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Rating of the Mobility of Military Logistic Vehicles Used in the Polish Armed Forces

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Abstract:

Mobility of military vehicles is a key element of military transport and it guarantees safety of the logistic system of the Armed Forces. The aim of this article is to compare medium-load and high-mobility means of transport belonging to the Polish Armed Forces and to identify the vehicle with the best parameters. The Analytic Hierarchy Process method was used for this, and this paper approximates its assumptions and process. Seven vehicles currently in use by the Polish Armed Forces were compared. As a result of the analysis, a hierarchy of the studied vehicles was established, ranking them from the highest to the lowest rated. The paper allows to assess whether the currently purchased Jelcz 442.32 is a good choice in the procuring policy of the Polish army.

Keywords:

analytic hierarchy process, military logistics, military vehicles, multicriteria decision making

1 Introduction

Transportation is a very important part of the logistics system of the armed forces of any country. Regardless of the time of peace, crisis, or war, troops are required to move efficiently, and with them the appropriate equipment and resources [1, 2]. In times of conflict, the use of transportation includes the delivery of supplies necessary for the success of military operations, while in peacetime it is primarily concerned with meeting training needs. In both the first and second cases, military transportation often takes place over terrain that is difficult to traverse, so appropriately constructed all-terrain trucks are necessary to traverse it. Mobility of military vehicles is therefore an important determinant of logistical security of the Armed Forces of the Republic of Poland [3].

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Consequently, it is reasonable to conduct research on which of the possessed means of transport are best suited to meet the requirements, and which vehicles should be either modernized or replaced. Such an analysis would also provide direction for making new transportation fleet acquisitions in the Army. The authors found no other studies in the literature addressing the topic of the submitted article.

Analysis of technical objects that differ in many parameters is a complex problem. Because of the large amount of data needed to be analysed at one time, it is difficult to know with certainty which option is the best one. In such a situation, multi-criteria decision making (MCDM) methods are applicable to rank the options in order of the most to the least desirable ones and to make the best choice. One such method is the Analytic Hierarchy Process (AHP), which was proposed by Thomas L. Satty. AHP allows for a hierarchical structure in the decision-making process by evaluating criteria expressed both quantitatively and qualitatively [4]. This method is thus versatile and applicable in many fields. The breadth of applications of AHP was explored in work by Ishizaka and Labib [5]. Researchers have also used the method in the field of transportation for applications such as public transportation mode choice [6], identification of the optimal means of air transport [7] or determination of the best electric car [8].

The aim of this article is to compare means of transport of medium capacity and high mobility being in the equipment of Polish Armed Forces using the AHP method and to determine which of the vehicles has the best parameters in terms of adaptation to their requirements.

The scope of the research in question includes:

- developing a list of medium-duty, high-mobility all-terrain vehicles currently in use by the Polish Armed Forces along with their capabilities,
- assessing the significance of criteria through pairwise comparisons,
- determining local and global preferences for the vehicles shown,
- classification of the analysed means of transport.

2 Analytic Hierarchy Process Method

AHP is a structured technique for organizing and analysing complex decision problems based on mathematics and psychology. It is primarily used to support the selection of the optimal decision option. The AHP method was developed by Professor Thomas L. Saaty in the 1970s and is still being researched and refined. It stands out for its simplicity and flexibility in use compared to other multi-criteria decision-making methods. The strength of AHP is that it is relatively simple to solve complex decision problems by breaking them down into their component parts and building a hierarchy of criteria. This makes the meaning of the elements (criteria) clear and understandable. As a result of the analysis, the researcher obtains a hierarchy of the options being compared and, in addition to ranking them, can determine how much difference there is between the options [9].

The first step in AHP is to create a matrix that allows criteria to be listed in pairs, and then each pair is compared to each other [10]. The result of such a comparison is evaluated according to the scale shown in Tab. 1. The weight of the more important element is expressed as a number between 1 and 9 depending on the strength of the element being compared relative to the other, and the weight of the less important element in the pair is its inverse (e.g. 1/3, 1/5) [6].

Tab. 1 Rating scale for pairwise comparisons in the AHP method [10, 11]

Intensity of Importance	**Verbal judgment of preferences**
1	Equally preferred
3	Moderately preferred
5	Strongly preferred
7	Very strongly preferred
9	Extremely preferred
2, 4, 6, 8	Intermediate values between the two adjacent judgments

The next step is to normalize the values in the created matrix. This is done by dividing all the values in the matrix by the sum of the values of the corresponding column. This way, a normalized criteria preference matrix is obtained. From it, the weight of each criterion – w_j – can be calculated. It corresponds to the mean value of each row of the normalized matrix [10].

An analogous procedure is followed to create an option preference matrix for each of the adopted criteria. The matrices are then normalized and as described above, averages are calculated corresponding to the local preferences of the option i depending on the criterion j which corresponds to the value l_{ij} from Eq. (1) [10].

The final step in arriving at an overall rating for each of the options studied is a synthesis of local priorities. Equation (1) is used for this purpose. The results obtained allow comparing the options and choosing the best solution [5].

$$p_i = \sum_{j=1}^{n} w_j l_{ij} \tag{1}$$

where:

p_i – the global priority of the alternative,

w_j – the weight of the criterion j,

l_{ij} – the local priority,

The detailed methodology of AHP with flowcharts, algorithms, and formulas is more fully presented in the literature by Saaty [10].

3 Conducting an Analysis for the Selected Vehicles

For the analysis using the AHP method, the following criteria were selected for evaluating medium-duty, high-mobility all-terrain vehicles: the type of drive used – number of driven axles, the type of tires used, specific power, average fuel consumption, maximum speed, maximum range at full tank filling, payload, ground clearance, angle of charge and descent [12]. The data collected are included in Tab. 2.

The first step in performing the comparative analysis was to create and complete a criterion precedence matrix in which individual criteria were compared in pairs. Priority scores were selected according to Tab. 1 and placed in the matrix Tab. 3.

For the criteria precedence matrix data to be useful, it firstly had to be normalized. To do this, the sums of the grade values in each column were counted, and then each value in the column was divided by its sum. This way, a normalized criteria precedence matrix was obtained. Then, the mean in each row was calculated to determine which criterion the authors believe is most important and what weight w_j has from Eq. (1). The obtained results are presented in Fig. 1.

Tab. 2 Summary of parameters of high mobility medium duty vehicles [13-24]

Criterion	**Star 266**	**Star 266M2**	**Star 1466**	**Star 944**	**Jelcz 442.32**	**Mercedes-Benz Atego**	**Mercedes Benz 1017A**
Drive type	6 × 6	6 × 6	6 × 6	4 × 4	4 × 4	4 × 4	4 × 4
Tires	single	single	single	single	single	single	twins
Specific power [kW/t]	8.9	10.3	12.5	11.8	15.2	13.6	10.4
Fuel consumption [l/100 km]	29	30	33	25	36	21	31
Maximum speed [km/h]	90	90	86	95	85	86	81
Maximum range [km]	1040	650	740	650	830	600	435
Payload [kg]	5 000	5 000	6 000	4 000	6 000	5 500	5 400
Ground clearance [mm]	325	325	350	312	400	246	288
Charge angle [deg]	37	37	35	39	35	27	25
Descent angle [deg]	42.5	42.5	40.0	41.0	35.0	18.0	23.0

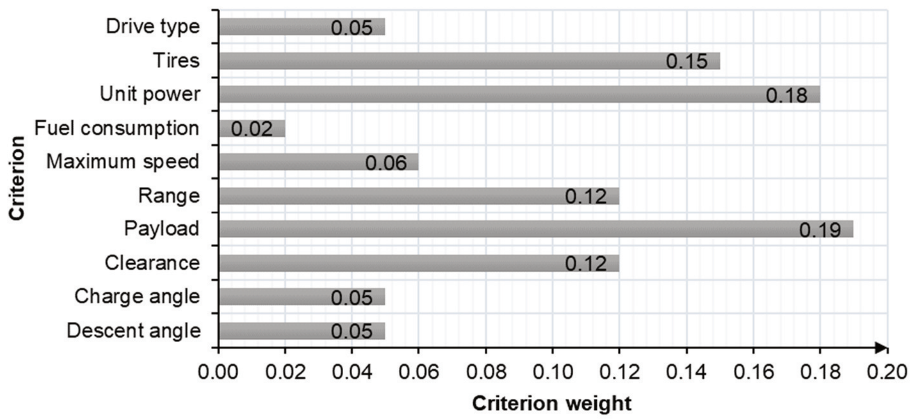

Fig. 1 Criteria priority weights

Tab. 3 Criteria precedence matrix

	Drive type	Tires	Specific power	Fuel consumption	Maximum speed	Range	Payload	Clearance	Charge angle	Descent angle
Drive type	1	1/3	1/5	5	3	1	1/5	1/3	1/3	1/3
Tires	3	1	1/3	5	3	3	1/3	3	3	3
Specific power	5	3	1	7	5	2	1	1/2	3	3
Fuel consumption	1/5	1/5	1/7	1	1/5	1/5	1/7	1/4	1/4	1/4
Maximum speed	1/3	1/3	1/5	5	1	1/4	1/5	1/3	3	3
Range	1	1/3	1/2	5	4	1	1	2	3	3
Payload	5	3	1	7	5	1	1	2	4	4
Clearance	3	1/3	2	4	3	1/2	1/2	1	3	3
Charge angle	3	1/3	1/3	4	1/3	1/3	1/4	1/3	1	1
Descent angle	3	1/3	1/3	4	1/3	1/3	1/4	1/3	1	1
Total	**24.5**	**9.2**	**6.0**	**47.0**	**24.9**	**9.6**	**4.9**	**10.1**	**21.6**	**21.6**

Based on Fig. 1, the most significant parameters of the analysed vehicles are payload, unit power and the type of tires used. Vehicles that have high values in these categories will also have high overall scores. Average fuel consumption proved to be the least significant parameter and therefore it will have the least impact on the overall rating of the compared vehicles.

In the next step, vehicle preference matrices were performed. Since some parameters are descriptive and the rest have quantifiable values, two approaches were needed to assign ratings in the preference matrices. For the descriptive parameters (drive type criterion and tires), the rating values were predetermined. When the paired comparison vehicles had the same number of driven axles or the same type of tires, they received a rating of 1. When they had a higher number of driven axles relative to the comparison vehicle or had single tires instead of twin tires, they received a rating of 5. For numerical parameters to determine how much advantage one vehicle has over another, ranges of advantage values were developed. The highest and lowest value was selected for each parameter. The minimum value was subtracted from the maximum value to obtain a range, which was then divided into 9 parts. Each of these sections was assigned a score from 1 to 9 depending on the magnitude of the advantage. To complete the vehicle preference matrices, the differences in the values of a given parameter were calculated for each pair of vehicles and assimilated to the preference sub-ranges developed earlier, allowing the appropriate score to be assigned for each pair of vehicles. This way, separate matrices were developed for each criterion, which were then normalized analogous to the procedure described for the criteria precedence matrix. In the resulting matrices, an average was determined in each row, which determines the preference index of a particular vehicle over the corresponding criterion – l_{ij} from Eq. (1).

The final step to complete the AHP analysis and to undertake the interpretation of the results obtained was to calculate the overall preference indices for each of the cars analysed. These calculations were based on Eq. (1) and the results are shown in Fig. 2.

The presented chart shows the advantage of Jelcz 442.32 over other vehicles in the segment of medium-load, high-mobility vehicles. This is in line with the current procuring policy of the Armed Forces of the Republic of Poland, which have selected this particular vehicle as the basic medium-payload high-mobility vehicle, and further copies are being produced and delivered to the army [25]. The car that took the second place in the classification was Star 1466. Unfortunately, despite the fact that its position is high, it is impossible to purchase it anymore, and thus to supplement the car fleet of the Polish Armed Forces. The same is true of the remaining Star vehicles, since MAN, which took over the Starachowice plant, has ceased the production of those models.

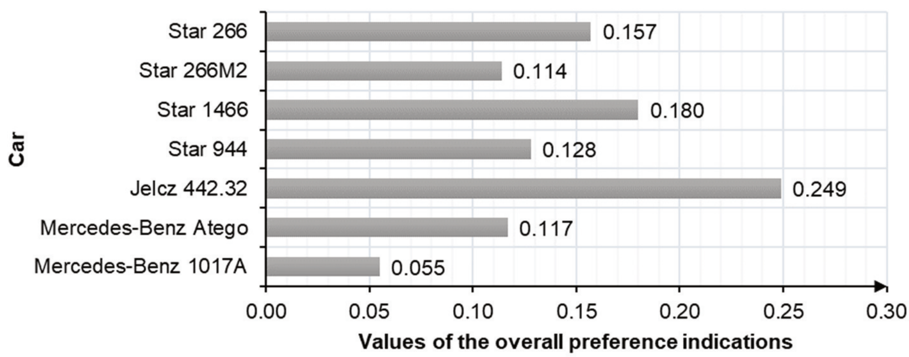

Fig. 2 Values of overall preference indicators

4 Conclusion

The analysis has shown that the most important parameters concerning the analysed vehicles are payload, unit power and type of tires. Proper specification of the requirements for the parameters of the vehicle is crucial from the point of view of its suitability for the Polish Armed Forces. The application of multi-criteria analysis using the AHP method made it possible to compare different vehicles, characterized by a number of parameters, with each other and assess which ones are most desirable.

With the criteria assumed by the authors, the analysis indicated that the Jelcz 442.32 vehicle is the best vehicle in the segment of medium-load trucks of high mobility that the Polish Armed Forces have. The article indicates that the procurement of the discussed Jelcz vehicles is a good choice, and Polish Armed Forces should continue its purchasing policy in order to increase the logistic security of the Polish Armed Forces.

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