

Evaluation of light commercial vehicles operation process in a transport company using the regression modelling method

Indexed by:



Paulina Owczarek^a, Marian Brzeziński^a, Jarosław Zelkowski^a

^aMilitary University of Technology, ul. gen. Sylwestra Kaliskiego 2, 00-908 Warsaw 46, Poland


Highlights

- A research method aimed at evaluating light commercial vehicles (LCV) operation process was proposed.
- Statistical analysis and operational indicators were used to evaluate vehicle operation.
- The economic efficiency of three types of LCV was evaluated.
- A mathematical model was developed based on variables not previously considered in the research.
- The developed mathematical model provides a tool for forecasting the effects of vehicles operation.

Abstract

This paper presents an analysis of the results of daily observations from the execution of transport orders by three types of vehicles over a period of 2 years. The purpose of the research was to evaluate the operation process and determine the influence of important technical and operational variables on the economic efficiency of the operation process. A set of 7 quantitative variables, previously not considered in the evaluation of the commercial vehicle operation process, was subjected to statistical data analysis. An indicator analysis and evaluation of the intensity of use of the following types of vehicles was conducted: Renault Master, Fiat Ducato and Citroen Jumper. Based on the results of the research, the vehicle with the highest efficiency was determined and possible assumptions of the strategy applied in the company were indicated. The analysis and evaluation of vehicle efficiency gave rise to the identification of independent variables determining the company's income. Using the indicator method and the multivariate regression model, transport companies can evaluate the efficiency of transport tasks undertaken.

Keywords

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vehicle operation, light commercial vehicles, economic efficiency, regression modelling.

1. Introduction

In the era of constantly increasing demand for transport services, transport companies operate vehicles in such a way as to achieve the highest possible level of profitability whilst operating them at maximum intensity. The multifaceted nature of operation tasks and dynamic character of transport systems means that effective methods are constantly being sought to evaluate individual processes. Conducting research in the field of operation is primarily aimed at providing units managing operation of vehicles with information necessary to make rational operational and strategic decisions. The need for research concerns the determination of the influence of designated factors on technical and operational characteristics of interest, e.g. reliability, technical readiness, and the search for optimal solutions for managing vehicle operation.

Statistical analyses are predominantly used in the area of motor vehicle management in transport companies, with the aim of minimizing operating costs and maximizing income [18]. Both theory and practice are focused on increasing economic efficiency determined by the level of reliability and durability of vehicles. Research in this area

has focused on verifying vehicle failure rates [4, 9, 26] and formulating conditions under which preventive replacements increase the readiness of vehicle operating systems and contribute to an increase in income per unit of time of vehicle operation [20]. On the basis of recorded operational events, a detailed analysis is conducted of the factors shaping the level of reliability of vehicles, taking into account all phases of their existence [30].

The activities of transport companies are aimed at minimizing vehicle operating costs, which is why the literature addresses the subject of predicting the frequency of vehicle damage [2, 31] and the wear and tear of elements of vehicle functional systems and their durability [16, 24]. With the technological development, construction of modern vehicles, the fatigue strength of structural materials and the effects of operational loads on selected components, e.g. vehicle bearings [10, 23] and leaf springs [8], are constantly being studied. The objective of the ongoing research in the field of operation can be to analyse the operational capability of vehicles and improve the operation process by introducing an indicator that informs about the equivalent vehicle availability [22]. Both in theory and practice, appropriate methods are

(*) Corresponding author.

E-mail addresses: P. Owczarek (ORCID: 0000-0001-6442-9576): paulina.owczarek@wat.edu.pl, M. Brzeziński (ORCID: 0000-0002-7123-7748): marian.brzezinski@wat.edu.pl, J. Zelkowski (ORCID: 0000-0002-6698-2938): jaroslaw.zelkowski@wat.edu.pl

sought to predict the profitability of transport tasks and to minimize the discrepancies between the actual and assumed characteristics of a motor vehicle. Using the method of driving test synthesis, the values of evaluated, zero-dimensional characteristics defining the performance of the vehicle can be determined, and the probabilistic properties of these quantities can be evaluated [6]. Available studies analyse the intensity of use of vehicles taking into account characteristics such as mileage, fuel consumption, operating costs.

This paper presents a set of variables so far not considered in the evaluation of LCV operation, namely: operating time, standstill time, overloading coefficient. A paucity of studies relating to the comparative analysis and evaluation of the intensity of use of a diverse fleet led the authors to seek a relationship between efficiency and following types of vehicle: Renault Master, Fiat Ducato and Citroen Jumper.

Increasingly, transport companies use the resources of specialized information systems of TMS (Transport Management System) class in their operational activities. The most common are on-board computers based on GPS (Global Positioning System) technology [13], telematics systems [3, 32], and platforms that enable GIS (Geographic Information System) data collection and analysis [14, 19]. They act as an on-line advisor and controller, continuously monitoring fuel consumption, informing about "idling" time, temperature inside the refrigerated superstructure. They also feature an eco-driving function that collects data on the number of accelerations and decelerations and thus evaluates driving efficiency and forms the basis for minimizing operating costs. These systems are confirmed to reduce fuel costs by 5% to 15% through ongoing monitoring of fuel consumption [25, 34] and help to ensure that vehicles are maintained in a roadworthy condition [28]. The problem of systems supporting vehicle operation processes is increasingly becoming an object of research for artificial intelligence. Attempts to use evolutionary algorithms to model the use of smart vehicles and highways have been presented in papers [15]. Multi-objective evolutionary algorithms have been used to evaluate and model vehicle performance [36, 39], resource utilization and safe operation of electric vehicles [38].

Available research points to the use of specialized transportation systems, whose implementation costs are often an obstacle to their implementation in the structures of micro and small enterprises. In theory as well as in practice, there was no method of modelling the LCV operation process using multivariate regression. According to the results presented, the method provides an opportunity to estimate the parameters that determine the dependent variable, namely income. In practice, it can therefore support transport companies in their decision-making regarding the efficiency of their transport tasks. Combined with the indicator method presented here, it can support decisions concerning the allocation of vehicles to tasks, the ongoing monitoring and the intensity of vehicle use. The developed method can also be a tool supporting the assumptions of the operation strategy adopted by a company.

The analysis of the literature, both Polish and foreign, indicates the theoretical and practical interest in motor vehicle operation, particularly in relation to the use and maintenance of trucks with a maximum authorized mass of over 3.5 tonnes. Available research boils down to methodological and systematic analysis of individual areas of vehicle operation systems and most often concerns: strength tests, increasing vehicle reliability, performance tests, vehicle damage, service costs forecasting. There is a small number of studies concerning research on sets of technical and operational characteristics describing LCV and presenting their comparison and evaluation of the operation process.

The research presented in this article refers to the evaluation of the operation process of LCVs, which, due to their specificity and difficulties in collecting data describing the process of their operation, are not often the object of the authors' research. Statistical analysis of significant variables determining the efficiency of vehicles, a set of operation indicators and a method of proceeding for modelling the operation process presented in the study provide in the opinion of the

authors a contribution to the theoretical knowledge in the area of vehicle operation.

2. Methods for evaluating the vehicle operation process

Evaluation of the vehicle operation process is possible only on the basis of its technical and operational parameters collected over the longest possible study period. These parameters determine the individual specifics of the use of a particular vehicle. It is possible to analyse and evaluate the given process only on the basis of the collected information about the vehicle. In a company with a diverse fleet, it seems necessary to conduct detailed analyses to determine the performance, efficiency or reliability of each vehicle. For this purpose, statistical analysis and indicator analysis can be used, which can synthetically characterize the operation process of each vehicle and compare its effects.

Descriptive statistics deals with methods of statistical description of data by which concise and generalized characterizations of important properties of the population under study are obtained. The purpose of performing mathematical statistics of unknown probability distributions of random variables is to verify statistical hypotheses using statistical tests (parametric or non-parametric).

A synthetic description of the distributional properties of each variable is presented using:

a) measures of position:

- arithmetic mean:

$$\bar{x} = \frac{x_1 + x_2 + \dots + x_n}{n} = \frac{\sum_{i=1}^n x_i}{n} \quad (1)$$

where: \bar{x} – the symbol for the arithmetic mean, x_i – variants of a measurable characteristic, n – the size of the studied population, is a measure of the tendency of the "central distribution" of given variable;

b) measures of variability:

- range:
 - $R = x_{max} - x_{min}$, defines the range between the minimum and maximum values of the variable;
- the variance of variable X is the arithmetic mean of squares of deviations of individual values of the variable from the arithmetic mean of the whole population:

$$s^2 = \frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2 \quad (2)$$

- standard deviation indicates the average deviation of the values of the studied variables from the arithmetic mean value of the given population:

$$s = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2} \quad ; \quad (3)$$

c) measures of asymmetry and concentration:

- coefficient of variation:

$$V_s = \frac{s}{\bar{x}} \cdot 100 \quad (4)$$

where: V is the symbol for the coefficient of variation, and the subscript s indicates the type of absolute measure of dispersion used in the calculation. It is a measure of the variability of a variable, most

often expressed as a percentage; a coefficient of no more than 30% is assumed to indicate low variability.

Performing statistical analysis on a data set for each vehicle and for individual quantitative variables can provide a basis for evaluating the process of operation of each vehicle. The analysis carried out is worth supplementing with the indicator method, which boils down to the construction of relations between different quantities [7, 37]. The choice of indicators depends on the purpose of the research. The following indicators can be used to evaluate the process of motor vehicle operation in transport enterprises:

d) **Vehicle operating time utilization indicator E_1 :**

$$E_1 = \frac{C_{u1}}{E_w} \cdot 100\% \quad (5)$$

where:

C_{u1} – total vehicle operating time [h];

E_w – maximum total vehicle operating time [h].

For the period studied, it was assumed that the maximum total vehicle operating time is 5463 h with the assumption that vehicles do not operate on Sundays and holidays and their maximum daily operating time is 9 h.

e) **Effective vehicle operation indicator E_2 :**

$$E_2 = \frac{J_{u1}}{C_{u1}} \cdot 100\% \quad (6)$$

where:

J_{u1} – total vehicle driving time [h].

f) **Vehicle use intensity indicator E_3, E_4 :**

$$E_3 = \frac{P_{u1}}{J_{u1}} \quad (7)$$

where:

P_{u1} – total mileage traveled [km].

$$E_4 = \frac{M_{u1}}{P_{u1}} \quad (8)$$

where:

M_{u1} – total cargo weight transported [t].

g) **Vehicle technical readiness indicator E_5 :**

$$E_5 = \frac{C_{u1}}{C_{u1} + C_{NZ}} \quad (9)$$

where:

C_{NZ} – total vehicle down time [h].

For vehicles in repair after a breakdown, the total vehicle down time was determined according to the formula $C_{NZ} = L_{d1} \cdot L_{zt}$, where: L_{d1} – Number of days the vehicle is in repair, L_{zt} – average duration of a transport order.

a) **Vehicle economic efficiency indicator E_6 :**

$$E_6 = \frac{D_{u1}}{M_{u1} \cdot P_{u1}} \quad (10)$$

where:

D_{u1} – total earned income [PLN].

The evaluation of the vehicle operation process can be the basis for the development of effective diagnostic models, providing information about the changing condition of the vehicle and the relationships and dependencies between individual parameters characterizing the process. A precisely built model can serve as a tool supporting strategic business decisions. The operation process model is aimed at finding effective methods of eliminating problems and disruptions in the flow of cargo and increasing the economic efficiency of transport enterprises. In operation practice, mainly mathematical models are developed [29], which usually constitute the basis for evaluation or forecasting of the condition of a given system, vehicle [5, 33]. The literature on the subject deals with the modelling of operation processes based on statistical methods. The most common are reliability models [1, 12, 17] and vehicle operation models developed using Markov chain theory [21, 23].

Many studies consider methods of minimizing vehicle operating costs and the risk of undesirable events during vehicle operation [11, 27, 35]. As a result, preventive measures are proposed to reduce the susceptibility of vehicles to the occurrence of such events, resulting in lower operating costs.

3. Regression modelling assumptions

Statistics provides tools to verify already known relationships between variables or to detect hitherto unknown correlations. Correlation and regression theory provides a basis for accurately determining the degree and direction of relationship between variables. Regression analysis is used to model the relationship between random variable Y (dependent, explanatory) and one or more explanatory variables (called predictors, independent, explanatory): X_1, X_2, \dots, X_n , where for $n = 1$ we have a simple regression, while for $n > 1$ we have a multivariate regression. The complexity of the vehicle operation process in transport companies means that a number of characteristics are observed and their effects on the dependent variable are analysed, hence the multivariate regression modelling method seems to be appropriate for modelling the vehicle operation process.

Given n observations of variables $x_1, x_2, x_3, \dots, x_k$ influencing variable y , the linear multivariate regression model takes the following form:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_k x_k + \varepsilon \quad (11)$$

where:

β_j – model parameters (regression coefficients);

ε – random component.

The coefficients β_j are theoretical values, the determination of which would require measuring an infinite number of observations. Therefore, sample-based estimates of these coefficients should be used. The estimate of the multivariate regression equation takes the form:

$$y = b_0 + b_1 x_1 + b_2 x_2 + \dots + b_k x_k \quad (12)$$

In practice, it is not possible to obtain complete information on the entire population. The regression function determined by the least squares method from a sample drawn from the general population is an approximation of the regression in the general population. Related to the determination of the regression function is the problem of assessing the differences describing the discrepancy between the values of the dependent variable and the values calculated from the model. The standard deviation of the residuals can be used as a measure of this discrepancy. In statistics, the accuracy of an estimator is measured by its variance. The standard error of estimate informs about the aver-

age size of empirical deviations of the dependent variable from the values determined by the model and is defined by the formula:

$$S_e = \sqrt{\frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{n-2}} \quad (13)$$

where:

- y_i – empirical values;
- \hat{y}_i – theoretical values;
- n – number of elements.

The smaller the value of the standard error of estimate S_e , the better model fit.

In regression modelling, it is necessary to determine the coefficient of determination. The basis for determining the coefficient of determination is the sum of squares of deviations of individual observations from their mean, which can be described by the following relation:

$$\sum_{i=1}^n (y_i - \bar{y})^2 = \sum_{i=1}^n (\hat{y}_i - \bar{y})^2 + \sum_{i=1}^n (y_i - \hat{y}_i)^2 \quad (14)$$

Table 1. Technical specification of vehicles in the transport company

Vehicle No.	Type of vehicle	Year of production	Unladen weight [kg]	Permissible payload [kg]	Engine displacement [dm ³]	Initial mileage as of 1/1/2016 [km]	Factory mixed cycle fuel consumption [dm ³ /100km]
P1	RM	2011	2400	1100	2.3	203362	12
P2	FP	2011	2270	1230	3.0	396725	13
P3	CJ	2010	2300	1200	2.2	113610	13

where:

- $\sum_{i=1}^n (y_i - \bar{y})^2$ – total sum of squares;
- $\sum_{i=1}^n (\hat{y}_i - \bar{y})^2$ – the explained sum of squares describing the variability explained by the model;
- $\sum_{i=1}^n (y_i - \hat{y}_i)^2$ – the residual sum of squares describing the variability unexplained by the model;

The coefficient of determination represents the ratio of explained variation to total variation and is defined by the following equation:

$$R^2 = \frac{\sum_{i=1}^n (\hat{y}_i - \bar{y})^2}{\sum_{i=1}^n (y_i - \bar{y})^2} \quad (15)$$

The introduction of additional variables to the model increases the R^2 coefficient, while the aim of the research is to show the relationship between variables while trying to maintain the highest possible value of the coefficient of fit. When the independent variables are correlated, then they deprive each other of explanatory power. In this situation, the use of a corrected (adjusted) R^2 is justified. The value of the adjusted R^2 decreases when variables that do not cause a significant increase in the sum of squares of deviations are introduced into the model.

Conducting research on simplified models provides the necessary support to assess performance, predict behaviour, and minimize the likelihood of problems and disruptions in the motor vehicle operation process, which are typically interpreted in a probabilistic sense.

The use of multivariate regression analysis to evaluate and model the process of vehicle operation in transport companies appears to be a suitable method for verifying the measurable information that can be obtained from a set of independent variables with respect to the dependent variable. It also provides an opportunity to recognize the magnitude and type of influence of one variable on another and to predict the value of the dependent variable.

4. A study of the vehicle operation process in a transport company on a set of real data

A transport company providing trucking services across the country was analysed. The company has 3 LCVs in use. Each of the vehicles in the period from 1/1/2016 to 31/12/2017 performed transport services on the basis of the terms and conditions specified in the transport order. Each transport order represents an observation that is the basis for the study carried out to evaluate and then model the vehicle operation process. The company's fleet is diverse and includes 3 different types of delivery vehicles, namely Renault Master – RM, Fiat Ducato – FD, and Citroen Jumper – CJ. The initial mileages of the vehicles at the start of the study ranged from 113000 km to 396000 km. The permissible payload of the vehicles oscillates between 1100–1230 kg. The technical specifications of the vehicles are shown in Table 1.

Each observation refers to the daily execution of a transport order by one vehicle. It is described by 7 quantitative variables which are a set of characteristics that represent an important property of the phenomenon under study. The vehicle operation process in the studied transportation company is characterized by the following variables:

- D_u – Gross revenue, which determines the value of the economic surplus/deficit earned from a transport order;
- K_k – The total cost of transport order execution;
- P_u – The number of kilometres travelled in the execution of a given transport order;
- C_u – Driver working time including driving time, stops, breaks and other work (loading, unloading);
- W_u – A numerical quantity expressed as a percentage that represents the ratio between the actual weight of the cargo and the permissible payload of the vehicle;
- S_u – Fuel consumption in dm³ per 100 km;
- J_u – Driving time of the driver, not including stops, breaks, other work (loading, unloading);

The procedure for evaluating the operation process follows three steps. The first is a statistical analysis of the variables that characterize the process for each vehicle. Tables 2 – 4 present a comparative parametric characterization of the variables to each vehicle type.

Table 2. Statistical analysis of variables for Renault Master

Variable	ValidN	Average	Minimum	Maximum	Variance	Standard deviation	Coefficient of variation
Gross income [PLN]	590	273.87	-2374.34	976.76	38770.35	196.90	71.90
Cost of transport order execution [PLN]	590	501.40	315.42	3112.34	17672.31	132.94	26.51
Daily mileage [km]	590	348.40	120.00	650.00	7763.68	88.11	25.29
Operating time [min]	590	466.00	159.00	810.00	0.01	0.07	23.03
Overloading coefficient [%]	590	1.50	0.89	2.18	0.12	0.35	23.29
Fuel consumption dm ³ /100km	590	15.33	13.00	17.00	1.86	1.37	8.91
Driving time [min]	590	419.00	144.00	780.00	0.01	0.07	24.44
Standstill time [min]	590	47.00	0.00	170.00	0.00	0.03	79.74

Table 3. Statistical analysis of the variables for Fiat Ducato

Variable	ValidN	Average	Minimum	Maximum	Variance	Standard deviation	Coefficient of variation
Gross income [PLN]	579	293.02	-916.88	1034.15	33489.11	183.00	62.45
Cost of transport order execution [PLN]	579	523.94	350.98	1753.28	13541.71	116.37	22.21
Daily mileage [km]	579	374.36	120.00	650.00	10294.03	101.46	27.10
Operating time [min]	579	515.00	236.00	780.00	0.01	0.09	25.79
Overloading coefficient [%]	579	1.36	0.80	2.07	0.10	0.31	23.09
Fuel consumption dm ³ /100km	579	15.49	13.00	18.00	2.17	1.47	9.52
Driving time [min]	579	449.00	144.00	780.00	0.01	0.08	26.97
Standstill time [min]	579	66.00	0.00	210.00	0.00	0.03	70.96

Table 4. Statistical analysis of variables for Citroen Jumper

Variable	ValidN	Average	Minimum	Maximum	Variance	Standard deviation	Coefficient of variation
Gross income [PLN]	563	184.03	-1551.53	875.79	34203.30	184.94	100.49
Cost of transport order execution [PLN]	563	486.33	328.78	2166.53	16864.03	129.86	26.70
Daily mileage [km]	563	365.81	170.00	650.00	12103.75	110.02	29.08
Operating time [min]	563	532.00	219.00	900.00	0.01	0.10	25.86
Overloading coefficient [%]	563	1.15	0.83	2.00	0.02	0.15	12.87
Fuel consumption dm ³ /100km	563	14.26	13.00	17.00	0.71	0.84	5.91
Driving time [min]	563	438.00	204.00	780.00	0.01	0.09	28.04
Standstill time [min]	563	93.00	0.00	300.00	0.00	0.03	50.47

When analysing the set of variables for each vehicle type, it should be noted that the Renault Master carried out the most transport orders in 2016-2017 – 590, while the Citroen Jumper carried out the least – 563. Taking the average number of orders carried out, the Fiat Ducato has the highest average income, which is 37% higher than that of the Citroen Jumper and 7% higher than that of the Renault Master. At the same time, the Fiat Ducato shows the highest average value of the variable: cost of transport order execution, daily mileage, fuel consumption and driving time. The highest value of the operating time variable was recorded for the Citroen Jumper, for which the standstill time represents 17% of the total operating time, where for the Renault Master the ratio of standstill time to operating time is 10% and for the Fiat Ducato 13%. Citroen Jumper also has the lowest average value of the variable: income, cost of order execution, overloading coefficient and fuel consumption. The Renault Master had the highest average overloading coefficient of 150% and also the lowest average

mileage and operating time. The lowest value of average income was recorded for Renault Master at PLN -2374, where as a comparison for Fiat Ducato it was PLN -917. This vehicle was also characterized by the highest maximum value of the costs of transport order execution of PLN 3112, and for Fiat Ducato this variable took the value of PLN 1753. For each vehicle type, the range between daily minimum and maximum mileage varied from 120 km to 650 km. The average value of the overloading coefficient for each type of vehicle reaches a value of not less than 80%, the highest maximum value of this coefficient of 218% was achieved by the Renault Master. Each vehicle type had large variance values of the variables: income, cost of order execution, and mileage. The highest value of variance of 38770.35 of income variable and standard deviation of 196.90, as well as the value of 17672.31 and standard deviation of 132.94 for the cost of order execution variable were recorded for Renault Master. The highest value of variance of 12103.75 and the highest value of standard deviation of

Table 5. Summary of operation indicators for the three vehicle types

Type of vehicle	Vehicle operating time utilization indicator [%]	Effective vehicle operation indicator [%]	Vehicle use intensity indicator [km/h]	Vehicle use intensity indicator [t/km]	Vehicle technical readiness indicator	Vehicle economic efficiency indicator [PLN/tkm]
Renault Master	84%	90%	50	0,0047	0,98	0,00081
Fiat Ducato	91%	88%	49	0,0045	0,97	0,00081
Citroen Jumper	91%	83%	50	0,0038	0,99	0,00065

110.02 for the mileage variable was taken by Citroen Jumper. For this type, the coefficient of variation for the standstill time variable takes a value between 30% and 70%, which indicates an average degree of variation in the values of this variable. For the Renault Master and Fiat Ducato, the coefficient of variation for the variables income and standstill time takes a value above 70%, which confirms the strong degree of variation in the value of the variable. The income variable for the Citroen Jumper vehicle type has the highest degree of variation in the value of the variable.

In the second stage of the study, an analysis was conducted in which operation indicators were used to evaluate three types of vehicles used in the transport company. The results of the performed analysis are presented in Table 5.

The results of the indicator analysis showed that the Renault Master vehicle type is characterized by the lowest value of the operating time utilization indicator, which is confirmed by the lowest average value of the operating time presented in the statistical analysis (Table 2). This vehicle maintained the highest value of the effective operation indicator of 90%, vehicle use intensity indicator of 0.0047 t/km, and thus achieved one of the two highest values of economic efficiency indicator of 0.00081 PLN/tkm. The Fiat Ducato, with one of the two highest values of the operating time utilization indicator – 91%, also achieved the lowest technical readiness indicator value of 0.97, thus achieving one of the two highest economic efficiency indicator values along with the Renault Master. Citroen Jumper is characterized by the lowest value of economic efficiency indicator, namely 0.00065 PLN/tk, the lowest value of effective operation indicator of 83%, the lowest value of use intensity indicator of 0.0038 t/km and at the same time it is the vehicle type with the highest level of technical readiness indicator – 0.99.

The purpose of operation of the studied types of vehicles in the transport company is the assumed (always subjectively assessed) level of economic efficiency, indicating the profitability of the company, which in the presented set is characterized by the gross income variable. In the next stage of the study, taking into account the main objective of the company, modelling of the operation process will be carried out for the vehicle, the use of which brings the highest income to the company. The purpose of modelling will be to determine the independent variables that determine the dependent variable which is the income of the company.

The statistical and indicator analysis carried out showed that the Fiat Ducato vehicle type shows the highest average value of the income variable and thus obtains, together with the Renault Master, the highest value of the economic efficiency indicator. Figure 1 shows the average income values for each vehicle type earned in each month from 2016 to 2017. Figure 2 shows the average income value for vehicles.

In practice, the attempt to evaluate the vehicle operation process usually focuses on the analysis of costs generated by the use of a given vehicle and its profitability. The transport company analysed has a diverse fleet. The study conducted in the first and second stage indicated that the most efficient vehicle in terms of economy is the Fiat Ducato, which has the highest average value of income from transport orders execution. Thus, in the next step, the modelling of the Fiat Ducato vehicle operation process using the multivariate regression modelling method will be presented. The purpose of the conducted modelling

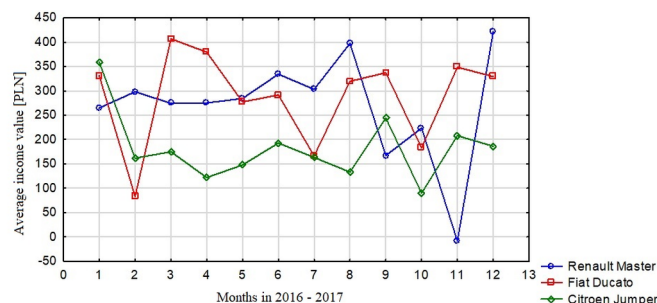


Fig. 1. Average monthly income from transport orders execution

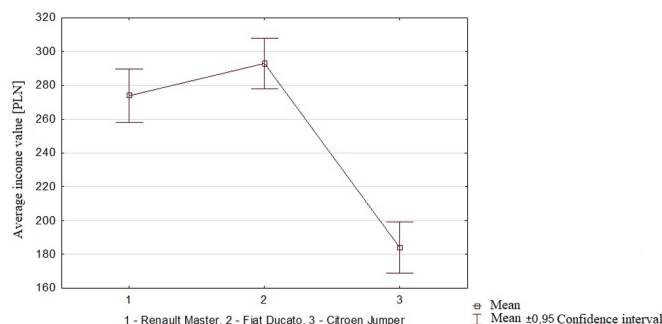


Fig. 2. Average value of income from transport orders execution

is to assess the impact of significant technical and operational variables on the efficiency of the operation process of the selected type of vehicle, which is characterized by the highest profitability in the company. The modelling takes into account a set of variables describing the vehicle in the process of its operation. The types and nature of the 7 variables are shown in Table 6.

To achieve the stated goal of modelling the vehicle operation process, the following assumptions were made:

- the dependent (output) variable was defined: D_u ;
- a set of independent, quantitative (input) variables was defined: K_k ; P_u ; C_u ; W_u ; S_u ; J_u ;
- each observation relates to the actual execution of a transport order by a given vehicle;
- the time scale of the model covers the period from 01/01/2016 to 31/12/2017.

The limitations of the model are identified:

- only applicable to LCV;
- daily mileage: $P_u \leq 650$ km;
- vehicle payload: $1100 \text{ kg} \leq \xi_p \leq 1230$ kg;
- operating time $C_u \leq 9$ h.

Various variants of both linear and nonlinear models with statistically significant variables were considered for multivariate regression modelling. The regression model for the Fiat Ducato vehicle operation process was built based on the variables most correlated with the output variable, i.e. P_u – Daily mileage, W_u – Overloading coefficient, K_k – Cost of transport order execution. Entering statistically insignificant variables into the regression model i.e. C_u – Operating

Table 6. Summary of significant technical and operational variables of the Fiat Ducato vehicle operation process

No.	Name of the variable	Mark	Label	Variable type
1	Gross income	D_u	[PLN]	Quantitative
2	Cost of transport order execution	K_k	[PLN]	Quantitative
3	Daily mileage	P_u	[km]	Quantitative
4	Operating time	C_u	[min]	Quantitative
5	Overloading coefficient	W_u	[%]	Quantitative
6	Fuel consumption	S_u	[dm ³ /100 km]	Quantitative
7	Driving time	J_u	[min]	Quantitative

Table 7. Summary of multivariate regression of the dependent variable Income D_u for Fiat Ducato

	b*	std. error of b*	b	std. error of b	t	p
Absolute term			604.89	109.99	5.49	0.00
P_u daily mileage [km]	0.25	0.08	0.45	0.15	2.92	0.00
Overloading coefficient W_u [%]	0.34	0.08	201.15	51.94	3.87	0.00
Cost of transport order execution K_k [PLN]	-0.75	0.03	-1.19	0.06	-19.31	0.00

Table 8. Results of regression analysis for Fiat Ducato

R	0.64	0.64
R ²	0.41	0.41
Adjusted R ²	0.40	0.40
Std. error of estimation	14.89	14.89

time, S_u – Fuel consumption, J_u – Driving time was the reason for the decrease in the goodness of fit coefficient value. The result of the study was the formulation of a linear equation for the three predictors most correlated with the output variable:

$$D_u = b_0 + b_1 P_u + b_2 W_u + b_3 K_k + \varepsilon \quad (16)$$

The results of the multivariate regression performed for the Fiat Ducato vehicle are presented in tables 7 – 8.

The determined regression model for the Fiat Ducato vehicle has the following form:

$$D_{u1} = 604,89 + 0,45P_u + 201,15W_u - 1,19K_k \pm 14,89 \quad (17)$$

The value of the coefficient of determination $R^2 = 0.41$ means that 41% of the total variation in the variable *Income* D_u is explained by the model. The remaining 59% was hidden in the random factor. The standard error of estimation amounting to 14.89 represents the average deviation of the variable *Income* D_u observed in the sample from the value determined from the model.

The regression coefficients determined from the sample are estimates of the regression coefficients for the entire population. They are subject to error in the form of mean error of estimation of the parameters, which is an estimate of the average discrepancy between the model parameters and its possible estimates. For the operation process regression model for the Fiat Ducato, the following was obtained:

- the ratings for parameter b_0 deviate from this parameter by 109,99;
- the ratings for parameter b_1 deviate from this parameter by 0,15;
- the ratings for parameter b_2 deviate from this parameter by 51,94;
- the ratings for parameter b_3 deviate from this parameter by 0,06.

Estimating the absolute term $b_0 = 604.89$, the possible error is on average 109.99, therefore the error of estimation is $109.99/604.89=0.18$. The estimation errors and significance of the obtained parameters confirm the good fit of the model. A tolerance greater than 0.1 indicates that there are no redundant variables in the model (Table 9). In the next step, model validation is performed.

In conclusion, the selection of the modelling method, which is the multivariate regression, and its individual stages, i.e. estimation of the regression model estimators, the standard error of estimation, the coefficient of determination R^2 , the redundancy index, and the verification of statistical hypotheses, made it possible to develop a mathematical model that provides the basis for predicting the value of the variable *Income* D_u in the Fiat Ducato vehicle operation process. The next step in modelling is the verification of the regression model. Performing verification effectively detects deviations from a valid regression analysis. Analysis of the residuals allows the detection of outliers that can significantly affect the regression model. Removing the outlier can then lead to completely different results from the analysis performed. Therefore, after estimating the model parameters in the next step, it is necessary to analyse the residual values. A correctly constructed model should be characterized by certain properties of the residuals, i.e. normality, constancy of variance, lack of autocorrelation and expected value equal to 0. First, the assumption of normality of residuals was verified using the Shapiro-Wilk test, where the hypothesis of normality of the distribution of residuals was verified at the significance level of $\alpha=0,05$. The resulting p-value = 0, which dictates the acceptance of the alternative hypothesis that the distribution of the residuals is not close to a normal distribution. The

Table 9. Regression model redundancy analysis for the Fiat Ducato vehicle operation process

Redundancy	Tolerance	R-squared
P_u daily mileage [km]	0.138851661	0.861148339
Overloading coefficient W_u [%]	0.12989955	0.87010045
Cost of transport order execution K_k [PLN]	0.66530687	0.33469313

histogram of the residuals is shown in Figure 3. This means that there are dependencies left unexplained in the model.

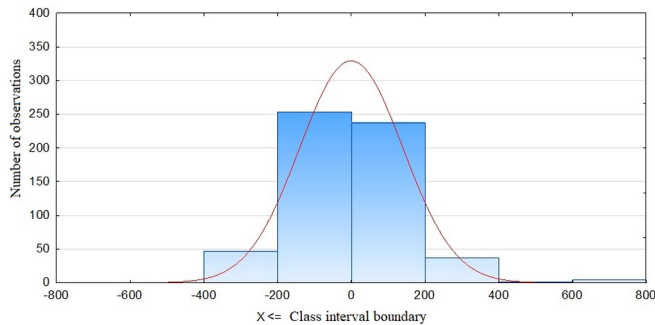


Fig. 3. Residuals histogram

Next, the homoskedasticity of the residuals was verified. White's test was used for this purpose, for which the null hypothesis is that there is homoskedasticity of the residuals. The obtained p-value=0.1 means that the null hypothesis should be accepted. The next step was to verify the autocorrelation of the residuals. It was conducted using the Durbin Watson test. For the model where the number of observations is $n=588$ and the number of predictors is $k=3$, the outliers $d_l=1.84$ and $d_g=1.87$ were determined. The value of the calcu-

lated DW statistic=1.43. This means that there is positive autocorrelation of the model residuals, as shown in Figures 4 – 5.

The methodology presented allowed for the analysis and evaluation of the vehicle operation process and provided a basis for determining the most efficient type of LCV in the company. The development of the multivariate regression model for the Fiat Ducato was carried out in accordance with the assumptions made and provided a basis for forecasting the effects, i.e. the value of income from the vehicle operation in the transport company.

5. Summary

The studies conducted based on statistical methods, indicator analysis and regression modelling gave the basis for evaluating the process of operation of various vehicles in the transport company.

The statistical results confirmed that the Fiat Ducato showed the highest efficiency in the operation process. The management strategy adopted for the Fiat Ducato favours achieving the greatest daily mileage. It thus earns the highest income from execution of orders over a period of 2 years. This is 5% higher than the income of the Renault Master, which had the highest average overloading coefficient of 150% and the lowest average mileage. The economic efficiency of the Fiat Ducato is also 39% higher than the revenue generated by the Citroen Jumper. Fiat Ducato obtained one of the two highest values of operating time utilization indicator $E_1 = 91\%$ and the lowest value of technical readiness index $E_5 = 0.97$. This may indicate that the nature of operation of the Fiat Ducato, aimed at achieving long and profitable distances, involves the greatest risk of vehicle downtime and unfitness. Nonetheless, this vehicle showed one of the two highest values of the economic efficiency indicator $E_5 = 0.00081$ during the study period.

The use of the multivariate regression procedure provided a basis for determining the relationships occurring between the dependent variable income and the independent variables describing the dynamic process of vehicle operation. The results of the studies using the regression model gave the basis for determining the independent variables which determine the Fiat Ducato operation process, namely: Daily mileage P_u , Overloading coefficient W_u and Cost of transport order execution K_k . Evaluating the efficiency of the operation process, we received information that with an increase in the daily mileage P_u by 1 km, the income D_u increases by 0.45 PLN, with an increase in the overloading coefficient W_u by 100 %, the income D_u increases by PLN 200.16, while in the case of the variable: cost of transport order execution K_k , with an increase by PLN 1, the income D_u decreases by PLN 1.19. The developed form of the model explains 41% of the overall variability of the dependent variable, which confirms that the value of income is also influenced by other variables not included in the study and often difficult to measure, i.e. speed of taking up the order, flexibility, and number of loading and unloading places.

Theoretical assumptions and model presented in the article can be a tool to support and evaluate the effectiveness of the undertaken transport tasks. The indicator method developed on a set of variables not previously considered in research (operating time, standstill time, overloading coefficient) gives the possibility of ongoing control of the intensity of vehicle use. The research method presented in this paper adds to the theoretical knowledge in the area of LCV operation. In practice, it is a ready-to-implement tool that can support the assumptions of the adopted operation strategy in transport companies.

Developed methodology and presented tools inspire to continue research towards issues related to the impact of overloading LCV on the safety of road traffic, the driver and the trans-

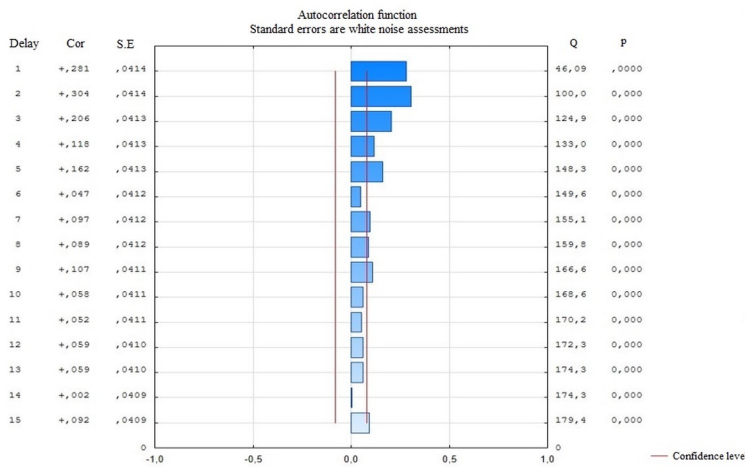


Fig. 4. Autocorrelation of residuals

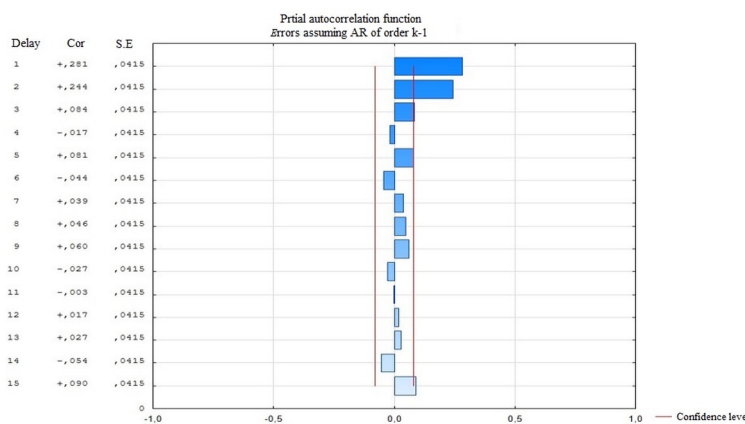


Fig. 5. Partial autocorrelation

ported cargo, and to develop operational strategy for micro transport companies.

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