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Concept and Evaluation of an Unmanned Ground System for Last Mile Logistic

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Abstract

This study addresses the issue of last-mile logistics tasks, particularly in areas inaccessible to conventional military vehicles. As a solution, the use of a homogeneous system composed of Unmanned Ground Vehicles is proposed. Ten UGVs (seven wheeled and three tracked) were selected and subsequently evaluated based on their primary parameters in order to identify the most suitable solution for implementation within such a system. The assessment was conducted using two methods: direct comparison of the UGVs with respect to the values of individual parameters, combined with the assignment of ranking scores, and the application of the Analytic Hierarchy Process (AHP).

KEY WORDS: *Unmanned Ground Vehicles, logistic, last mile supply, evaluation system*

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1. Introduction

Ensuring the continuity of supply of essential items - such as ammunition, food rations, and medical kits - constitutes one of the key factors determining the ability to conduct combat operations. In the absence of uninterrupted supply, particularly to the area of operations, the combat capabilities of the deployed forces rapidly deteriorate. Last mile logistic in a military context is the distribution of supplies from the last point of bulk disaggregation to dispersed forces located in the area of operations [1, 2].

Conventionally, supplies are delivered using transport vehicles. Their mass and external dimensions significantly limit the areas in which they can operate (e.g., paved roads, unpaved roads, and relatively accessible off-road terrain). Areas accessible to conventional vehicles are typically highly exposed, which means that such supply operations cannot be conducted in a way which is invisible to the enemy, even at night. As a result, the enemy can easily detect, engage, and destroy the means of transport. Since transport vehicles are crew-operated, the consequences of such actions include the loss of the vehicle, the transported cargo, and at least soldier serving as a driver. An alternative approach involves delivering supplies using regular transport vehicles to a relatively secure location situated beyond the enemy's range of engagement and reconnaissance, unloading them there, and subsequently conducting dismounted resupply operations within the area of operations. In this case, however, the speed of delivery is significantly reduced, and a greater number of soldiers moving within the operational area are exposed to detection and direct enemy fire.

A viable solution to both challenges may lie in the application of a last-mile logistics system composed of multiple Unmanned Ground Vehicles (UGVs), responsible for delivering supplies from a location situated at a safe distance to the positions of soldiers deployed within the operational area [3 – 5]. An analysis of commercially available UGVs suggests that such a system can be configured by employing platforms with different masses, dimensions, and consequently payload capacities. This enables supply operations to be conducted both in open areas—where feasible, for example, due to the disruption of the adversary's reconnaissance systems - using larger and heavier platforms, as well as in densely forested areas through the use of smaller and lighter platforms. The objective of this study is to propose and evaluate a system composed of unmanned ground platforms (UGVs) intended for the execution of last-mile logistics missions in relatively challenging terrain characterized by numerous obstacles and limited maneuvering space, for example, forested environments.

Taking into account the requirement for maximum unification of military equipment, it is assumed that such a system should constitute a homogeneous formation (i.e., composed of identical UGVs). Given that the system is expected to operate in forested areas, platform mobility—defined in terms of obstacle traversal capability and rollover stability margin - plays a critical role in the selection process.

Payload capacity, in contrast, is of lesser importance; instead, the system should adopt a distributed architecture (i.e., employing a greater number of smaller platforms rather than a single large one), thereby ensuring continuity of supply operations. Firing by enemy and disabling one large platform results in the loss of all supplies.

2. Method

The study was divided into two stages:

– an analysis of commercially available UGVs that may be employed in logistics tasks, along with the compilation of their technical parameters (Section 2.1);
– an evaluation of UGVs with respect to their suitability for last-mile logistics applications (Section 2.2).

2.1. Unmanned Ground Vehicles

First, a review of numerous solutions available on the global market of Unmanned Ground Platforms was conducted, and these solutions were evaluated with respect to their potential application in last-mile logistics missions. Based on this review, ten platforms were selected (three with tracked system and seven with wheeled system). Subsequently, the available key technical parameters of the selected platforms were collected. Some of these parameters were publicly available and provided, for example, by manufacturers, while others were estimated based on the available data. Particular attention was paid to the following parameters:

– UGV weight (parameter 1);
– UGV payload (parameter 2);
– payload/UGVweight ratio (parameter 3);
– cargo area (parameter 4);
– UGV length (parameter 5);
– UGV width (parameter 6);
– UGV tipping angle change (parameter 7);
– UGV tipping angle (parameter 8).

Weights of the analyzed platforms (Fig.1. and Fig.2.) ranged from 260 kg to 6350 kg, while their payload capacity varied between 150 kg and 3000 kg. Collected and estimated data of analyzed UGVs are presented in Table.1.

Fig. 1. Analyzed UGVs with wheeled running gear system: a) IBIS; b) Hunter; c) UNL; d) Ratel X e) Boguś; f) Protector; g) ExMot. [6 - 11]

Fig. 2. Analyzed UGVs with tracked running gear system: a) Themis; b) Gereon RCS; c) Ripsaw M3 [12 - 14]

Table 1

Selected tactical and technical parameters of the analyzed UGVs [6 - 14]

Parameter name and unit	UGV name									
	IBIS Transport version	**Hunter**	**Themis**	**UNL**	**ExMot**	**Boguś**	**GEREON RCS**	**Ratel X**	**Protector**	**Ripsaw M3**
UGV weight, kg	260	4500	1630	830	400	4000	370	1130	4000	6350
UGV payload, kg	150	500	rated - 750 max. - 1200	300	200	3000	400	400	700	2268
Payload/UGV weight ratio	0,58	0,11	0,74	0,36	0,50	0,75	1,08	0,35	0,18	0,36
Dimensions L x W x H, m	1,3 x 0,9 x 0,9	4,25 x 2,23 x 1,7	2,47 x 2,04 x 1,17	2 x 1,2 x 1	1,5 x 1 x 1,05	7,8 x 2,1 x 1,45	1,47 x 1,34 x 0,89	2,58 x 1,78 x 0,83	5,2 x 1,87 x 1,45	5,2 x 2 x 1,2
Cargo area, m²	1,17	8,92	4,6	2,16	1,5	2,88	1,82	4,25	8,64	5,85
Max. speed, km/h	8	50	25	30 on road, 5 off - road	15	30	15	14	60	48
Steering system	skid steering	Ackermann steering system	skid steering	skid steering	skid steering	double Ackermann and articulated steering system	skid steering	skid steering	Ackermann steering system	skid steering
Drive system	electric	hybrid	hybrid	electric	hydraulic	hydraulic	electric	electric	diesel engine	hybrid
Running gear	wheeled 6x6	wheeled 4x4	tracked	wheeled 6x6	wheeled 6 x 6	wheeled 10 x 10	tracked	wheeled 6 x 6	wheeled 4x4	tracked

2.2. Unmanned Ground System Evaluation

In the subsequent part of the study, an assessment was undertaken of the effectiveness of establishing an Unmanned Ground System for last-mile logistics composed of the platforms presented in Section 2.1. In accordance with the adopted assumptions, the system should constitute a homogeneous formation (composed of identical UGVs).

In the first stage, a system was applied in which:

a) based on the value of each parameter (Section 2.1 – parameters 1 to 8), the platforms were ranked in descending order, from the best parameter value (rank 1) to the worst (rank 10);
b) based on the position of each platform in the ranking, points were assigned to each platform for each criterion (10 points for rank 1, 9 points for rank 2, …, 1 point for rank 10);
c) the final evaluation was determined as the sum of the points obtained by a given platform.

In the second approach, the AHP (Analytic Hierarchy Process) method was applied. In the AHP [15 – 19] method, three principal stages of the algorithm can be distinguished:

I. Construction of pairwise comparison matrices for n alternatives within each solutions (matrices $A^{(1)}, A^{(2)}, \ldots , A^{(K)}$), as well as for the parameters themselves (matrix $A^{(0)}$). This process results in K+1 pairwise comparison matrices ($A^{(0)}, A^{(1)}, A^{(2)}, \ldots , A^{(K)}$). An important component of this stage is the assessment of the consistency of the decision-maker's judgments.
II. Determination of individual rankings derived from each matrix developed in Stage I.
III. Aggregation of results to obtain a multi-criteria ranking of the n alternatives.

However, prior to the implementation of Stage I, it is necessary to define the parameters to be compared. Their selection should reflect the primary needs of the end-user of the AHP analysis, that is, the key decision-making factors relevant to the specific operational context.

The outcomes of pairwise comparisons between decision elements are recorded in matrix form. In matrix $A^{(0)}$, the criteria are compared against one another, whereas in matrices $(A^{(0)}, A^{(1)}, A^{(2)}, \ldots , A^{(K)})$, the alternatives are compared within each individual criterion. The comparisons are conducted using a nine-point qualitative scale translated into numerical values, as presented in Table 2.

The prioritization process for both criteria and alternatives is conducted in an identical manner and follows the scheme outlined below [15 - 19]:

1. For each parameter C_i, where $i=1, 2, ..., n$, a comparison is made with parameter C_j where $j=1, 2, ... , n$, to determine the relative importance of C_i over C_j. Based on this assessment, numerical values a_{ij} are assigned in accordance with the scale presented in Table 2. The results of these comparisons are recorded in the form of a square matrix. The matrix should satisfy the condition of consistency (transitivity):

$$a_{ij}^{(k)} = \frac{1}{a_{ij}^{(k)}} \ and \ a_{ii}^{(k)} = 1, (k = 0,1,2, \ldots, K), \tag{1}$$

and exhibit consistency in the decision-maker's judgments:

$$a_{ij}^{(k)} = a_{ir}^{(k)} \times a_{rj}^{(k)}. \tag{2}$$

$$A = \begin{bmatrix} 1 & a_{12} & \ldots & a_{1j} \\ \frac{1}{a_{12}} & 1 & \ldots & a_{2j} \\ \ldots & \ldots & \ldots & \ldots \\ \frac{1}{a_{1j}} & \frac{1}{a_{2j}} & \ldots & 1 \end{bmatrix}$$

2. Normalization of the matrix results:

$$\bar{a}_{ij}^{(k)} = \frac{a_{ij}^{(k)}}{\sum_{i=1}^{n} a_{ij}^{(k)}}. \tag{3}$$

3. Individual preference indices (local priorities):

$$s_i^{(k)} = \frac{\sum_{i=1}^{n} \bar{a}_{ij}^{(k)}}{n}. \tag{4}$$

The column vector $s^{(k)} = \left[s_i^{(k)}\right]$ is the individual ranking vector. The value of the index $s_i^{(k)}$ i indicates the position of object i in the individual ranking within the criterion k, i.e. the higher the value of the index $s_i^{(k)}$, the higher the position of object i within the given criterion.

Similarly for the pairwise comparison matrix for criteria A^0 alone. The value of the $s_i^{(0)}$ index indicates the position of criterion i in the individual ranking in relation to the remaining $K-1$ criteria, i.e. the higher the value of the $s_i^{(0)}$ index, the more important the criterion is.

Similarly, for the pairwise comparison matrix of the criteria themselves A^0, the value of the index $s_i^{(0)}$indicates the position of criterion i in the individual ranking relative to the remaining $K-1$ criteria; that is, the higher the value of the index $s_i^{(0)}$, the more important the criterion.

4. Determining the multi-criteria ranking - calculating the multi-criteria vector of preference indices $P=[p_i]$. The components of the vector P are calculated as follows:

$$p_i = \sum_{k=1}^{K} s_k^0 s_i^{(k)} \tag{5}$$

The value of the multi-criteria preference index indicates the position of object i in the multi-criteria ranking, i.e. the higher the value of the p_i index, the higher the position of object i.

Table 2

Scale of ratings used in pairwise comparisons of criteria and alternatives (Saaty's scale) [15]

Definition	Explanation	Intensity of importance
Equal importance	Two activities contribute equally to the objective	1
Moderate importance	Experience and judgment slightly favor one activity over another	3
Strong importance	Experience and judgment strongly favor one activity over another	5
Very strong importance	An activityis favored very strongly	7
Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation	9
Intermediate values for subtle differences	Only use when necessary (Weak importance, Moderate plus, Strong plus, Very,verystrong)	2, 4, 6, 8

To verify the consistency of the judgments contained in the pairwise comparison matrix, the Consistency Ratio (CR) should be calculated.

$$CR = \frac{CI}{RI}, \tag{6}$$

where: *CI* – Consistency Index, *RI* – Random Index.

The consistency index is calculated as follows:

$$CI = \frac{\lambda_{max}^{(k)} - n}{(n-1)} \tag{7}$$

where: λ_{max} - eigenvector solution, calculated as:

$$\lambda_{max}^{(k)} = \frac{\sum_{k=0}^{n} sw_i^{(k)}}{s_i^{(k)}} / n \tag{8}$$

where: $sw^{(k)} = A^{(k)} s^{(k)}$ - column vector of partial sums.

According to the originator of the AHP method, the value of this coefficient should not exceed *CR*≤0. 1. Failure to meet this condition indicates inconsistency in the decision-maker's pairwise comparisons. Ultimately, the dependence on the consistency index can be written in the form:

$$CI = \frac{\lambda_{max}^{(k)}}{n-1\left(\left(\left(\sum_{i=1}^{n}(sw^{(k)}/s^{(k)})\right)-n\right)/n\right)(n-1))} . \tag{9}$$

The Random Index is selected from tabulated values corresponding to the size of the comparison matrix (Table 3).

Table 3

Value of the Random Index (RI) [15]

Matrix Size	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,53	1,56	1,57	1,59

In both approaches, it was assumed for the individual parameters that:

- UGV weight (parameter 1) – the lower the value, the more favorable;
- UGV payload (parameter 2) – the higher the value, the more favorable;
- payload/UGVweight ratio (parameter 3) – the higher the value, the more favorable;
- cargo area (parameter 4) – the higher the value, the more favorable;
- UGV length (parameter 5) – the lower the value, the more favorable;
- UGV width (parameter 6) – the lower the value, the more favorable;
- UGV tipping angle change (parameter 7) – im mniejsza wartość tym lepiej;
- UGV tipping angle (parameter 8) – the higher the value, the more favorable.

3. Results and Discussion

Following the adopted methodology (Section 2), the platforms were first ranked from the best to the worst - according to the values of the individual parameters. Figures 3 through 10 present the values of parameters (parameter 1 to 8) for the compared UGVs.

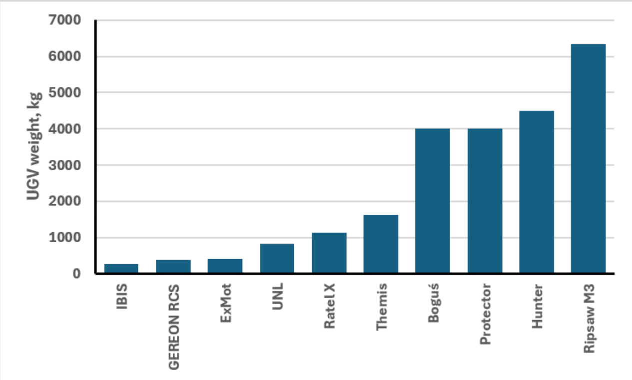

Fig.3. Comparison of separate UGVs weight

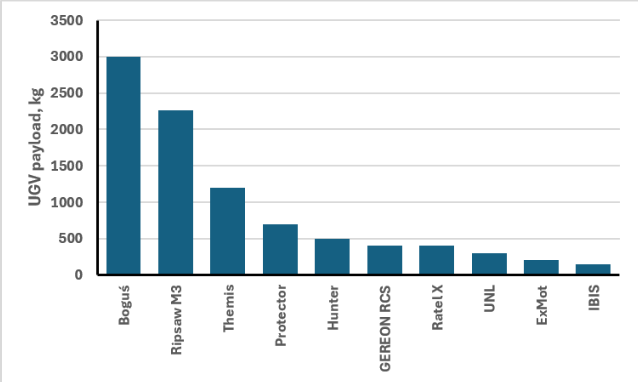

Fig.4. Comparison of separate UGVs payload

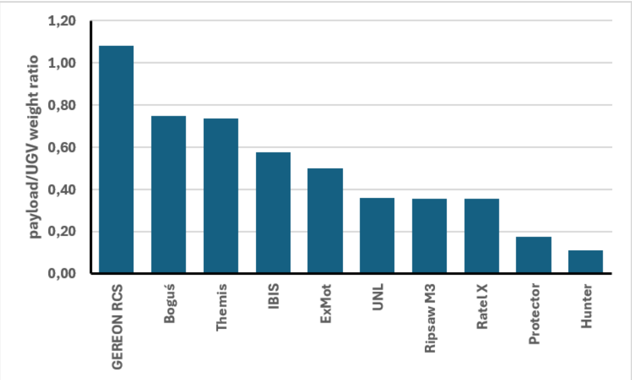

Fig.5. Comparison of payload/UGV weight ratio

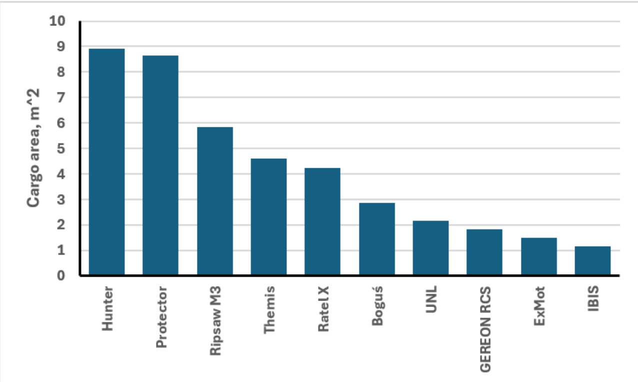

Fig.6. Comparison of separate UGVs cargo area

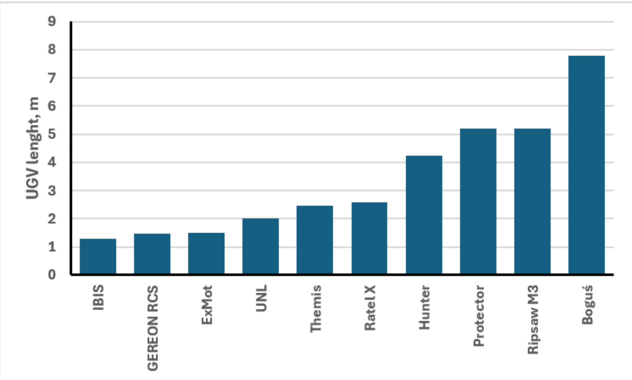

Fig.7. Comparison of UGVs length

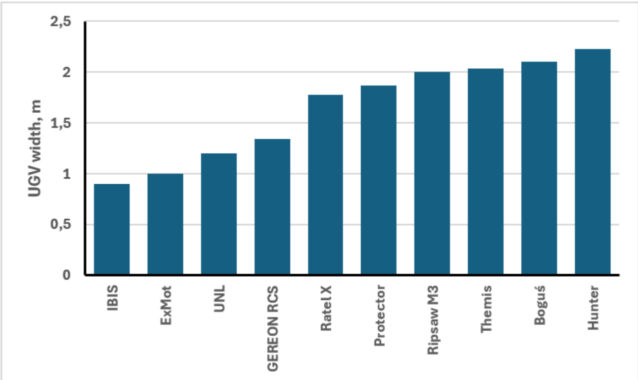

Fig.8. Comparison of separate UGVs width

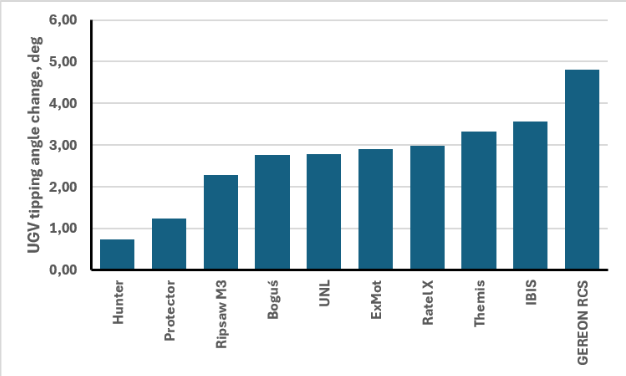

Fig.9. Comparison of UGVs tipping angle change

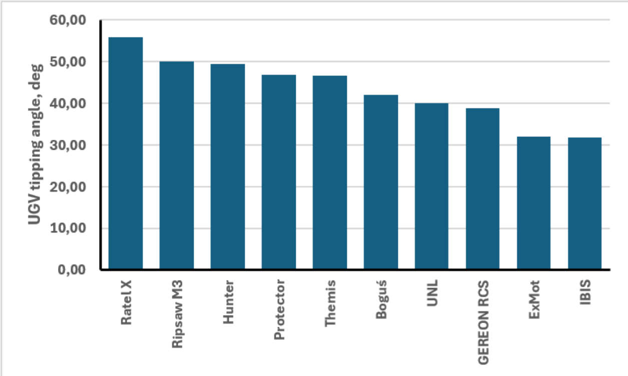

Fig.10. Comparison of separate UGVs tipping angle

The values of the scores assigned to individual UGVs, with respect to each evaluated parameter (Fig.3. - Fig.10.), are presented in Table 2.

Table 2

Scores obtained by each UGV

UGV name	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Parameter 5	Parameter 6	Parameter 7	Parameter 8	Total score
IBIS	10	1	7	1	10	10	2	1	**42**
Hunter	2	6	1	10	4	1	10	8	**42**
Themis	5	8	8	7	6	3	3	6	**46**
UNL	7	3	5	4	7	8	6	4	**44**
ExMot	8	2	6	2	8	9	5	2	**42**
Boguś	4	10	9	5	1	2	7	5	**43**
GEREON RCS	9	5	10	3	9	7	1	3	**47**
Ratel X	6	4	3	6	5	6	4	10	**44**
Protector	3	7	2	9	3	5	9	7	**45**
Ripsaw M3	1	9	4	8	2	4	8	9	**45**

Figure 11 presents the evaluated platforms ranked from the best (highest number of points) to the lowest-performing (lowest number of points). According to the first assessment approach, the Gereon RCS platform is the most suitable for last-mile logistics tasks (47 points), followed by the Themis platform (46 points), and jointly by the Protector and Ripsaw M3 platforms in third place (45 points). It should be noted that, given the number of evaluated solutions (10 UGVs) and compared parameters (8), the difference between the highest- and lowest-ranked UGV is only 5 points. This is despite the fact that most of the parameters differed quite significantly. This approach assigns equal importance to all evaluated parameters and does not account for distinct preferences arising from the specific requirements of last-mile logistics conducted in hard-to-access areas.

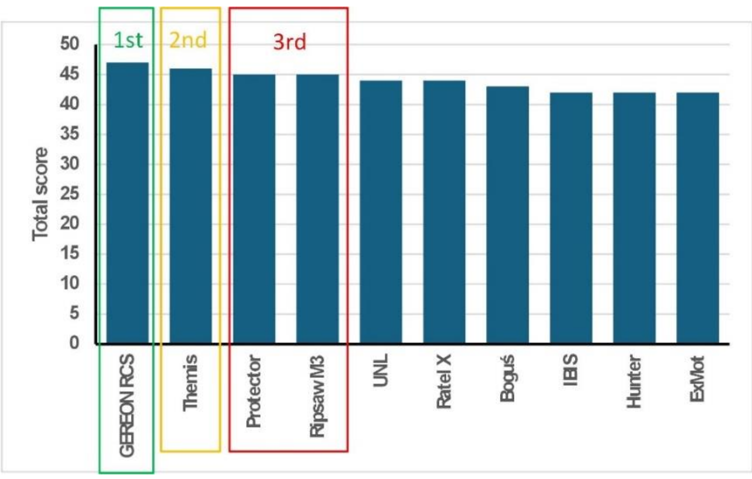

Fig.11. Final score of each UGV using first evaluation method

Subsequently, an assessment was conducted using the AHP method. First, pairwise comparisons of the individual parameters were performed (Table 3) in order to establish a ranking and prioritization of the parameters in accordance with the preferences and requirements of last-mile logistics (Table 4).

Table 4

Pairwise comparison matrix of evaluated UGVs parameters for last mile logistic

	UGV weight	UGV payload	Payload/UGV weight ratio	Cargo Area	UGV lenght	UGV width	UGV tipping angle change	UGV tipping angle
UGV weight	1,00	5,00	1,00	7,00	1,00	1,00	7,00	0,14
UGV payload	0,20	1,00	0,50	2,00	0,14	0,14	3,00	0,14
Payload/UGV weight ratio	1,00	2,00	1,00	1,00	0,14	0,14	3,00	0,14
Cargo Area	0,14	0,50	1,00	1,00	0,20	0,14	1,00	0,14
UGV length	1,00	7,00	7,00	5,00	1,00	1,00	7,00	0,20
UGV width	1,00	7,00	7,00	7,00	1,00	1,00	7,00	0,20
UGV tipping angle change	0,14	0,33	0,33	1,00	0,14	0,14	1,00	0,11
UGV tipping angle	7,00	7,00	7,00	7,00	5,00	5,00	9,00	1,00

Consistency Ratio CR = 7,4%

Table 5

Parameters ranking for last mile logistic

No	Parameter	Priority	Rank
1	UGV weight	11,90%	4
2	UGV payload	3,50%	6
3	Payload/UGV weight ratio	4,90%	5
4	Cargo Area	2,80%	7
5	UGV length	15,60%	3
6	UGV width	16,30%	2
7	UGV tipping angle change	2,10%	8
8	UGV tipping angle	42,90%	1

As a result of the comparison (Table 4), the parameters directly related to terrain mobility were identified as the most significant: UGV tipping angle (priority 42.9%), UGV dimensions (width with a priority of 16.3% and length with a priority of 15.6%), and UGV weight (priority 11.9%). Subsequently, pairwise comparisons of the evaluated UGVs were performed with respect to the value of each individual parameter. The results of these successive comparisons are presented in Tables 6 - 13. For each comparison, the consistency ratio (CR) was verified and ensured to remain below 10%.

Table 6.

Pairwise comparison matrix for UGV weight

	IBIS	Hunter	Themis	UNL	ExMot	Boguś	GEREON RCS	Ratel X	Protector	Ripsaw M3
IBIS	1,00	9,00	7,00	5,00	1,00	9,00	1,00	5,00	9,00	9,00
Hunter	0,11	1,00	0,14	0,14	0,11	1,00	0,11	0,20	1,00	1,00
Themis	0,14	7,00	1,00	0,33	0,14	7,00	0,20	1,00	7,00	7,00
UNL	0,20	7,00	3,00	1,00	0,20	7,00	3,00	3,00	7,00	9,00
ExMot	1,00	9,00	7,00	5,00	1,00	9,00	1,00	5,00	9,00	9,00
Boguś	0,11	1,00	0,14	0,14	0,11	1,00	0,14	0,20	1,00	3,00
GEREON RCS	1,00	9,00	5,00	0,33	1,00	7,00	1,00	5,00	9,00	9,00
Ratel X	0,20	5,00	1,00	0,33	0,20	5,00	0,20	1,00	5,00	7,00
Protector	0,11	1,00	0,14	0,14	0,11	1,00	0,11	0,20	1,00	3,00
Ripsaw M3	0,11	1,00	0,14	0,11	0,11	0,33	0,11	0,14	0,33	1,00

Consistency Ratio CR = 9,3%

Table 7.

Pairwise comparison matrix for UGV payload

	IBIS	**Hunter**	**Themis**	**UNL**	**ExMot**	**Boguś**	**GEREON RCS**	**Ratel X**	**Protector**	**Ripsaw M3**
IBIS	1,00	0,20	0,14	0,33	1,00	0,11	0,20	0,33	0,14	0,11
Hunter	5,00	1,00	0,20	3,00	3,00	0,14	1,00	1,00	1,00	0,20
Themis	7,00	5,00	1,00	5,00	7,00	0,20	5,00	5,00	3,00	0,33
UNL	3,00	0,33	0,20	1,00	0,33	0,11	0,33	0,33	0,20	0,11
ExMot	1,00	0,33	0,14	3,00	1,00	0,11	0,33	0,33	0,20	0,14
Boguś	9,00	7,00	5,00	9,00	9,00	1,00	7,00	9,00	7,00	3,00
GEREON RCS	5,00	1,00	0,20	3,00	3,00	0,14	1,00	1,00	0,33	0,14
Ratel X	3,00	1,00	0,20	3,00	3,00	0,11	1,00	1,00	0,33	0,14
Protector	7,00	1,00	0,33	5,00	5,00	0,14	3,00	3,00	1,00	0,20
Ripsaw M3	9,00	5,00	3,00	9,00	7,00	0,33	7,00	7,00	5,00	1,00

Consistency Ratio CR = 7,3%

Table 8.

Pairwise comparison matrix for payload/UGV ratio

	IBIS	**Hunter**	**Themis**	**UNL**	**ExMot**	**Boguś**	**GEREON RCS**	**Ratel X**	**Protector**	**Ripsaw M3**
IBIS	1,00	7,00	0,33	3,00	1,00	0,33	0,20	3,00	5,00	3,00
Hunter	0,14	1,00	0,14	0,33	0,20	0,14	0,11	0,33	1,00	0,33
Themis	3,00	7,00	1,00	3,00	3,00	1,00	0,33	3,00	5,00	5,00
UNL	0,33	3,00	0,33	1,00	0,33	0,20	0,14	0,14	3,00	1,00
ExMot	1,00	5,00	0,33	3,00	1,00	0,20	0,20	3,00	5,00	3,00
Boguś	3,00	7,00	1,00	5,00	5,00	1,00	0,33	5,00	5,00	3,00
GEREON RCS	5,00	9,00	3,00	7,00	5,00	3,00	1,00	7,00	7,00	7,00
Ratel X	0,33	3,00	0,33	7,00	0,33	0,20	0,14	1,00	3,00	1,00
Protector	0,20	1,00	0,20	0,33	0,20	0,20	0,14	0,33	1,00	0,33
Ripsaw M3	0,33	3,00	0,20	1,00	0,33	0,33	0,14	1,00	3,00	1,00

Consistency Ratio CR = 7,3%

Table 9.

Pairwise comparison matrix for cargo area

	IBIS	**Hunter**	**Themis**	**UNL**	**ExMot**	**Boguś**	**GEREON RCS**	**Ratel X**	**Protector**	**Ripsaw M3**
IBIS	1,00	0,11	0,14	0,33	0,33	0,11	0,33	0,20	0,11	0,14
Hunter	9,00	1,00	5,00	7,00	9,00	3,00	7,00	5,00	1,00	3,00
Themis	7,00	0,20	1,00	5,00	7,00	3,00	5,00	1,00	0,20	1,00
UNL	3,00	0,14	0,20	1,00	3,00	0,33	3,00	0,20	0,14	0,14
ExMot	3,00	0,11	0,14	0,33	1,00	0,11	1,00	0,20	0,14	0,20
Boguś	9,00	0,33	0,33	3,00	9,00	1,00	5,00	0,33	0,14	0,33
GEREON RCS	3,00	0,14	0,20	0,33	1,00	0,20	1,00	0,20	0,14	0,20
Ratel X	5,00	0,20	1,00	5,00	5,00	3,00	5,00	1,00	0,14	0,33
Protector	9,00	1,00	5,00	7,00	7,00	7,00	7,00	7,00	1,00	3,00
Ripsaw M3	7,00	0,33	1,00	7,00	5,00	3,00	5,00	3,00	0,33	1,00

Consistency Ratio CR = 9,1%

Table 10.

Pairwise comparison matrix for UGV length

	IBIS	Hunter	Themis	UNL	ExMot	Boguś	GEREON RCS	Ratel X	Protector	Ripsaw M3
,	1,00	7,00	5,00	3,00	1,00	9,00	1,00	5,00	9,00	9,00
Hunter	0,14	1,00	0,20	0,20	0,14	3,00	0,14	1,00	1,00	1,00
Themis	0,20	5,00	1,00	0,33	0,33	7,00	0,33	1,00	5,00	5,00
UNL	0,33	5,00	3,00	1,00	0,33	9,00	0,33	1,00	7,00	7,00
ExMot	1,00	7,00	3,00	3,00	1,00	9,00	1,00	5,00	7,00	7,00
Boguś	0,11	0,33	0,14	0,11	0,11	1,00	0,11	0,20	0,33	0,33
GEREON RCS	1,00	7,00	3,00	3,00	1,00	9,00	1,00	3,00	7,00	7,00
Ratel X	0,20	1,00	1,00	1,00	0,20	5,00	0,33	1,00	5,00	7,00
Protector	0,11	1,00	0,20	0,14	0,14	3,00	0,14	0,20	1,00	1,00
Ripsaw M3	0,11	1,00	0,20	0,14	0,14	3,00	0,14	0,14	1,00	1,00

Consistency Ratio CR = 5,5%

Table 11.

Pairwise comparison matrix for UGV width

	IBIS	Hunter	Themis	UNL	ExMot	Boguś	GEREON RCS	Ratel X	Protector	Ripsaw M3
IBIS	1,00	9,00	7,00	3,00	1,00	9,00	5,00	7,00	7,00	7,00
Hunter	0,11	1,00	1,00	0,14	0,11	1,00	0,20	0,33	0,33	3,00
Themis	0,14	1,00	1,00	0,20	0,14	1,00	0,33	0,33	0,33	1,00
UNL	0,33	7,00	5,00	1,00	0,33	7,00	3,00	1,00	5,00	5,00
ExMot	1,00	9,00	7,00	3,00	1,00	9,00	3,00	5,00	7,00	7,00
Boguś	0,11	1,00	1,00	0,14	0,11	1,00	0,20	0,33	0,33	1,00
GEREON RCS	0,20	5,00	3,00	0,33	0,33	5,00	1,00	3,00	5,00	5,00
Ratel X	0,14	3,00	3,00	1,00	0,20	3,00	0,33	1,00	1,00	1,00
Protector	0,14	3,00	3,00	0,20	0,14	3,00	0,20	1,00	1,00	1,00
Ripsaw M3	0,14	0,33	1,00	0,20	0,14	1,00	0,20	1,00	1,00	1,00

Consistency Ratio CR = 4,3%

Table 12.

Pairwise comparison matrix for UGV tipping angle change

	IBIS	Hunter	Themis	UNL	ExMot	Boguś	GEREON RCS	Ratel X	Protector	Ripsaw M3
IBIS	1,00	0,11	3,00	1,00	0,33	0,33	3,00	0,33	0,11	0,20
Hunter	9,00	1,00	9,00	7,00	7,00	5,00	9,00	7,00	3,00	5,00
Themis	0,33	0,11	1,00	0,33	0,33	0,33	3,00	1,00	0,14	0,20
UNL	1,00	0,14	3,00	1,00	1,00	1,00	5,00	1,00	0,20	0,33
ExMot	3,00	0,14	3,00	1,00	1,00	1,00	5,00	1,00	0,33	1,00
Boguś	3,00	0,20	3,00	1,00	1,00	1,00	5,00	1,00	0,33	1,00
GEREON RCS	0,33	0,11	0,33	0,20	0,20	0,20	1,00	0,33	0,11	0,14
Ratel X	3,00	0,14	1,00	1,00	1,00	1,00	3,00	1,00	0,20	0,33
Protector	9,00	0,33	7,00	5,00	3,00	3,00	9,00	5,00	1,00	3,00
Ripsaw M3	5,00	0,20	5,00	3,00	1,00	1,00	7,00	3,00	0,33	1,00

Consistency Ratio CR = 5,0%

Table 13.

Pairwise comparison matrix for UGV tipping angle

	IBIS	Hunter	Themis	UNL	ExMot	Boguś	GEREON RCS	Ratel X	Protector	Ripsaw M3
IBIS	1,00	0,14	0,20	0,33	1,00	0,33	0,33	0,11	0,14	0,11
Hunter	7,00	1,00	1,00	3,00	5,00	3,00	5,00	0,33	1,00	1,00
Themis	5,00	1,00	1,00	3,00	5,00	0,33	3,00	0,33	1,00	0,33
UNL	3,00	0,33	0,33	1,00	2,00	1,00	1,00	0,14	0,20	0,20
ExMot	1,00	0,20	0,20	0,50	1,00	0,33	0,33	0,11	0,14	0,14
Boguś	3,00	0,33	3,00	1,00	3,00	1,00	5,00	0,20	0,33	0,33
GEREON RCS	3,00	0,20	0,33	1,00	3,00	0,20	1,00	0,14	0,20	0,14
Ratel X	9,00	3,00	3,00	7,00	9,00	5,00	7,00	1,00	3,00	1,00
Protector	7,00	1,00	1,00	5,00	7,00	3,00	5,00	0,33	1,00	1,00
Ripsaw M3	9,00	1,00	3,00	5,00	7,00	3,00	7,00	1,00	1,00	1,00

Consistency Ratio CR = 5,1%

In the final stage of the AHP method application, a final ranking was established, taking into account the results of the comparisons for each parameter (Tables 6–13) while incorporating the relative importance of each parameter (Table 5). The final evaluation of the individual solutions is presented in Figure 12.

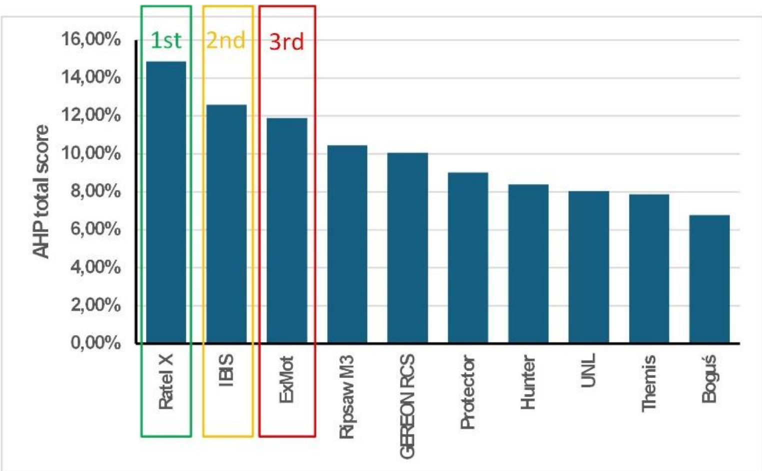

Fig.12. Final score of each UGV using AHP method

As a result of applying the AHP method, which accounts the relative importance of individual parameters in the context of last-mile logistics tasks, it was found that, compared with the previous method (Fig. 11), entirely different platforms emerged as the most suitable. In this case (Fig. 12), the highest score was achieved by the Ratel X (final score: 14.87%), followed by the IBIS (with a result lower by over 2%), and the ExMot in third place with a score of 11.9%.

Therefore, it can be concluded that smaller platforms are better suited for last-mile logistics tasks, as they are significantly more capable of operating in densely forested terrain. In the case of the final results obtained using the AHP method, the scores achieved by the individual platforms differ much more distinctly - they are not as flattened as in the previous method (Fig. 11).

4. Conclusions

The study proposes the use of a homogeneous grouping composed of identical Unmanned Ground Vehicles, which may constitute a distributed unmanned system capable of performing last-mile logistics tasks, particularly in hard-to-access areas (e.g., forested terrain), in situations where due to various factors (such as adversary actions or terrain inaccessibility). These tasks cannot be carried out by conventional military vehicles in such a terrain.

Given that a wide range of UGVs with diverse technical parameters are currently available on the market, the study evaluates selected solutions (Table 1) using both a direct data comparison method and a multi-criteria assessment (AHP). The application of both approaches made it possible to identify potentially optimal solutions. Notably, the AHP method enables the determination of the relative importance of individual parameters, thereby allowing the selected solution to better reflect the specific characteristics and requirements of last-mile logistics operations.

As directions for further research, it is recommended to conduct similar assessments for different operational environments in which last-mile logistics tasks are performed, as well as to base parameter prioritization directly on input from end users

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