Systems Logistyczne Wojsk
Zeszyt 57 (2022)
ISSN 1508-5430, s. 19-40
DOI: 10.37055/slw/163232

Instytut Logistyki
Wydział Bezpieczeństwa, Logistyki i Zarządzania
Wojskowa Akademia Techniczna
w Warszawie

Military Logistics Systems
Volume 57 (2022)
ISSN 1508-5430, pp. 19-40
DOI: 10.37055/slw/163232

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in Warsaw

The ELECTRE I decision supporting method in the selection of the organization of the transport of oversized military equipment

Metoda ELECTRE I wspomagania decyzji w doborze organizacji przewozu ponadgabarytowego sprzętu jednostek wojskowych

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Abstract. The publication presents an example of the application of the selected method of multi-criteria consideration. The purpose of the research undertaken was to identify the leading technical and technological features of oversized low-loader combinations used in the structures of the Polish Army and units of the United States Army, and to select the most favorable decision option using the ELECTRE I multi-criteria method. The research area analyzed in the publication is very important from the point of view of military units, with emphasis on the ever-increasing total weight and dimensions of this type of combat vehicles used by the Polish Army. The article reviews the literature on the essence and importance of multi-criteria methods. Identification of technical parameters of vehicles used in the transportation of militaria was made, taking into account their individual equipment, necessary during the organization of

transportation. In the second part of the article, a multi-criteria analysis of vehicle assemblies used in the movement of the heaviest combat units was carried out using the ELECTRE I method. The analysis of the results shows that the parameters that had the greatest impact on the course of the study were: maximum engine torques and the permissible weight of the transported load. The study indicates that the most favorable solution turned out to be the vehicle combination offered by the American company Oshkosh.
Keywords: multi-criteria analysis, decision variant, oversize cargo, ELECTRE I method, fifth-wheel tractora

Abstrakt. W publikacji przedstawiono przykład zastosowania wybranej metody rozważania wielokryterialnego. Celem podjętych badań było wyłonienie wodzących cech techniczno-technologicznych ponadnormatywnych zestawów niskopodwoziowych stosowanych w strukturach Wojska Polskiego i jednostkach Armii Stanów Zjednoczonych oraz wyłonienie najkorzystniejszego wariantu decyzyjnego przy użyciu metody wielokryterialnej ELECTRE I. Obszar badawczy analizowany w publikacji jest bardzo ważny z punktu widzenia jednostek wojskowych, z naciskiem na ciągle rosnącą masę całkowitą oraz wymiary tego typu pojazdów bojowych wykorzystywanych przez Wojsko Polskie. W artykule dokonano przeglądu literatury dotyczący istoty i znaczenia metod wielokryterialnych. Dokonano identyfikacji parametrów technicznych pojazdów wykorzystywanych w przewozach militariów uwzględniając ich indywidualne wyposażenie, niezbędne w trakcie organizacji przewozu. W drugiej części artykułu przeprowadzono analizę wielokryterialną zespołów pojazdów stosowanych w przemieszczaniu najcięższych jednostek bojowych z zastosowaniem metody ELECTRE I. Analiza wyników wskazuje, że największy wpływ na przebieg badań miały parametry: maksymalne momenty obrotowe silników oraz dopuszczalna masa przewożonego ładunku. Przeprowadzone badania wskazują, że najkorzystniejszym rozwiązaniem okazał się zespół pojazdów oferowany przez Amerykański koncern Oshkosh.
Słowa kluczowe: analiza wielokryterialna, wariant decyzyjny, ładunek ponadnormatywny, ELECTRE I, ciągnik siodłowy

Introduction

The dynamically developing logistics and its branch, which is oversize road transport, cause some kind of difficulties in the selection of appropriate means of transport for specific transport tasks. A tool that can support the decision-maker in the optimal adaptation of vehicle specifications to the planned transports is one of the scientific fields called multi-criteria decision support.

Military transport is a specialized field of oversize transport that requires careful planning of the project, flexibility and the use of various forms of transport. The character of this type of transport is mainly a result of physical and functional characteristics of the transported cargo. Self-propelled vehicles used by the military are characterized by a high curb weight and a width exceeding the gauge of standard semi-trailers. Another factor that gives the arms transport its individual character is the fact that this transport, unlike the transport for civil purposes, very often takes place in „difficult terrain", on unpaved land or off-road. Therefore, it is very important to properly adapt the tractor units and ballast vehicles used for this type of oversize transport and the individual configuration of low-loader semi-trailers in terms of the technical parameters of the transported cargo.

Literature review

According to the authors (Jacyna,2022; Saaty,1996), we can call multi-criteria decision support the activity of the analyst, who can be both an advisor and an expert to the decision-maker in the decision-making process. It is the analyst who assists the decision-maker in obtaining answers to questions arising from the search for the most desirable solutions, taking into account multiple sub-criteria for a given decision-making situation. The decision maker tasks include set-ting the goals of decision-making process, defining preferences and the final evaluation of the final solution obtained. On the other hand, on the side of the analyst, who is an external entity in relation to the analyzed decision problem, it is necessary to develop and supervise the course of decision support process.

Making optimal decisions by decision makers coming from different areas of the economy, production, as well as during the selection of investment projects, is very difficult by its complexity. The level of difficulty is dictated by the multiplicity of goals of the various stake-holders who are the different links in the decision--making process. Usually their goals are contradictory and they prefer different aspects (Goodwin, Wright, 2011; Ignasiak, 2001).

Every decision-maker in his professional or business activity faces the problem of choosing optimal decisions, both minor and very important ones. Decisions are significantly influenced by many factors, such as: amount of resources, financial situation, or expectations of particular stakeholders.

Analyzing the decision-making process, it can be noticed that when selecting the most favorable decision, the decision-maker usually uses not one, but several criteria simultaneous-ly. The set of different criteria determines the need to search for appropriate methods and reliable tools used to support decisions allowing their assessment from the point of view of many criteria.

Considering the variety of aspects that should be taken into account, the overall multi-criteria decision support comes down to choosing the best decision having regard to all the limitations and preferences of the decision maker. It is important that for each variant, a risk analysis of the feasibility of a given decision and its consequences in the event of implementation should be carried out. Figure 1 presents the selection of the best variant in general terms.

In the analysis of complex decision-making problems, there may be situations in which a set of decisions is divided into individual subsets established according to certain rules or norms (Trzaskalik, 2014). The process of the aforementioned search is carried out in an orderly manner, according to the implementation of successive steps, among which we can distinguish:

- identification of the decision-making situation,
- outlining the decision problem,
- construction of the decision model,

- determination of acceptable decisions and optimal decisions,
- making the final decision,
- implementation of the decision made.

The process approach outlined in the above paragraph is closely related to the way of achieving the goal by allocating resources in such a way as to maximize the effects resulting from the implementation of a given project (Devenport,1993). Figure 2 illustrates the procedures for selecting an effective option for a given decision-making process.

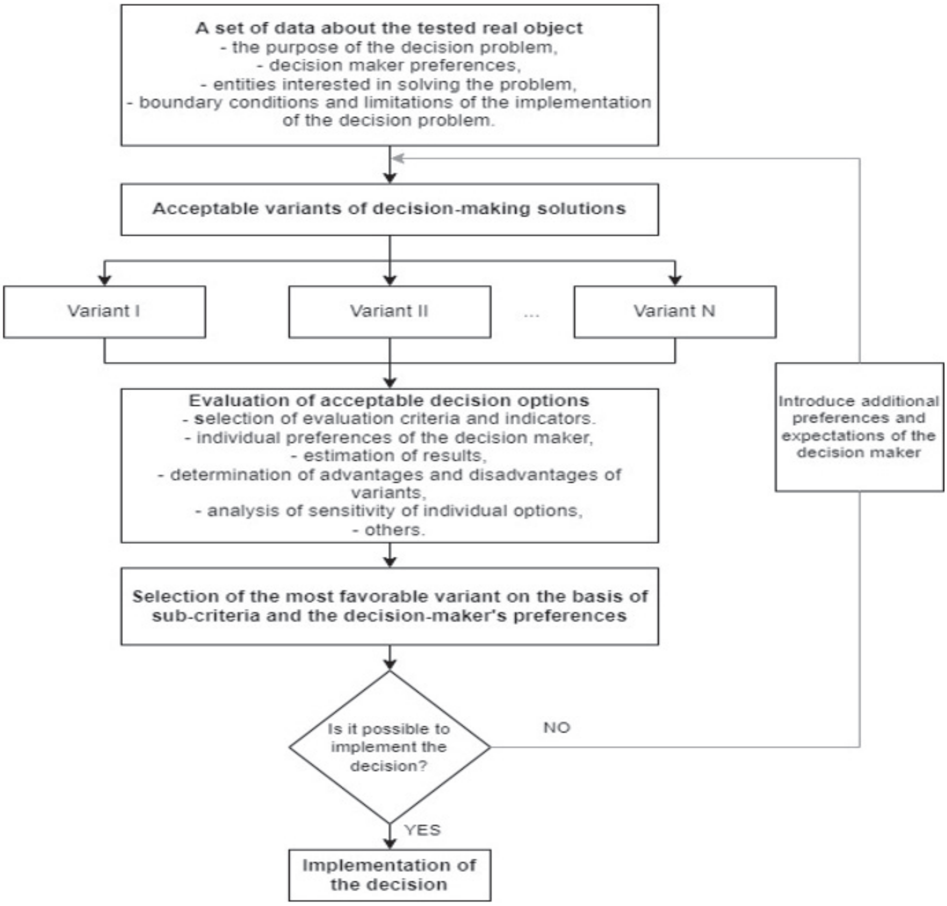

Fig. 1. The scheme of selecting the best decision variant from among the admissible solutions
Source: Own elaboration based on (Jacyna, 2022)

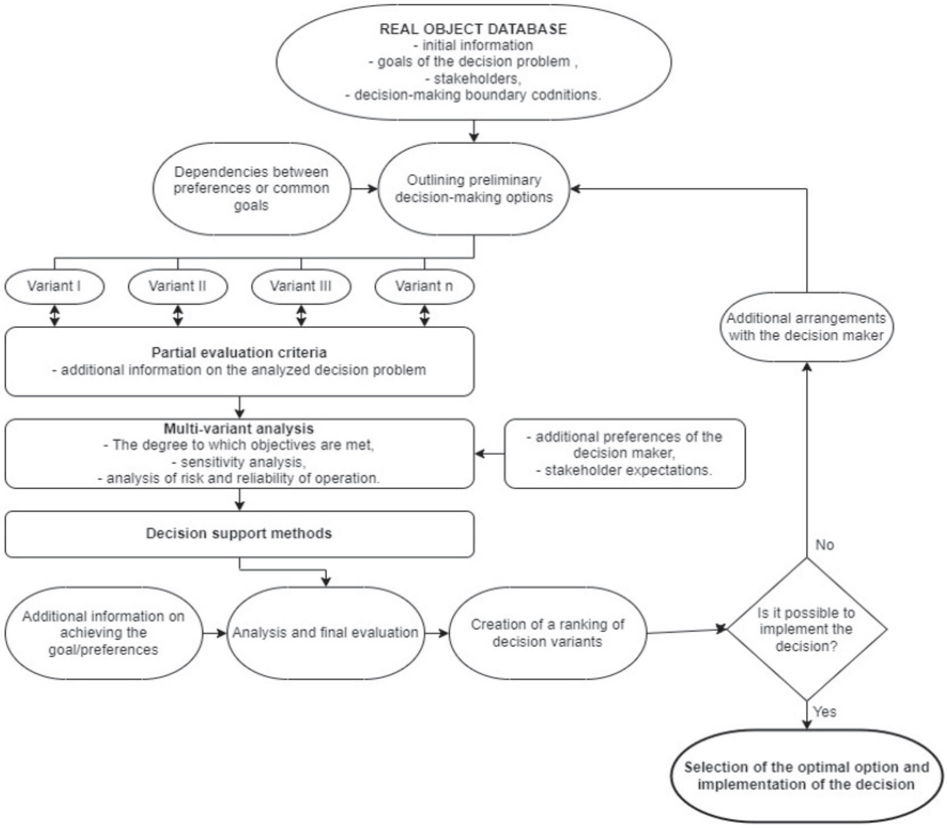

Fig. 2. The scheme of selecting the most favorable decision from among the admissible decision variants
Source: Own elaboration based on (Jacyna, 2022)

The development of multi-criteria analysis tools is mainly based on the specificity or class of problems being solved. The methods have undergone numerous modifications and improvements over the years, creating a kind of "families" of methods. The number of classes and mentioned families of multi-criteria evaluation methods is very wide, and its range covers each area of engineering practice (Simiński, Wardencki, Kończak, 2015).

There are many ways to classify multi-criteria methods in the literature, although the simplest way is to classify the methods on the basis of the main mechanism preferred by a given method. We can distinguish:

– Methods based on the exceedance relation (the best example is the family of ELECTRE and PROMETHEE methods) - the methods allow for the phenomenon of incomparability of variants, i.e., a situation in which the decision-maker is not able to indicate the better variant out of the two available. The height difference relation has a binary character and is defined on a set of variants (Roy, 1990).

- Methods based on the utility function (for example: Analytic Hierarchy Process) – a given feature is assigned a measure describing the utility, resulting from the individual preferences of the decision maker. The variety of criteria can be aggregated into a single utility function, which in turn is optimized. Knowledge of the utility parameter makes it possible to organize the set of decision variants and to identify the one most preferred by the decision maker (Vaidya, Kumar, 2006).
- Methods based on pairwise comparisons - these are sets of decision rules that use decision examples provided by decision makers in the form of pairwise comparisons of reference objects. The compiled examples form an array of pairwise comparisons and are analyzed on a *Dominance-based rough set approach* (DRSA) to generate decision rules that represent the decision maker's preferences(Simiński, Wardencki, Kończak, 2015).
- Other methods, including interactive methods (trial-and-error methods, dialogic local evaluations), which involve alternating the computational and decision-making phases. They are built taking into account the specific features of the problem and require the decision-maker to make a more adventurous choice of the optimal variant.

The family of multi-criteria assessment methods is extremely rich. Many methods are also used in the field of transport and logistics, such as:

- Analytic Network Process (ANP) (Leung, Lam, Cao, 2006),
- Choosing By Advantages (CBA) (Arroyo P., Molinos-Senante M., 2018),
- Conjoint Value Hierarchy (CVA) (Scholl, Manthey, Helm, Steiner, 2005),
- Disaggregation – Aggregation Approaches (UTA) (Siskos, Grigoroudis, 2010),
- Fuzzy Simple Additive Weighing Method (F-SAW) (Afshari, Yusuff, Derayatifar., 2012),
- Measuring Attractiveness by a categorical Based Evaluation Technique (MACBETH) (Dachyar, Pratama, 2014),
- Simple Multi-Attribute Rating Technique (SMART) (Siregar, Arisandi, Usman, Irwan, Rahim, 2017),
- Stratified Multi Criteria Decision Making (SMCDM) (Asadabadi, 2018),
- MAJA (Jacyna,1998),
- Multi-attribute utility theory (MAUT) oraz multi-attribute value theory (MAVT) (Loro, Mangiaracina, 2021; Zietsman, Rilett, Kim, 2006),
- Markovian Multi Criteria Decision Making (Fazlollahtabar, Saidi-Mehrabad, 2015),
- Simple Additive Weighting Method (SAW) (Jaberidoost, Olfat, Hosseini, Kebriaeezadeh, Abdollahi, Alaeddini, Dinarvand, 2015),
- Simple Multi-Attribute Ranting Technique (SMART) (Vaidya, Kumar, 2006),

– Simple Multi-Attribute Ranting Technique Exploiting Ranks (SMARTER) (Tangkesalu, Suseno, 2018),
– Technique for the Order of Prioritisation by Similarity to Ideal Solution (TOPSIS) (Bhutia, Phipon, 2012).

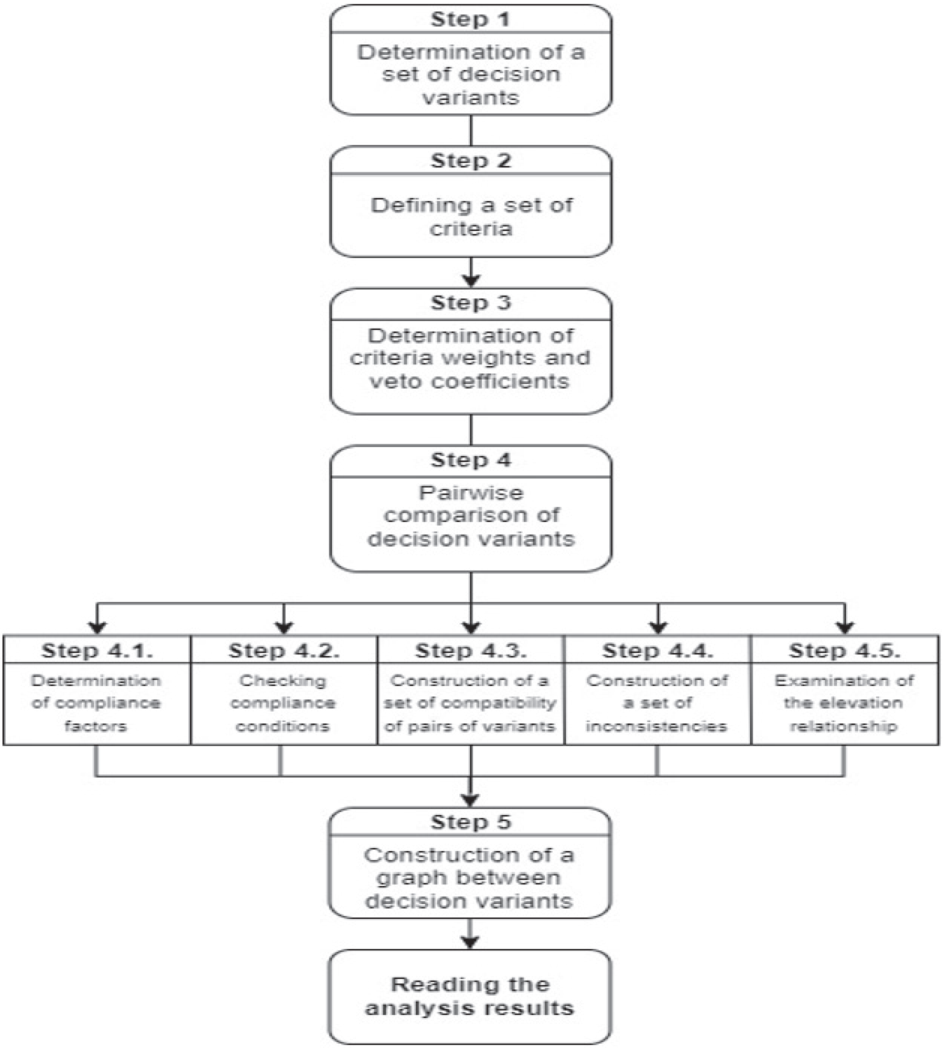

Fig. 3. The algorithm of proceeding in the ELECTRE I method
Source: Own elaboration

The above is a compilation of multi-criteria methods suitable for solving problems in the field of transportation, such as matching optimal financing of transportation means or selection of public transport vehicles, etc. Given the multitude of multi--criteria methods used in engineering practice, the ELECTRE I method, developed by Bernard Roy, was applied to the problem analyzed in this publication. The ELECTRE (Elimination et Choix Traduisant la Realite) family of methods is among the earliest developed methods of multi-criteria decision support. The method is based on dialogical ordering of alternatives. Methods belonging to the ELECTRE family adopt the axiom of limited comparability of alternatives, which is determined by recognizing four basic relationships: I - equivalence, P - strong preference, Q - weak preference and R – incomparability (Wasiak, 2016; Wasiak 2018).

The purpose of the analyses performed using the ELECTRE I method is to create preference groups. Based on the analyses performed, it can be concluded that the a_i variant placed at a higher level than the a_j variant should be considered more favorable than the a_j variant due to the relationship with all variants. All criteria are evaluated on the same rating scale. For each pair of decision variants, the set of concordance, the concordance coefficient, the veto threshold, the set of discordance and the predominance relation are determined (Wasiak, 2016; Wasiak, 2018). Figure 3 shows the general flowchart of the analysis performed using the ELECTRE I method.

Characteristics of oversize vehicles used to transport combat vehicles used by units of the Polish Army Identification of specific features of oversized loads on the example of self-propelled military vehicles

In the transportation of armored combat vehicles used in the Polish Army, it is necessary to organize a complex logistical process to enable the movement of such equipment. The reason for this is the relatively low durability of the running gear of such vehicles. Tracked chassis perform excellently in heavy, often boggy terrain, while when covering long distances, the running components wear out with much greater intensity. In order to increase service intervals on this type of equipment, they are transported to the point of destination as much as possible using road transport.

Another aspect that generates the need to transport armored combat vehicles by road means of transport, even for short distances of the order of 50 km, is the extremely high fuel requirements. For comparison, fuel consumption for the heaviest combat vehicles equipped with tracked chassis can reach up to several hundred liters per 100 km, where in the case of trucks used for transporting oversized cargo, combustion of 50 liters after covering the same distance is already a slightly exaggerated value.

Armored combat vehicles used by units of the Polish Army are characterized by an oversized width that can reach a ceiling of four meters. Cargo of this type requires the organization of transport processes using means of transport dedicated to the specifics of the cargo. An equally important technical parameter of vehicles that are part of the armament of the ground forces is their high total weight. The empty weight of combat vehicles oscillates in the interval from about 13 tons starting from combat reconnaissance vehicles to about 66 tons in the case of M1A2 "Abrams" tanks.

Characteristics of oversized low-loader vehicles used in transport

Oversize loads are characterized by a mass that sometimes exceeds the permissible load capacity of a standard semi-trailer several times, and external dimensions that significantly exceed the vehicle gauge. In the case of the transport of oversized combat equipment used by military units, there is an additional aspect of the surface on which the transport takes place, which significantly hinders the organization of the project. Moving military items, like ordinary cargo, takes place to a large extent on bituminous road surfaces, but in the case of specialized exercises or an armed conflict, transport takes place bypassing communication routes.

The fifth-wheel tractors cooperating with low-bed semi-trailers, used for the transport of heavy weapons, must meet the road traffic requirements and, additionally, should have features that enable movement in "difficult terrain". In case of transport in unfavorable terrain conditions, it is necessary to use vehicles equipped with all-wheel drive. This type of solution allows to increase the traction properties of the vehicle. The high weight of the transported combat vehicles, the curb weight of the low-loader sets and the transport in unfavorable areas generate the need to use high-capacity engines, the power of which oscillates in the range of 650-700 horsepower. Another undeniable aspect is the clearance of oversized low-loader sets used by military units, achieved mainly through the use of tall tires.

Iveco Trakker is a fifth-wheel tractor constituting the basic tool for the transport of oversized armored vehicles used by the Polish Army. The vehicle is characterized by a three-axle suspension and all-wheel drive (6x6). These versions of Iveco vehicles are powered by Cursor 13 engines, in a 6-cylinder in-line arrangement, with a displacement of 12.9 liters, a maximum power of 500 horsepower and 2200 Nm of torque (Simiński, Wardencki, Kończak, 2015).

The tractors work together with semi-trailers from DEMARKO Special Trailers, characterized by six-axle suspension with the last three steering axles, which ensures better maneuverability of the vehicle combination and reduces tire wear. Cargo surfaces of this type of trailers allow transport of combat vehicles, whose width can reach up to 3.70 meters. Table 1. below presents the basic data of the discussed Iveco Trakker truck tractor cooperating with an oversized Demarko semi-trailer.

Table 1. Basic data of the low-loader vehicle unit

Iveco Trakker, Demarko low loader semi-trailer		
No.	Parameter	Value
1.	Engine rated power	500 hp
2.	Max. engine torque	2200 Nm
3.	Type of suspension	3 axles, all-wheel drive (6x6)
4.	Max. load capacity	56 tons

Source: Own elaboration based on (Simiński, Wardencki, Kończak, 2015)

Another fifth-wheel tractor used in the structures of the Polish Army is the Jelcz 882.62 assembled by the Jelcz Sp. z o.o. company. The vehicle has a four-axle suspension and all-wheel drive (8x8). It is one of the heaviest units in the structures of the Polish Armed Forces used for transporting armaments. The version of the vehicle in question is based on an engine with a displacement of 15.6 liters and six cylinders in an in-line arrangement. The unit generates 625 horsepower and 3000 Nm. of torque.

Jelcz vehicles work with ST775-20W semi-trailers manufactured by DEMARKO Special Trailers. The trailers used are based on seven-axle suspension with five torsion axles. The use of torsion axles, as in the previously described case, greatly facilitates maneuverability of the long set and reduces tire wear. The discussed low-loader set was composed in order to move oversized combat vehicles weighing up to 70 tons in the most difficult off-road conditions. Table 2. shows the basic data of the discussed truck tractor Jelcz 882.62 cooperating with an oversized semi-trailer of the ST775-20W series (Sweklej, Żółtowski, 2021).

Table 2. Basic data of the low-loader vehicle unit

Jelcz 882.62, Demarko ST775-20W low loader semi-trailer		
No.	Parameter	Value
1.	Engine rated power	625 hp
2.	Max. engine torque	3000 Nm
3.	Type of suspension	4 axles, all-wheel drive (8x8)
4.	Max. load capacity	70 tons

Source: Own elaboration based on (Sweklej, Żółtowski, 2021)

Another solution used by the Polish Armed Forces is the heavy truck tractor FAUN SLT 50-2 “Elefant”. It is a construction of German origin, purchased together with the German Leopard 2 tanks. The vehicle has a four-axle all-wheel drive suspension (8x8). The drive is a high-capacity diesel engine of the German concern Deutz AG. The engine with a capacity of 29.9 liters and 8 cylinders in the V-shape generates a power of 730 km and 2600 Nm. of torque.

The vehicles produced by the German concern cooperate with the KRUPP--Kässbohrer Sa Anh. 52t. trailers. The German concern’s semi-trailers are based on slightly different solutions compared with modern low-loader trailers, which translates directly into increased mobility of the vehicle combination. The main aspect that increases the driving characteristics is the use of tires of the same size on the truck tractor and semi-trailer. German engineers estimated the payload capacity of the tank transporter at 52 tons. Table 3 below presents the basic data of the discussed FAUN SLT 50-2 truck-tractor cooperating with an oversized semi-trailer manufactured by KRUPP-Kässbohrer (Simiński, Wardencki, Kończak, 2015).

Table 3. Basic data of a tank transporter of German origin

FAUN SLT 50-2, KRUPP-Kässbohrer Sa Anh. 52t. low loader semi-trailer		
No.	Parameter	Value
1.	Engine rated power	730 hp
2.	Max. engine torque	2600 Nm
3.	Type of suspension	4 axles, all-wheel drive (8x8)
4.	Max. load capacity	52 tons

Source: Own elaboration based on (Simiński, Wardencki, Kończak, 2015)

Under the contract signed between state authorities and representatives of the commercial sector, tractor units from a German manufacturer will be used by the Polish Army in 2023. These will be Mercedes-Benz Zetros 3348AS vehicles. The vehicles will be equipped with a three-axle suspension and all-wheel drive (6x6). The vehicle variant in question will feature a 12.8-liter, six-cylinder engine. The unit will generate 476 horsepower and 2300 Nm. torque.

Under the signed contract will also include the delivery of semi-trailers NC wz. 21 produced by Dobrowolski Sp. z o. o. The low-loader platforms designed by the above-mentioned company will be equipped with six-axle suspension and four torsion axles. The delivered low-loader sets will be used to transport tanks and heavy military tracked equipment with a payload of more than 60 tons. Table 4 presents the basic data of the vehicle set in question (Sweklej, Żółtowski, 2021).

Table 4. Basic data of the low-loader vehicle unit

Mercedes-Benz Zetros 3348AS, Dobrowolski low loader semi-trailer		
No.	Parameter	Value
1.	Engine rated power	476 hp
2.	Max. engine torque	2300 Nm
3.	Type of suspension	3 axles, all-wheel drive (6x6)
4.	Max. load capacity	60 tons

Source: Own elaboration based on question (Sweklej, Żółtowski, 2021)

The low-loader set used by the US Army consists of a four-axle all-wheel drive tractor (8x8) manufactured by Oshkosh Corporation. Hence the name of the described carrier (Oshkosh M 1070A1) from the name of the company. In the current version of these vehicles, the Caterpillar 18.1-liter in-line six-cylinder engine is responsible for the drive. The used C18 engine generates 700 horsepower and 3200 Nm. torque. In addition, the vehicle is equipped with single tires, which enables operation in the most difficult terrain and weather conditions.

The fifth-wheel tractors of the American Oshkosh concern cooperate with the M1000 low-loader semi-trailers (Simiński, Wardencki, Kończak, 2015; Sweklej, Żółtowski, 2021). The design of the aforementioned oversize trailers is based on a five-axle suspension, a feature of which is the use of hydraulic oscillating axles. The special feature of this type of suspension is the optimal contact of all wheels with the ground and the equal pressure of the tires in difficult road conditions. The M1000 semi-trailer has a total of 40 wheels and offers a maximum load capacity of 70 tons at a travel speed of 80 km/h and 80 tons at a travel speed of 45 km/h. Table 5 presents the basic data of the discussed vehicle combination.

Table 5. Basic data of the low-loader vehicle combination used by the United States Army

Oshkosh M 1070A1, M1000 low loader semi-trailer		
No.	Parameter	Value
1.	Engine rated power	700 hp
2.	Max. engine torque	3200 Nm
3.	Type of suspension	4 axles, all-wheel drive (8x8)
4.	Max. load capacity	70 tons

Source: Own elaboration based on (Simiński, Wardencki, Kończak, 2015; Sweklej, Żółtowski, 2021)

Multi-criterial comparative analysis of oversized vehicles used for the transport of heavy combat vehicles
Initial assumptions for the analyzed research problem

The analysis of the oversize vehicles used in the structures of the Polish and American troops was performed on the basis of the criteria discussed in the previous section. In addition, a five-point scale was adopted, in which the grade 1 indicates little fulfillment of a given criterion, while note 5 indicates that the criterion is met to a very high degree.

The adopted evaluation criteria for fifth-wheel tractors:
- **MC** – Engine rated power [hp],
- **MO –** Maximal engine torque [Nm.],
- **Z** – Type of suspension,
- **DMC** – Permissible weight of the transported cargo [tons].

The work presents 5 low-loader sets that carry out logistic tasks, consisting in the transport of oversized military equipment in Poland and the United States:
- Iveco Trakker, Demarko semi-trailer – **Iveco**;
- Jelcz 882.62, Demarko ST775-20W semi-trailer – **Jelcz**;
- Faun SLT 50-2 „Elefant", KRUPP-Kässbohrer Sa Anh. 52t. semi-trailer – **Faun**;
- Mercedes-Benz Zetros 3348AS, Dobrowolski semi-trailer – **Mercedes-Benz**, **MB**;
- Oshkosh M 1070A1, M1000 low loader semi-trailer – **Oshkosh**.

Table 6 presents the basic technical data of five low-loader sets, which are the basis of the logistics base of the Polish Army and the United States Army. Table 7 shows the results of the assessment of five available solutions according to the adopted scale. The received assessments of individual options will be the basis for further considerations.

Table 6. Technical data of fifth-wheel tractors used in the structures of the Polish Army and the United States Army

Vehicle parameter	The size of the parameter				
Vehicle brand	Iveco	Jelcz	Faun	Mercedes-Benz	Oshkosh
Engine rated power [hp]	500	625	730	476	700
Engine torque [Nm]	2300	3000	2600	2400	3200
Type of suspension	3 axles, 6x6 drive	4 axles, 8x8 drive	4 axles, 8x8 drive	3 axles, 6x6 drive	4 axles, 8x8 drive
Permissible weight of the transported cargo [t]	56	70	52	60	70

Source: Own elaboration

Table 7. Results of the five available solutions assessment

Decision variants	Assessment criteria g_j			
	Criterion g_1 – Engine rated power [hp]	Criterion g_2 – Engine torque [Nm.]	Criterion g_3 – Type of suspension	Criterion g_4 – Permissible weight of the transported cargo [ton]
a_1 – Iveco	2	1	4	3
a_2 – Jelcz	3	4	5	5
a_3 – Faun	5	3	5	2
a_4 – MB	1	2	4	4
a_5 – Oshkosh	4	5	5	5
Wagi w_j	0.25	0.30	0.20	0.25
Progi weta v_j	1	2	4	2

Source: Own elaboration

The weights of the evaluation criteria wj and the veto thresholds vj were determined, and the level of compliance was assumed to be s = 0.50. The information provided above enables determination of elevation relationship on the basis of the ELECTRE I method.

Solving a decision problem using the multi-criteria decision support method – the ELECTRE I method

Stage 1 – *Determination of the compliance set.*

At the beginning, compliance tests were set for all pairs of decision variants (vehicle units), in relation to individual evaluation criteria. The results are summarized in zero-one matrices Φ, the expressions of which are: φ(a*i*, a*j*). Table 8 presents the results of the matrix in sequence: Φ_1, Φ_2, Φ_3, Φ_4.

Table 8. Compliance tests for the criterions: g_1, g_2, g_3, g_4

No.	The analyzed criterion	Result					
1.	Criterion g_1 – Engine rated power [hp]	Elements of matrix Φ_1	a_1	a_2	a_3	a_4	a_5
		a_1	1	0	0	1	0
		a_2	1	1	0	1	0
		a_3	1	1	1	1	1
		a_4	0	0	0	1	0
		a_5	1	1	0	1	1
2.	Criterion g_2 – Engine torque [Nm]	Elements of matrix Φ_2	a_1	a_2	a_3	a_4	a_5
		a_1	1	0	0	0	0
		a_2	1	1	1	1	0
		a_3	1	0	1	1	0
		a_4	1	0	0	1	0
		a_5	1	1	1	1	1
3.	Criterion g_3 – Type of suspension	Elements of matrix Φ_3	a_1	a_2	a_3	a_4	a_5
		a_1	1	0	0	1	0
		a_2	1	1	1	1	1
		a_3	1	1	1	1	1
		a_4	1	0	0	1	0
		a_5	1	1	1	1	1
4.	Criterion g_4 – Permissible weight of the transported cargo [t]	Elements of matrix Φ_4	a_1	a_2	a_3	a_4	a_5
		a_1	1	0	1	0	0
		a_2	1	1	1	1	1
		a_3	0	0	1	0	0
		a_4	1	0	1	1	0
		a_5	1	1	1	1	1

Source: Own elaboration based on (Jacyna, 2022;Trzaskalik, 2018)

Stage 2 – *Determination of compliance coefficients.*

Using the previously calculated values of the function φ (a_1, a_2) (listed in Table 8), we estimate the value of the compliance coefficients using the following formula:

$$c(a_1, a_3) = w_1\, \Phi_1(a_1, a_3) + w_2\, \Phi_2(a_1, a_3) + w_3\, \Phi_3(a_1, a_3) + \\ + w_4\, \Phi_4(a_1, a_3) = 0.25 \cdot 0 + 0.30 \cdot 0 + 0.15 \cdot 0 + 0.30 \cdot 1 = 0.30 \quad (1)$$

The determined compliance rates are summarized in Table 9.

Table 9. List of compliance factors

Elements of the matrix C	a_1	a_2	a_3	a_4	a_5
a_1	1.00	0.00	0.30	0.40	0.00
a_2	1.00	1.00	0.75	1.00	0.45
a_3	0.70	0.40	1.00	0.70	0.40
a_4	0.75	0.00	0.30	1.00	0.00
a_5	1.00	1.00	0.75	1.00	1.00

Source: Own elaboration based on (Jacyna, 2022;Trzaskalik, 2018)

The compatibility set for the threshold s = 0.50 has the following form

$$C_{0,50} = \{(a_2, a_1), (a_2, a_3), (a_2, a_4), (a_3, a_1), (a_3, a_4), (a_4, a_1), (a_5, a_1), (a_5, a_2), (a_5, a_3), (a_5, a_4)\}$$

Stage 3 – *Determination of a set of non-compliance.*

Checking the condition of non-compliance is performed only for pairs of variants for which the compliance condition is met. At this stage of considerations, the fulfillment of the condition of non-compliance for the pairs making up the compatibility set should be checked. The equations are made according to the following dependence.

(a_2, a_1): $g_1(a_2) + v_1[g_1(a_2)] \geq g_1(a_1)$ $(3 + 1 \geq 2)$ lack of non-compliance (3)

(a_2, a_3): $g_1(a_2) + v_1[g_1(a_2)] \geq g_1(a_3)$ $(3 + 1 \geq 5)$ identified non-compliance (4)

The results of the calculation of the non-compliance sets for the g_1-g_4 criteria are presented in Table 10. Number "1" means that for the pair (a_i, a_j) a non-compliance has been found due to the g_1 criterion, value of "0" occurs when the non--compliance is not found, in turn "-" means the case where the verification of the condition of non-compliance is not necessary due to the non-compliance condition for the pair (a_i, a_j).

Table 10. Determination the compliance test for the compared decision variants

<table>
<tr><th>No.</th><th>The analyzed criterion</th><th>Result</th></tr>
<tr><td>1.</td><td>Criterion g_1 – Engine rated power [hp]</td><td>
<table>
<tr><th>Criterion g_1</th><th>a_1</th><th>a_2</th><th>a_3</th><th>a_4</th><th>a_5</th></tr>
<tr><td>a_1</td><td>1</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>a_2</td><td>0</td><td>1</td><td>1</td><td>0</td><td>-</td></tr>
<tr><td>a_3</td><td>0</td><td>-</td><td>1</td><td>0</td><td>-</td></tr>
<tr><td>a_4</td><td>0</td><td>-</td><td>-</td><td>1</td><td>-</td></tr>
<tr><td>a_5</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
</table>
</td></tr>
<tr><td>2.</td><td>Criterion g_2 – Engine torque [Nm]</td><td>
<table>
<tr><th>Criterion g_2</th><th>a_1</th><th>a_2</th><th>a_3</th><th>a_4</th><th>a_5</th></tr>
<tr><td>a_1</td><td>1</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>a_2</td><td>0</td><td>1</td><td>0</td><td>0</td><td>-</td></tr>
<tr><td>a_3</td><td>0</td><td>-</td><td>1</td><td>0</td><td>-</td></tr>
<tr><td>a_4</td><td>0</td><td>-</td><td>-</td><td>1</td><td>-</td></tr>
<tr><td>a_5</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
</table>
</td></tr>
<tr><td>3.</td><td>Criterion g_3 – Type of suspension</td><td>
<table>
<tr><th>Criterion g_3</th><th>a_1</th><th>a_2</th><th>a_3</th><th>a_4</th><th>a_5</th></tr>
<tr><td>a_1</td><td>1</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>a_2</td><td>0</td><td>1</td><td>0</td><td>0</td><td>-</td></tr>
<tr><td>a_3</td><td>0</td><td>-</td><td>1</td><td>0</td><td>-</td></tr>
<tr><td>a_4</td><td>0</td><td>-</td><td>-</td><td>1</td><td>-</td></tr>
<tr><td>a_5</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
</table>
</td></tr>
<tr><td>4.</td><td>Criterion g_4 – Permissible weight of the transported cargo [t]</td><td>
<table>
<tr><th>Criterion g_4</th><th>a_1</th><th>a_2</th><th>a_3</th><th>a_4</th><th>a_5</th></tr>
<tr><td>a_1</td><td>1</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>a_2</td><td>0</td><td>1</td><td>0</td><td>0</td><td>-</td></tr>
<tr><td>a_3</td><td>0</td><td>-</td><td>1</td><td>0</td><td>-</td></tr>
<tr><td>a_4</td><td>0</td><td>-</td><td>-</td><td>1</td><td>-</td></tr>
<tr><td>a_5</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
</table>
</td></tr>
<tr><td>5.</td><td>Summary analysis</td><td>
<table>
<tr><th>Elements of the matrix D</th><th>a_1</th><th>a_2</th><th>a_3</th><th>a_4</th><th>a_5</th></tr>
<tr><td>a_1</td><td>1</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>a_2</td><td>0</td><td>1</td><td>1</td><td>0</td><td>-</td></tr>
<tr><td>a_3</td><td>0</td><td>-</td><td>1</td><td>0</td><td>-</td></tr>
<tr><td>a_4</td><td>0</td><td>-</td><td>-</td><td>1</td><td>-</td></tr>
<tr><td>a_5</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
</table>
</td></tr>
</table>

Source: Own elaboration based on (Trzaskalik, 2014)

Stage 4 – *Determination of the relationships of superiority*

Relationship of superiority for the pair (a_i, a_j) takes place when conditions of compliance and lack of non-compliance are met simultaneously (value "0"). This relationship was determined on the basis of the data contained in Table 9 and point 5 of Table 10. Results of relationship of superiority are presented in Table 11. Value "1" means that for the pair (a_i, a_j) both the compliance condition and the non-compliance condition are met (Jacyna, 2022).

Table 11. Designated relationships of superiority

	a_1	a_2	a_3	a_4	a_5
a_1	1	0	0	0	0
a_2	1	1	0	1	0
a_3	1	0	1	1	0
a_4	1	0	0	1	0
a_5	1	1	1	1	1

Source: Own elaboration based on (Jacyna, 2022)

Furthermore relationships of superiority were written by listing individual items as follows:

$$S(s, v) = C_s \cap Dv = \tag{5}$$

$$= \{(a_2, a_1), (a_2, a_4), (a_3, a_1), (a_3, a_4), (a_4, a_1), (a_5, a_1), (a_5, a_2), (a_5, a_3), (a_5,a_4)\}$$

Stage 5 – *Construction of a graph of dependencies between decision variants*

The variant that is not exceeded by any other variant was placed at the highest level, in the case of the analyzes it is the variant a_5. In accordance with the assumptions of the ELECTRE I method, variants that are only surpassed by the variant placed on the first level should be placed on the second level. These are the variants: a_2, a_3. Similarly, at the third level there should be variants surpassed by the variants from the first and second levels (variant a_4 is surpassed by variants a_2 and a_3). According to the above assumptions, the next level is a set of variants surpassed by the three higher levels, as can be seen (variant a_1 is surpassed by variants a_2 and a_3 from the second level and by the variant a_4 from the third level) (Jacyna, 2022; Trzaskalik, 2008).

Vertices of the graph are decision variants, while the arcs connecting the vertices are the superiority relations. Lack of arcs between the nodes means that the variants are incomparable. Based on the considerations, the a_5 variant represented by the set of Oshkosh M 1070A1 vehicles and the M1000 semi-trailers was found as the best, advantageous variants represented by vehicles used in the structures of the Polish Army are variants a_2 (Jelcz 882.62 with a Demarko ST775-20W semi-trailer) and variant a_3 (Faun SLT 50-2 "Elefant" cooperating with KRUPP-Kässbohrer Sa Anh. 52t. semi-trailer).

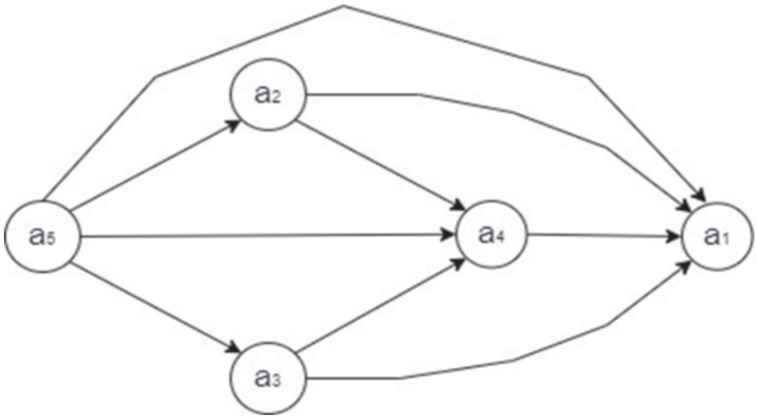

Fig. 4. Relationship graph between decision variants
Source: Own elaboration

Conclusions

In the case of carrying out multi-criteria analyzes in the field of heavy weapons transportation, it is necessary to know the requirements set by buyers on vehicles, factors that determine the selection of vehicles and individual conditions generated by combat equipment, which is also an oversize load.

The multi-criteria decision support methodology makes it possible to conduct research that supports the decision-maker making a decision on the selection of vehicles based on technical, technological and functional conditions. Research based on multi-criteria decision support can be an effective tool for carrying out analyzes aimed at the proper selection of vehicle combinations for individual transport tasks in the field of oversized transport of military vehicles.

A characteristic parameter of armored combat vehicles, compounding the specificity of the transportability of these devices, is their overall width, reaching a ceiling of 3.80 meters. This fact generates the need to use low-loader semi-trailers with increased width, both of the loading area and wheelbase, in relation to the oversize tractors used. When transporting in rough terrain, the tracks of fifth-wheel tractors and low-loader semi-trailers do not overlap, resulting in increased rolling resistance. The increase in rolling resistance, in turn, generates difficulties in the dynamics of the trip, and ultimately problems with the delivery of equipment to a specific location.

In the case of military transport, a significant aspect of the vehicles used is their universal character. The main determinant of the aforementioned versatility is the ability to use sets of oversized vehicles to service all combat units at the disposal of the army. In the case of the conducted analyzes, the following vehicles are leading in this criterion: Oshkosh M 1070A1, Jelcz 882.62 and Faun SLT 50-2 "Elefant". Technical parameters that have a decisive influence on the creation of the classification are: equipping the compared vehicles with all-wheel drive, engine torque and permissible total weight of the transported cargo.

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