METHOD OF EVALUATING TRANSPORT TASKS IN THE ARMY WITH THE USE OF MATHEMATICAL MODELLING

Eliza Łagowska

Summary

The article analyzes military transport operating within the Armed Forces logistics system. The proprietary method of its evaluation was presented. The technical subsystem has been characterized with the specification of the requirements it is faced with. General criteria for the assessment of the technical subsystem were identified, distinguishing the equipment, personnel, technical material resources, training and experience of soldiers, as well as their combat readiness and flexibility.

The essential part of the discussion is devoted to empirical evaluation. It was made through the analysis of completed transport tasks. The research conducted with respect to the mileages of motor vehicles allows to ascertain whether the system is sufficient to meet the current needs. The mathematical model proposed allows to estimate the development tendency, based on which it is possible to formulate improvement proposals.

Key words

transport, technical subsystem, operation

To cite this article:

Łagowska, E. Method of evaluating transport tasks in the army with the use of mathematical modelling. Motor Transport, 63(1), 24 - 28.
DOI: 10.5604/01.3001.0014.8157

1. Introduction

Military transport is an extremely important issue. It allows to transport equipment, ammunition and soldiers. Many publications in this area have been written recently. Kowalski K. in the article [6] described the characteristics of the military transport system. He also presented the characteristics of military means of road, water, air and pipeline transport. Ślaski P. and Giga A. in the article [10] presented the use of the excel spreadsheet in order to solve performing a classic transport task, where the key problem was the analysis of costs related to transport. The article by T. Jałowiec [5] deals with the characterization of the development of the transport organization system in the army through the use of cooperation with economic entities.

Transport tasks in the army are performed as part of the technical subsystem, which is an essential component of the logistic system of the Armed Forces of the Republic of Poland, on which remaining logistic subsystems depend. Such as - material, transport, medical subsystem, as well as the military infrastructure subsystem. Faulty organization and functioning of the technical subsystem limits the efficient operation of individual subsystems. The lack of coherence between the activities for the technical subsystem and remaining elements of military logistics, weakens the overall development possibilities of the Polish army.

In economic terms, the technical subsystem includes not only tasks related to the repair and combat readiness of military equipment [1, 7], as well as providing services such as: control and management, operation, support and technical backup[4].

According to the DD-4.22 (A) doctrine, the essence of the technical subsystem is to keep military equipment ready for use and restore its technical efficiency in the event of damage, as well as supplying military equipment and technical materials necessary in the operation process "[13].

The most important undertaking under implementation is operation, which determines the scope of tasks performed by the subsystem organs. Operation concerns the implementation of tasks such as: control and management, usage, as well as technical support and backup. The control and management is carried out at all organizational levels.

The area, that military equipment operators deal with is the usage. The essence of usage concerns organizing specific possibilities for the proper use of equipment, storage and rational consumption of operational service lives [7, 11, 1].

The users as well as executive bodies of the technical subsystem and non-military system are responsible for the area of support and technical backup activities. It covers all intended activities affecting the condition of military equipment, as well as its storage and usage. In this area, the key activity is to ensure organizational and technical conditions [4, 9].

The objective of the article is therefore to analyze the transport tasks carried out at the examined military unit and to propose a method of their evaluation using mathematical modelling. The assumption (hypothesis) was to verify whether the adopted operation model is sufficient to provision the vehicles or whether it should be improved.

2. Evaluation of the transport tasks

The proposed criteria for assessing military transport tasks are as follows:

1) **Possessing the equipment** with appropriate technical parameters, in the appropriate amount necessary to perform the tasks. It is also the equipment necessary to meet the maintenance and repair needs.
2) **Possessing people** is necessary to perform tasks, also in the field of repairs, servicing, and supplying technical materials necessary in the operation process.
3) **Possessing technical material means** is necessary to conduct activities by the soldiers.
4) **Training and experience of soldiers** is necessary for quickly and correctly performing tasks related to the usage and maintenance of equipment. This criterion is directly related to availability of the personnel.
5) **Combat readiness and flexibility** is an indirect combination of possessing the equipment, people, technical material measures and training of soldiers.

The transport tasks in the army can be assessed in various aspects, e.g. by the degree of completeness as far as personnel or equipment is concerned, as well as the degree of combat readiness. The impact of staff training on the effectiveness of performing specific tasks can also be evaluated. They can also be assessed in terms of the percentage of completing specific tasks, as well as the time of their implementation. This is especially important when carrying out overhauls, maintenance and repairs. The efficiency of transport tasks will decline as more vehicles are added without increasing the number of personnel and technical resources to handle them.

The evaluation of transport tasks for the purposes of this article was conducted through the analysis of mileages of motor vehicles. Depending on whether these mileages decrease, remain constant or increase, it will be possible to determine whether changes in the operation of the technical subsystem at the military units under study are needed.

Based on the total mileage of vehicles performing tasks at the military units in individual months of 2019, their analysis was prepared in terms of the technical backup (Table 1). The data collected on the scopes of conducted operations are presented in Fig. 1. As can be seen, the course for the individual units varies. This is related to different specifics of each unit, as well as having a variety of equipment and performing specialized tasks. In total, in 2019 the units performed a total of 2,344,818 km of journeys, which amounts to an average of 195,402 km per month. The smallest number of kilometres was recorded in January and it was 63,217 km, while the highest number was 390,666 km in December.

Table 1. Mileage in km of trips conducted at the examined military units

Military unit	CSŁiI	CYBER MIL	JW5699	JW4019	JW2189	JW1230	JW3470	5 BOT	6 BOT
January	231 837	63 288	169 721	212 993	261 771	368 291	111 778	163 162	63 217
February	233 841	63 658	169 908	213 169	264 132	372 717	112 255	164 998	66 532
March	234 398	66 102	170 161	215 462	264 586	377 289	112 527	166 733	66 635
April	235 938	66 505	172 458	216 479	266 599	379 573	114 582	170 756	70 287
May	239 790	68 272	173 337	218 984	267 534	380 382	115 639	171 133	73 457
June	239 992	70 274	180 236	220 407	269 832	380 852	116 717	174 411	78 830
July	240 765	82 040	184 080	221 966	273 844	381 320	118 049	175 930	81 149
August	243 887	83 761	189 709	222 472	274 534	382 093	119 762	176 359	85 933
September	244 201	84 531	195 145	224 465	275 456	384 229	120 580	186 716	89 788
October	245 341	90 181	197 001	229 728	277 620	387 740	127 154	194 172	98 462
November	247 229	91 206	197 326	230 568	291 868	389 145	137 262	197 055	98 818
December	256 311	94 834	197 469	240 772	296 598	390 666	144 121	198 303	99 245

Fig. 1. Average mileage of completed trips

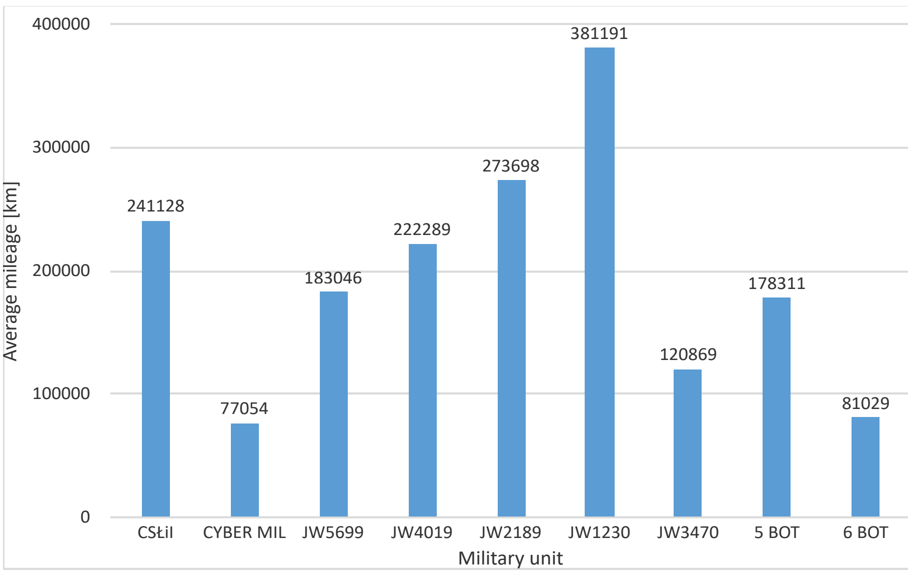


Fig. 2 shows average mileages of the units studied in each month. A linear trend is noticeable, where the values are increasing month by month and the fluctuations are slight and random. Taking all these aspects into account, the analysis was performed using a **linear regression model**.
Pearson's linear correlation coefficient was used to confirm the linearity of the trend. This coefficient determines the level of linear dependence between random variables, where the correlations can be interpreted as strong, weak or negative. The value of the correlation coefficient is in the range [-1.1], where the greater its absolute value, the stronger the linear relationship between the variables. The Pearson's linear correlation coefficient is calculated using the following formula:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i-1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y^2 - \bar{y})^2}}$$

(1)

Where in our case:
x - number of average mileages,
$\bar{x}$ - average value of all mileages,
y - number of months,
$\bar{y}$ - average number of months.

Using the previous formula, the correlation coefficient was calculated, which amounted to:

$$r = 0{,}9858$$

It is a positive linear relationship, where, with the passing of subsequent months, the average total number of kilometres travelled in all units increases. This result means that the correlation is practically complete, and that for 98% of the results, the coefficient of months variability determination confirms the variability of the mileages (i.e. growth) and is statistically significant. This is clearly shown in the dispersion plot below (Fig. 3).

Based on the above analyses, the parameters of the regression model were then estimated using the **least squares method**. Regression is a statistical method that allows to describe the covariance of several variables by matching an appropriate function to them. This allows to predict the unknown value of one function, with respect to the known quantities of other functions. The least squares method is a way of finding the minimum for the sum of the squared differences in the observed values and the theoretical value. For this purpose, we use the following formula, which, after transformation, allows to calculate the coefficient a and inserting arithmetic mean x and the arithmetic mean y - the coefficient b:

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

$$a = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (3)$$

$$b = \bar{y} - a\bar{x} \quad (4)$$

Inserting the values from the model, we obtain the regression model presented in the table (Table 2).

By analyzing the results obtained, we obtain the model in the following form:

$$y = 24402 * t + 1599988 \quad (5)$$

where: t - another month of observation.

The conditions necessary to confirm the reliability of the least squares method are linear dependence, distribution of normal residuals, constant dispersion, and independent observations. The evaluation of the model was performed first with the use of the **determination coefficient** R^2, which for a given model amounts to $R^2 = 0{,}97$, which we interpret as 97% of the examined variables is explained by the presented model. This is a very good result. Another important element is studying of the residuals of the model. These are the differences between the predicted and theoretical values, which should be distributed close to normal, and preferably normal. In order to check compliance with the normal distribution, the **Shapiro-Wilk test** was performed, where we calculate the value depending on the adopted probability level and the number of observations, and then compare the obtained result with the critical value in the Shapiro-Wilk table. If the calculated value (p) is smaller than the value of the S-W statistics, it can be concluded that for a given significance level our results are statistically insignificant, which means that the variable has a distribution close to the normal distribution. The Shapiro-Wilk test statistic was $W = 0{,}8975$ and the associated with it value $p = 0{,}1474$, which means that the distribution of the residuals in the tested model is normal.

To summarize, it can be concluded that the model has been constructed correctly. The obtained values of the a and b coefficients relate correctly to the forecasting of subsequent values. The dispersion around the regression line is slight and fairly even. The observed changes are independent, the results have no direct influence on each other, and the residuals distribution is normal, which was confirmed by the Shapiro-Wilk test. As for the relationship, it has been unequivocally proven that there is an almost linear relationship between the number of kilometres of mileage in the tested units and the subsequent months of observation.

As it has been shown, the average mileage, will constantly increase over the next months, which entails an increase in the need to operate the equipment. The greater number of kilometres travelled by military vehicles will be associated with increasingly faster wear of parts and mechanisms, moreover, more frequent trips of cars will result in an increase in the number of their servicing. Based on the designed model and its forecasts, the following conclusions can be drawn with regard to the increasing number of mileages:

- greater and more frequent wear of vehicles' parts,
- faster exhaustion of the inter-period service lives,
- the need to conduct more maintenance,
- greater probability of defects and failures to occur,
- the need to purchase more parts due to the possibility of greater failure rate.

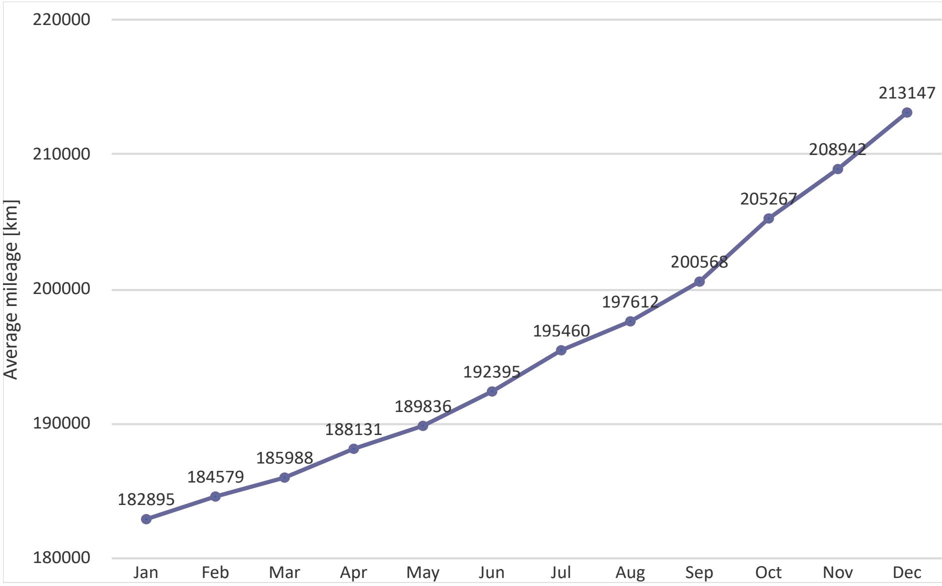
All these aspects determine the increased maintenance and repair needs, which, as shown by the designed model, will constantly increase over time. In order to meet the increased needs, it is necessary to introduce such changes that will enable the technical subsystem to perform tasks more effectively. Therefore, there is a need to optimize the processes that have an impact on maintaining the technical efficiency of this military equipment.

3. Conclusions

Continuous development, implementation of new military equipment, as well as organizational changes in the military force the improvement of important aspects of the technical subsystem. The essential task of the technical services is currently the adaptation of the military service and repair base, as well as the assigned personnel, to introduce the new technology, which implies the need to know the technology of repairing this equipment.

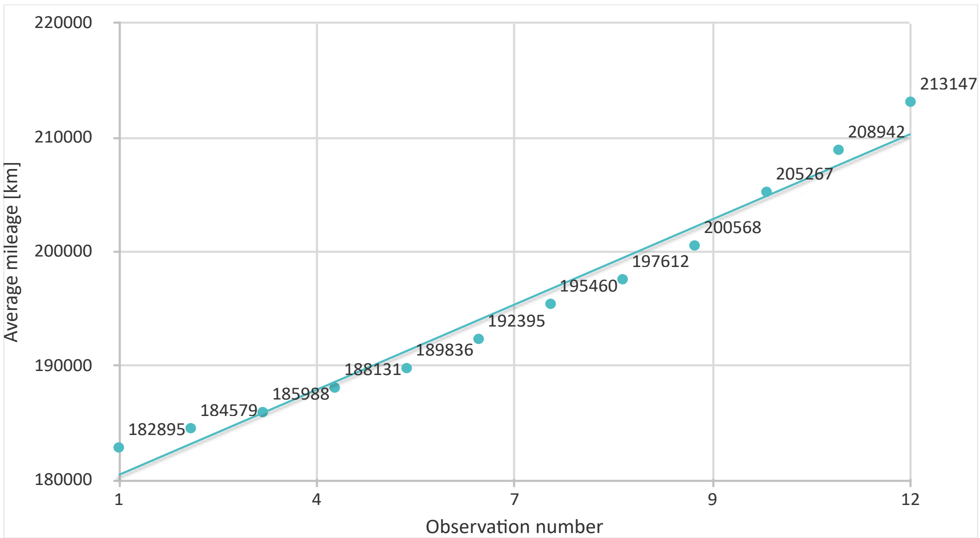
The most important issues include the time needed to carry out specific services and equipment repairs, as well as the increasing number of kilometres travelled by the military vehicles. In the current economic and legal reality, the creation of an efficient system for obtaining and securing technical material resources becomes the basic determinant. Planning and support for the operation of military equipment should be performed by the most experienced personnel in order to reduce the waiting time for a given service, as well as to reduce the number of stored equipment.

Fig. 2. Average monthly mileage of trips at the surveyed units



Source: author's own study

Fig. 3. The dispersion of the average mileage in kilometres, in relation to subsequent observations



Source: author's own study

Table 2. Regression model concerning the average mileage of trips

	Parameter value	Standard Error	t(10)	p
Parameter	1599988	9689,35	165,13	$< 2{,}2*10^{-16}$
t	24404	1316,52	18,54	$< 2{,}2*10^{-16}$

Source: author's own compilation

Bibliography

1. Borucka A., Niewczas A., Hasilova, K. Forecasting the readiness of special vehicles using the semi-Markov model. Eksploatacja i Niezawodność – Maintenance and Reliability; 2019, 21(4), 662–669.
2. Borucka A., Świderski A.: Mathematical Analysis of Factors Affecting the Road Safety in Selected Polish Region, Transport Means 2018, Proceedings of the 22nd International Scientific Conference part II, Lithuania, 2018, s. 651- 654 .
3. Borucka A.: Risk Analysis of Accidents in Poland Based on ARIMA Model, Transport Means 2018, Proceedings of the 22nd International Scientific Conference part I, Lithuania, 2018, pp. 162-16.
4. Grzelak M., Borucka A. Model ewakuacji technicznej na przykładzie brygady zmechanizowanej, Gospodarka Materiałowa i Logistyka, 5/2015, 242-253, ISSN 1231-2037.
5. Jałowiec, T. (2011). Innowacje w zarządzaniu transportem w Siłach Zbrojnych Rzeczypospolitej Polskiej. Logistyka, (1), 36-38.
6. Kowalski, Kazimierz. „Organizacja utrzymania wojskowych środków transportu." Autobusy: technika, eksploatacja, systemy transportowe 11 (2010).
7. Kozłowski E., Borucka A., Świderski A. Application of the logistic regression for determining transition probability matrix of operating states in the transport systems. Eksploatacja i Niezawodność – Maintenance and Reliability 2020, 22 (2), 192–200.
8. System logistyczny Sił Zbrojnych Rzeczypospolitej Polskiej, Raport 2019, Warszawa 2019.
9. System logistyczny Sił Zbrojnych Rzeczypospolitej Polskiej, Raport 2019, Warszawa 2019.
10. Ślaski, P., Giga, A. (2002). Klasyczne zadanie transportowe w wojsku. Problemy Techniki Uzbrojenia, 31(84), 127-131.
11. Świderski A., Borucka A., Jacyna-Gołda I., Szczepański E. Wear of brake system components in various operating conditions of vehicle in the transport company, Eksploatacja i Niezawodność – Maintenance and Reliability, 1(29), 2019, 1-9.
12. Świderski A., Borucka A., Skoczyński P.: Characteristics and Assessment of the Road Safety Level in Poland with Multiple Regression Model, Transport Means 2018, Proceedings of the 22nd International Scientific Conference part I, Lithuania 2018, s. 92 – 97.
13. Wsparcie i zabezpieczenie techniczne Sił Zbrojnych Rzeczypospolitej Polskiej, Zasady funkcjonowania, DD-4.22(A), Warszawa 2017.

Eliza Łagowska
eliza.lagowska@student.wat.edu.pl
Military University of Technology, 2 Gen. Sylwestra Kaliskiego Str.; 00-908 Warsaw