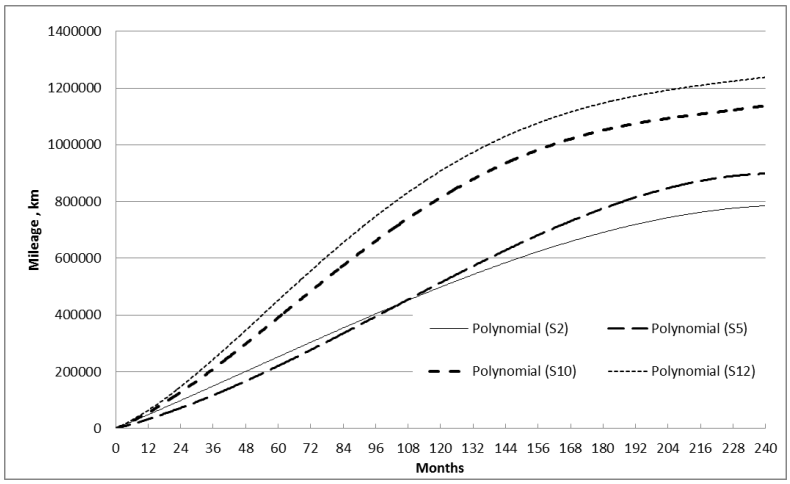

Fig. 1. Growth in the motor truck mileage

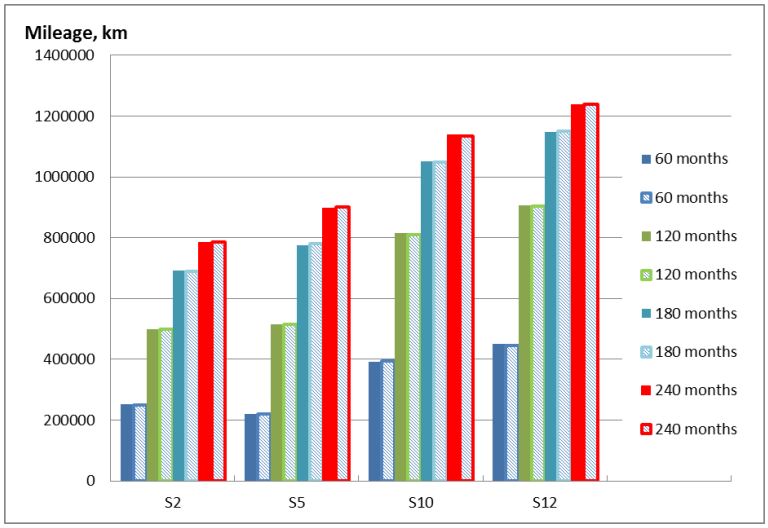

Fig. 2. Summary of the mileage values achieved, by engine capacity categories

Figure 2 shows a graphical summary of the motor truck mileage values achieved after 60 months, 120 months, 180 months, and 240 months of vehicle operation. The mileage values were determined by two methods:

– as L_i values, calculated from the time series for $i = 5$, 10, 15, and 20, represented by full-colour bars,
– as $L_{Ri} = f(12i)$ values, determined from the regression curve, represented by hatched bars.

Both of these calculation methods produced practically identical results.

The values characterizing the process of mileage growth with vehicle operation time, brought together in Tab. 2, were calculated with using the mileage growth curves presented in Fig. 1. The tabulated figures show a high mileage growth rate during the first 60 months of operation of the S10 and S12 vehicles, reaching more than 1/3 (i.e. 34.7-36.6%) of their target mileage within this period, and of the S2 vehicles, which cover 31.8% of their L_{20} mileage during the first 1/4 of the vehicle service life planned. On the other hand, a very low rate of growth in the vehicle mileage can be observed in the last 5 years of the planned vehicle operation period (service life): the vehicles of the S10 and S12 engine capacity categories cover then as little as 7.2-8.7% of their target mileage. This shows that the intensity of operation of such vehicles in this period is reduced to 1/4 (for the S10 category) or even 1/5 (for the S12 category) of that observed in the initial period. For the S2 vehicle category, this ratio of reduction in the intensity of vehicle operation is 1/2.2.

For the S5 category vehicles, far smaller changes in the intensity of vehicle operation are observed with increasing vehicle age. In the initial period, the distance travelled is proportional to the vehicle operation time (24.6% of the target mileage covered during the first 25% of the vehicle service life planned) and the intensity of vehicle operation during the last 5 years is 0.7 of that observed in the initial period.

Tab. 2. Characteristic vehicle mileage values, in% of L_{20}, covered with growing vehicle operation time, for various categories of vehicle engine capacity

Vehicle operation time [months]	S2	S5	S10	S12
24	12.7	8.7	12.5	13.3
60	31.8	24.6	34.7	36.6
120	61.7	54.7	69.6	72.0
180	85.8	82.5	91.3	92.8
216	95.8	94.7	97.5	98.0
240	100	100	100	100

A comparison between the values of the mileage covered during the first and last 2-year vehicle operation periods shows even bigger differences in the intensity of vehicle operation than those described for the 5-year periods. During the first two years, the vehicles covered 8.7-13.3% of their target mileage as against mere 2.0-5.3% recorded for the last two years. For the S12 category, these figures are 13.3% and 2.0%, respectively. This means that the mileage covered by the vehicles of this category during the closing part of their service life planned was one-seventh as long as that recorded when the vehicle operation was started. For the S2 category vehicles, a corresponding mileage reduction to one-third was recorded for identical 24-month initial and final vehicle operation periods. This very low rate of growth in the vehicle mileage covered at the last stage of vehicle operation confirms the reasonability of adopting a motor truck operation model with 20-year target mileage.

The analysis of the process of growth in the vehicle mileage makes it also possible to estimate the rate of achieving the target mileage, i.e. to plan the vehicle operation period or the vehicle fleet replacement schedule in a transport company. Tab. 3 shows the time of vehicle operation until the thresholds of 50%, 75%, and 90% of the L_{20} mileage are reached. These time values depend on the cubic capacity of the vehicle engine. The highest rates can be observed in the process of operation of the S10 and S12 vehicles. In these vehicle categories, a half of the target mileage is achieved as early as after 78-84 months of vehicle operation, i.e. when 32-35% of the vehicle service life planned has elapsed. The vehicles of these categories reach 90% of their target mileage when the vehicle operation time reaches 69-70% of the planned value.

Tab. 3. Vehicle operation time necessary for the planned mileage to be achieved

Quantity calculated	S2	S5	S10	S12
Total mileage after 20 years of vehicle operation (target mileage) [km]	784 800	898 400	1 137 900	1 238 200
Vehicle operation time to reach 50% of the target mileage [months]	93-95	106-108	82-84	78-80
Vehicle operation time to reach 75% of the target mileage [months]	144-146	154-156	126-128	122-124
Vehicle operation time to reach 90% of the target mileage [months]	186-188	188-191	167-169	166-168

The S2 vehicles reach a half of their planed 20-year ("target") mileage after 93-95 months, i.e. after a time definitely shorter than a half of the vehicle service life planed, i.e. as early as after 39-40% of their service life. For this vehicle category, the operation time to reach 90% of the target mileage is 186-188 months, i.e. by about five years shorter than the 20-year vehicle service life planned.

3.2. Changes in the *PM* (monthly mileage) growth rate

Figure 3 shows changes in the *PM* (monthly mileage) values, observed with vehicle operation time, in the form of bar graphs, which represent the monthly mileage values calculated by two methods:

- *PM*1 values, determined from the vehicle mileage growth curves of Fig. 1:

$$PM1i = \frac{1}{12}(L_{Ri} - L_{Ri-1}) \quad , \tag{2}$$

- *PM*2 values, determined as mean values of the vehicle mileage in the i^{th} interval of vehicle operation time:

$$PM2i = \frac{1}{12ik_i}\sum_{1}^{k_i} L_{ik} \quad . \tag{3}$$

The following can be seen from the bar graphs shown in Fig. 3 and representing the *PM* values as functions of time:

- the predominating values of the monthly mileage vs. time curves are the higher, the bigger the engine capacity is,
- the S2, S10, and S12 vehicles achieve the highest specific mileage values between the 49th and 72nd month of the vehicle operation time,
- for the S5 vehicles, the maximum monthly mileage values occur between the 97th and 108th month of the vehicle operation time,
- in the S5, S10, and S12 vehicle categories, a particularly high rate of growth in the *PM* values occurs in the period from the second to the fourth year of vehicle operation; this rate is from 420 km/m a year for the S5 category to 800 km/m a year for the S12 category.

The mean and peak values of the monthly mileage, brought together in Tab. 4, strongly depend on the category of engine cubic capacity. The mean *PM*1 values calculated for the whole vehicle service life planned range from 3 270 km/m for the S2 category to 5 160 km/m for the S12 category. Simultaneously, the peak *PM*1 values reached from 131% (for the S2 category) to 169% (for the S12 category) of the corresponding mean values. This means that the dynamics of changes in the intensity of vehicle operation rises with the category of vehicle engine capacity.

Tab. 4. Values characterizing the intensity of vehicle operation, determined from the regression curve

Engine capacity category	Mean *PM*1 value [km/m]	Peak *PM*1 values [km/m]	The months when the peak mileage values are obtained	The months after which $PM < P_{sr}$
S2	3 720	4 280-4 290	49-60	154-155
S5	3 740	4 970-5 000	97-108	178-179
S10	4 920	7 690-7 730	61-72	138-139
S12	5 160	8 650-8 770	61-72	136-137

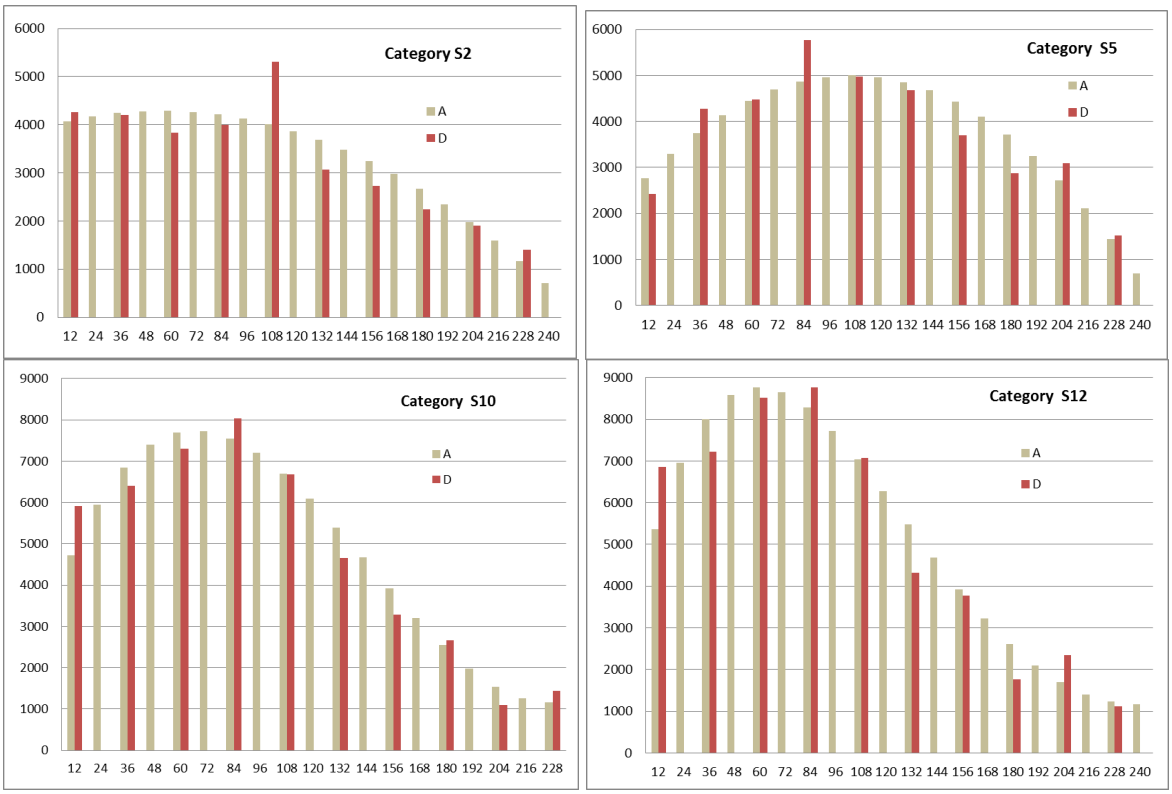

Fig. 3. PM1 and PM2 values vs. vehicle operation time (in months), in a few categories of engine cubic capacity; the PM1 and PM2 values, denoted by letters A and B, respectively, have been specified in kilometres per month [km/m]

The low rate of decline in the *PM* values for the S2 and S5 categories in the period directly following the achieving of the peak monthly mileage values indicates a long period of serviceability of vehicles of these categories thanks to the wide range of their possible uses.

4. Recapitulation and conclusions

For the motor truck operation process under analysis, the following basic findings may be formulated:

- changes in the values of the numerical indicators that describe the vehicle operation intensity are the more dynamic the higher vehicle engine capacity category is,
- for the vehicles with engines of over 5 000 cm^3 capacity, a high rate of growth in the specific mileage (by more than 12% a year) occurs in the period from the second to the fourth year of vehicle operation,
- the S2, S10, and S12 category vehicles achieve the highest monthly mileage (*PM*) values in the fifth and sixth year of vehicle operation (Fig. 3),
- the vehicles with engines of over 10 000 cm^3 capacity reach more than 1/3 of their target mileage for the first five years of operation and they cover 90% of their target mileage as early as after 166-169 months of operation.

An analysis of the values of the mileage covered during the first and last two-year periods of the 20-year vehicle service life reveals very big differences in the intensity of vehicle operation (Tab. 2). As an example, vehicles of the S10 and S12 categories cover 12.5-13.3% of their target mileage during the initial two years of operation as against mere 2.0-2.5% recorded for the final period of the same duration.

Motor trucks with engines of up to 4 999 cm^3 capacity are used in significant part for urban distributional deliveries and local transport; they achieve the highest monthly mileage values (4 280-4 290 km/m) in the fourth and fifth year of operation. The vehicles of this category reach

a half of their target mileage as early as after 39-40% of the planned 20-year service life. By contrast, for the vehicles with engines of over 10 000 cm^3 capacity, the highest increments in their mileage are recorded in the sixth year of operation, with the monthly mileage (*PM*) values reaching then 7 690-7 730 km/m in the S10 category and as much as 8 650-8 770 km/m in the S12 category.

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