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THE SELECTION OF INDUSTRIAL ROBOTS FOR MILITARY INDUSTRY USING AHP METHOD: A CASE STUDY

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Abstract: *Given the multitude of industrial robots manufacturing companies, the complex structural configuration and the automation degree, the selection of industrial robots in order to carry out specific task, is becoming more and more difficult. In this research paper, the AHP method was applied to select the most favorable configuration of an industrial robot that must perform the technological process of ARC welding of the tracked mini-robots housing, used in military applications. For this purpose, several industrial robots manufacturing companies that are producing industrial robots with different technical specifications were taken into consideration. The study highlights the usefulness in applying decision-making methods in automated technological processes, in order to facilitate and simplify the selection process of the industrial robot, to obtain the best version of industrial robot, from a set of alternatives that carry out one or more specific tasks.*

Key words: *selection of industrial robots, welding, military industry, AHP method.*

1. INTRODUCTION

The improved performance of the industrial robots was determined by the fast development, in the last years, of information technology and engineering science, making them increasingly used in most common work areas, such as: engineering, medical domain, military, maintenance, food industry, etc., as well as in industrial environments and in hazardous environments such as: explosive, nuclear, or aquatic domain, and many others [1-8].

A wide range of industrial robots is offered by the international market, from lightweight robots, for which precision, repeatability and high working speed are important requirements, respectively heavy duty industrial robots for which high loading capacity is required [9-10]. Thus, the selection of industrial robots for a specific field of work or for a specific task becomes increasingly difficult, considering the structural variations of industrial robots available on international market.

Selecting an industrial robot for a specific application consists in identifying the robot configuration, taking into account certain factors (technical, economic, maintenance), so the selected robot will correspond to the functional requirements.

In the selection process of industrial robots, the objective (tangible) factors that can be taking into consideration are: the control resolution, velocity, accuracy, repeatability, load carrying capacity, degrees of freedom, manipulator reach (arm, body and wrist), maximum tip speed, memory capacity and supplier's service quality [9,11].

The subjective (intangible) factors are: reliability, programing flexibility, man–machine interfacing ability, mounting type, vendor's service quality [9].

Selection of the best suited industrial robot from many available alternatives and/or to ranking the entire set of alternatives is a typical Multi-Criteria Decision-Making (MCDM) problem [12-13]. Each decision table in MCDM methods consists of four main stages: setting up the global objective, the alternatives, the criteria, the attributes, finding out the relative importance of each attribute, establishing the global weight of each alternatives, taking into account all considered criteria.

For decisional aspects, mathematical models have been developed, based on some influence factors, which allow the identification of the best solution, from technically, economically and maintenance point of view, from a wide range of finished products, like industrial robots. The research focuse on selecting industrial robots, in order to accomplish a certain task, by using different decision methods: Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR), Analytic Network Process (ANP) and Fuzzy models [1, 3-5, 14]. More studies regarding industrial robots selection are given in [10-13, 15-20].

The aim of this research paper was to select the best variant of an industrial robot from 15 alternatives, that can perform the welding process. The task for the selected industrial robot was to perform the welding of the tracked mini-robots for military applications housing, while complying some requirements like: high speed, accuracy, large arm reach, reduced dimensions of the robot’s body and arm, high flexibility and reduced cost. For this purpose, the AHP method was used to obtain the weights of the criteria that influence the selection decision, and also to hierarchize the proposed industrial welding robots (the alternatives).

2. MATERIAL AND METHOD

Analytical Hierarchy Process (AHP) is a powerful multi-criteria decision-making tool especially in hierarchical decision-making where the decision problem is structured into components of different levels. Decision-makers elicit pairwise comparisons, based on their value judgments, of the elements in the same level, respecting an element in higher immediate level. The strength of the AHP consist in capturing subjective judgments of decision-makers and integrating them into the decision-making process [21]. According to [20-23] the main steps in computing the AHP method are:

Step 1: Constructing of the model. Problem should be clearly defined, established the general objective and then decomposed into criteria and sub criteria for each studied alternative. Subsequently, the hierarchical tree would be realized, based on criteria and sub criteria previously defined. The General Objective of this study was to select the best alternative of industrial robot with AHP method, from a set of industrial robots. The task for the industrial robots is to perform the welding of the tracked mini-robots for military applications housing made of 4 – 15 mm thickness high quality steels. Thus, for this case study were selected 15 industrial robots (A 1÷A 15) that execute ARC welding (the most commonly used metal welding process) from three manufacturing companies. Some of these 15 selected industrial robots are not limited to ARC welding, they can also perform PLASMA and/or MIG welding. From each company where chosen five ARC welding industrial robots, with different technical specifications. In figure 1 is illustrated the hierarchical tree for this case study.

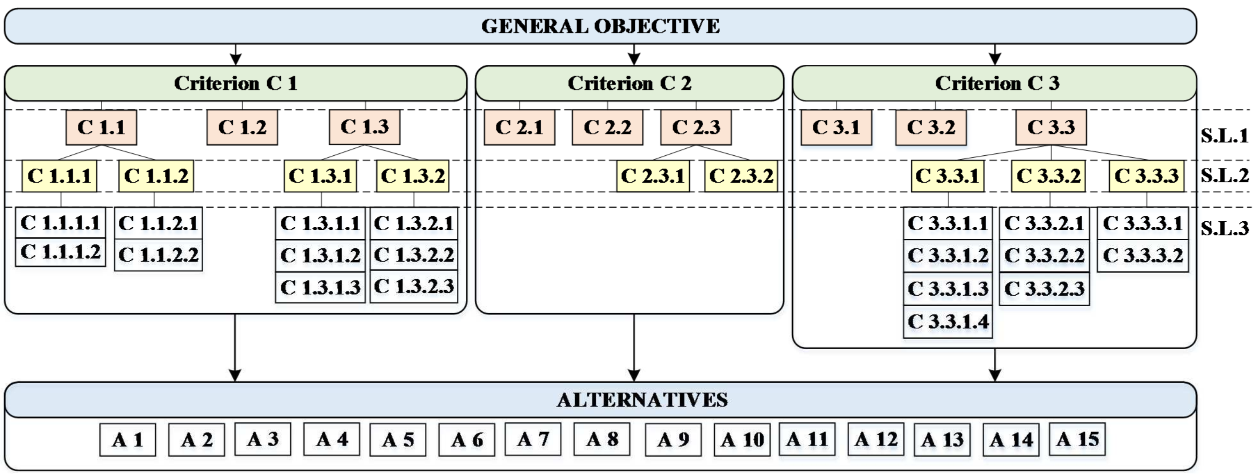


Fig. 1. The hierarchical tree for the selection the best alternative of industrial robots for military industry, where S.L.1, S.L.2 and S.L.3 means sub criteria level 1, 2 and 3

The hierarchical tree used for the selection of the best alternative of industrial robots for military industry was divided into three main criteria: C 1 – Technical criterion, C 2 – Size and dimensional criterion, C 3 – Other criterion.

The technical criterion (C 1) is divided into sub-criteria: C 1.1 – Motion (with: C 1.1.1 (Speed of axis) grouped into C 1.1.1.1 – Min and C 1.1.1.2 – Max; C 1.1.2 (Range) grouped into C 1.1.2.1 – Min and C 1.1.2.2 – Max); C 1.2 – Repeatability; C 1.3 – Allowable loading moment (with: C 1.3.1 – Wrist grouped into C 1.3.1.1 – J4, C 1.3.1.2 – J5 and C 1.3.1.3 – J6; C 1.3.2 – Inertia grouped into C 1.3.2.1 – J4, C 1.3.2.2 – J5 and C 1.3.2.3 – J6).

The size and dimensional criteria (C 2) is divided into following sub-criteria: C 2.1 – Payload; C 2.2 – Robot mass and C 2.3 – Robot reach (with C 2.3.1 – V-reach and C 2.3.2 – H-reach).

The C 3 – Other criteria, is grouped as following: C 3.1 – Power rate; C 3.2 – Cost; C 3.3 –Flexibility (with: C 3.3.1 – Mounting type grouped into: C 3.3.1.1 – Floor, C 3.3.1.2 – Ceiling; C 3.3.1.3 – Angle and C 3.3.1.4 – Wall; C 3.3.2 – Welding type, grouped into: C 3.3.2.1 – ARC, C 3.3.2.2 – Plasma, C 3.3.2.3 – MIG; C 3.3.3 – Other applications, grouped into: C 3.3.3.1 – Material Handling and C 3.3.3.2 – No other application. For this specific application, the type of welding was considered a level 2 sub-criterion (S.L.2) indicating the degree of flexibility of the industrial robots from the welding process (criteria C 3.3) point of view.

In table 1 (part 1÷3) are given the characteristics of the alternatives for each criterion.

Table 1

The characteristics of the alternatives for each criterion (part 1).

Criteria /Alter-natives	**C 1.1.1.1**	**C 1.1.1.2**	**C 1.1.2.1**	**C 1.1.2.2**	**C 1.2**	**C 1.3.1.1**	**C 1.3.1.2**	**C 1.3.1.3**
A 1	215 (Axis J2)	625 (Axis J6)	250 (AxisJ2)	720 (Axis J6)	± 0,08	8.9	8.9	3
A 2	270 (Axis J1,2,3)	720 (Axis J6)	230 (Axis J2)	720 (Axis J6)	± 0,03	11.9	11.9	6.7
A 3	260 (Axis J1)	630 (Axis J6)	250 (Axis J2)	720 (Axis J6)	± 0,08	7.7	7.7	0.22
A 4	380 (AxisJ2)	1000 (AxisJ6)	245 (AxisJ2)	720 (AxisJ6)	± 0,02	16.6	16.6	9.4
A 5	200 (AxisJ1,2)	630 (AxisJ6)	255(AxisJ2)	900 (AxisJ6)	± 0,08	7.7	7.7	0.2
A 6	250 (Axis1,2)	700(Axis6)	+145 - 105(Axis2)	±360 (AxisJT6)	± 0,06	13	13	7.5
A 7	220 (Axis J3)	650 (Axis J6)	+150-90 (Axis J2)	±360 (AxisJT6)	± 0,06	12	12	3.75
A 8	215 (Axis J3)	700 (Axis J6)	+145-150(Axis J2)	±360 (AxisJT6)	± 0,06	22	22	10
A 9	300(Axis1,2,3)	740(axis6)	+118-172(Axis3)	±360 (AxisJT6)	± 0,03	12.3	12.3	7
A 10	190(Axis1)	610(Axis6)	+155 - 105(Axis2)	±360 (AxisJT6)	± 0,06	22	22	10
A 11	175 (Axis2)	600 (Axis6)	+155 -100 (Axis2)	±360 (Axis6)	± 0,08	38	38	17.7
A 12	175 (Axis J2)	560 (Axis6)	+155-100 (Axis J2)	±200 (Axis6)	± 0,08	38.6	38.6	7.5
A 13	200 (Axis J2)	610 (Axis6)	+155-90 (Axis J2)	±360 (Axis6)	± 0,08	11.8	9.8	5.9
A 14	200 (AxisJ2)	630 (Axis J6)	+155 -90 (Axis2)	±10 (Axis6)	± 0,08	10.5	10.5	3.2
A 15	170(Axis1,2)	520 (Axis6)	±150 (Axis4)	±200 (Axis6)	± 0,08	8.8	8.8	2.9

The characteristics of the alternatives for each criterion (part 2).

Criteria /Alternatives	**C 1.3.2.1**	**C 1.3.2.2**	**C 1.3.2.3**	**C 2.1**	**C 2.2**	**C 2.3.1**	**C 2.3.2**	**C 3.1**	**C 3.2**	**C 3.3.1.1**
A 1	0.28	0.28	0.035	3	145	1507	1437	1.25	23000-32000	YES
A 2	0.3	0.3	0.1	5	29	1147	892	1	25000-35000	YES
A 3	0.24	0.24	0.0027	12	130	1398	1098	1	25000-35000	YES
A 4	0.47	0.47	0.15	7	25	997	717	1	13000-18000	YES
A 5	0.24	0.24	0.0027	8	150	2328	2028	1	14000-20000	YES
A 6	0.45	0.45	0.13	6	150	1980	1650	2	12000-21000	YES
A 7	0.4	0.4	0.07	6	150	1710	1445	2	12000-21000	YES
A 8	0.7	0.7	0.2	10	150	1780	1450	2	12000-21000	YES
A 9	0.4	0.4	0.12	5	37	1093	903	1.5	12000-21000	YES
A 10	0.7	0.7	0.4	10	230	2240	1925	3	12000-21000	YES
A 11	1.5	1.5	0.32	10	280	2935	1653	2.8	Not available	YES
A 12	1.04	1.04	0.04	15	380	3243	1807	5	Not available	YES
A 13	0.27	0.27	0.09	6	120	1597	997	1.5	Not available	YES
A 14	0.28	0.28	0.06	6	130	1734	1440	1.5	Not available	YES
A 15	0.27	0.27	0.03	3	280	2559	1904	2.8	Not available	YES

The characteristics of the alternatives for each criterion (part 3).

Criteria /Alternatives	**C 3.3.1.2**	**C 3.3.1.3**	**C 3.3.1.4**	**C 3.3.2.1**	**C 3.3.2.2**	**C 3.3.2.3**	**C 3.3.3.1**	**C 3.3.3.2**	References
A 1	Yes	Yes		Yes				Yes	[24-27]
A 2	Yes	Yes	Yes	Yes	Yes			Yes	
A 3	Yes	Yes		Yes				Yes	
A 4	Yes		Yes	Yes			Yes		
A 5	Yes		Yes	Yes				Yes	
A 6	Yes			Yes				Yes	
A 7	Yes			Yes				Yes	
A 8	Yes			Yes				Yes	
A 9	Yes			Yes				Yes	
A 10	Yes			Yes				Yes	
A 11				Yes	Yes	Yes		Yes	
A 12				Yes	Yes	Yes		Yes	
A 13	Yes		Yes	Yes					
A 14	Yes		Yes	Yes			Yes		
A 15				Yes	Yes			Yes	

Step 2: Generating the pairwise comparison matrices. The relative importance for each alternative, criteria or sub criteria was establish by using Saaty's nine-point scale (table 2) to convert the verbal judgments in numerical quantities from 1 (equal importance) to 9 (extreme importance) [21]. Then building the pairwise comparison matrices for each alternatives, sub criteria and criteria, where the a_{ij} (i,j = 1÷n) element indicate the relative importance for alternative *i* respecting the alternatives *j* using the relation (1).

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \quad (1)$$

$$a_{ii} = 1, a_{ji} = \frac{1}{a_{ij}}, a_{ij} \neq 0.$$

Step 3: Developing a normalized matrix by dividing each number from the column of the pairwise comparison matrix by its column sum. Then, averaging each row of the normalized matrix to obtain the relative weight W_i (i=1÷n) of the alternative preferences respecting each criterion/ sub-criterion.

Step 4: Constructing the n – dimensional column vector, which represents the weighted sum of each alternative considered separately and considering each criterion:

$$X = A \cdot W = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{bmatrix} . (2)$$

Step 5: Obtaining the priority vectors (w) from the pairwise comparison matrix (A) by solving an eigenvalue problem in the following equation:

$$A \cdot w = \lambda_{max} \cdot w \quad (3)$$

Step 6: Calculating the consistency index (CI), random inconsistency (RI) and consistency ratio (CR) using the relations (4)-(6):

Table 2

Saaty`s fundamental scale [21]

Rating scale	**Definition**	**Explanation**
1	Equal importance	Two elements contribute equally to the objective
2	Weak	Between equal and moderate
3	Moderate importance	Experience and judgment slightly favor one element over another
4	Moderate plus	Between moderate and strong
5	Strong importance	Experience and judgment slightly favor one element over another
6	Strong plus	Between strong and very strong
7	Very strong	An element is favored very strongly over another
8	Very, very strong	Between very strong and extreme
9	Extreme importance	The evidence favoring one element over another is one of the highest possible order or affirmation

$$CI = (\lambda_{max} - n)/(n-1) \quad (4)$$

$$RI = [1.987 \cdot (n-2)]/n \quad (5)$$

$$CR = CI/RI. \quad (6)$$

If $CR < 0.1$, then the matrix is consistent, namely the vector of the weights is well determined [22, 23], thus the algorithm is reiterated form step 2 until this condition is fulfilled.

3. RESULTS AND DISCUSSION

Because the mathematical model obtained after running the AHP algorithm is complex, in tables 3÷5 are illustrated, as examples, decision matrix, normalized matrix and the results obtained for the general objective, for criterion 2, respectively for sub criteria level 3 (S.L.3) C 1.1.1.1÷C 1.1.2.2.

Table 3

Steps and results obtained for the criterion C 1.1.1.1 level 3 (model).

Decision matrix C 1.1.1.1

C 1.1.1.1	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 9	A 10	A 11	A 12	A 13	A 14	A 15
A 1	1.00	0.25	0.25	0.11	1.00	0.25	1.00	1.00	0.17	2.00	2.00	2.00	1.00	1.00	2.00
A 2	4.00	1.00	1.00	0.11	4.00	1.00	4.00	4.00	0.17	4.00	4.00	4.00	4.00	4.00	4.00
A 3	4.00	1.00	1.00	0.11	4.00	1.00	4.00	4.00	0.17	4.00	4.00	4.00	4.00	4.00	4.00
A 4	9.00	9.00	9.00	1.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
A 5	1.00	0.25	0.25	0.11	1.00	0.25	1.00	1.00	0.17	2.00	2.00	2.00	1.00	1.00	2.00
A 6	4.00	1.00	1.00	0.11	4.00	1.00	4.00	4.00	0.17	4.00	4.00	4.00	4.00	4.00	4.00
A 7	1.00	0.25	0.25	0.11	1.00	0.25	1.00	1.00	0.17	2.00	2.00	2.00	1.00	1.00	2.00
A 8	1.00	0.25	0.25	0.11	1.00	0.25	1.00	1.00	0.17	2.00	2.00	2.00	1.00	1.00	2.00
A 9	6.00	6.00	6.00	0.11	6.00	6.00	6.00	6.00	1.00	6.00	6.00	6.00	6.00	6.00	6.00
A 10	0.50	0.25	0.25	0.11	0.50	0.25	0.50	0.50	0.17	1.00	1.00	1.00	0.50	0.50	1.00
A 11	0.50	0.25	0.25	0.11	0.50	0.25	0.50	0.50	0.17	1.00	1.00	1.00	0.50	0.50	1.00
A 12	0.50	0.25	0.25	0.11	0.50	0.25	0.50	0.50	0.17	1.00	1.00	1.00	0.50	0.50	1.00
A 13	1.00	0.25	0.25	0.11	1.00	0.25	1.00	1.00	0.17	2.00	2.00	2.00	1.00	1.00	2.00
A 14	1.00	0.25	0.25	0.11	1.00	0.25	1.00	1.00	0.17	2.00	2.00	2.00	1.00	1.00	2.00
A 15	0.50	0.25	0.25	0.11	0.50	0.25	0.50	0.50	0.17	1.00	1.00	1.00	0.50	0.50	1.00

Decision matrix C 1.1.1.2

C 1.1.1.2	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 9	A 10	A 11	A 12	A 13	A 14	A 15
A 1	1.00	0.25	1.00	0.11	1.00	0.25	0.33	0.25	0.25	1.00	1.00	2.00	1.00	1.00	2.00
A 2	4.00	1.00	4.00	0.11	4.00	1.00	4.00	1.00	1.00	4.00	4.00	4.00	4.00	4.00	4.00
A 3	1.00	0.25	1.00	0.11	1.00	0.25	0.33	0.25	0.25	1.00	1.00	2.00	1.00	1.00	2.00
A 4	9.00	9.00	9.00	1.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
A 5	1.00	0.25	1.00	0.11	1.00	0.25	0.33	0.25	0.25	1.00	1.00	2.00	1.00	1.00	2.00
A 6	4.00	1.00	4.00	0.11	4.00	1.00	4.00	1.00	1.00	4.00	4.00	4.00	4.00	4.00	4.00
A 7	3.00	0.25	3.00	0.11	3.00	0.25	1.00	0.25	0.25	3.00	3.00	3.00	3.00	3.00	3.00
A 8	4.00	1.00	4.00	0.11	4.00	1.00	4.00	1.00	1.00	4.00	4.00	4.00	4.00	4.00	4.00
A 9	4.00	1.00	4.00	0.11	4.00	1.00	4.00	1.00	1.00	4.00	4.00	4.00	4.00	4.00	4.00
A 10	1.00	0.25	1.00	0.11	1.00	0.25	0.33	0.25	0.25	1.00	1.00	2.00	1.00	1.00	2.00
A 11	1.00	0.25	1.00	0.11	1.00	0.25	0.33	0.25	0.25	1.00	1.00	2.00	1.00	1.00	2.00
A 12	0.50	0.25	0.50	0.11	0.50	0.25	0.33	0.25	0.25	0.50	0.50	1.00	0.50	0.50	1.00
A 13	1.00	0.25	1.00	0.11	1.00	0.25	0.33	0.25	0.25	1.00	1.00	2.00	1.00	1.00	2.00
A 14	1.00	0.25	1.00	0.11	1.00	0.25	0.33	0.25	0.25	1.00	1.00	2.00	1.00	1.00	2.00
A 15	0.50	0.25	0.50	0.11	0.50	0.25	0.33	0.25	0.25	0.50	0.50	1.00	0.50	0.50	1.00

Results for C 1.1.1.1								Results for C 1.1.1.2								
C 1.1.1.1	W	X	CV	λ	CI	RI	CR	C 1.1.1.2	W	X	CV	λ	CI	RI	CR	CR<0.1
A 1	0.030	0.028	13.948					A 1	0.027	0.029	15.861					
A 2	0.084	0.056	9.999					A 2	0.093	0.071	11.449					
A 3	0.084	0.056	9.999					A 3	0.027	0.029	15.861					
A 4	0.322	0.426	19.856					A 4	0.346	0.424	18.408					
A 5	0.030	0.028	13.948					A 5	0.027	0.029	15.861					
A 6	0.084	0.056	9.999					A 6	0.093	0.071	11.449					
A 7	0.030	0.028	13.948					A 7	0.057	0.041	10.739					
A 8	0.030	0.028	13.948	14.951	-0.003	1.722	-0.002	A 8	0.093	0.071	11.449	15.273	0.019	1.722	0.011	TRUE FOR C 1.1.1.1 and C 1.1.1.2
A 9	0.173	0.143	12.430					A 9	0.093	0.071	11.449					
A 10	0.018	0.024	19.573					A 10	0.027	0.029	15.861					
A 11	0.018	0.024	19.573					A 11	0.027	0.029	15.861					
A 12	0.018	0.024	19.573					A 12	0.017	0.025	21.560					
A 13	0.030	0.028	13.948					A 13	0.027	0.029	15.861					
A 14	0.030	0.028	13.948					A 14	0.027	0.029	15.861					
A 15	0.018	0.024	19.573					A 15	0.017	0.025	21.560					

Table 4

Steps and results obtained for the criterion 2 (model).

Decision matrix				W	X	CV	λ	CI	RI	CR	CR<0.1
C 2	C 2.1	C 2.2	C 2.3								
C 2.1	1.00	9.00	1.00	0.474	0.474	3.000	3.000	0.000	0.662	0.000	TRUE
C 2.2	0.11	1.00	0.11	0.053	0.053	3.000					
C 2.3	1.00	9.00	1.00	0.474	0.474	3.000					
Decision matrix				W	X	CV	λ	CI	RI	CR	CR<0.1
C 2.3	C 2.3.1	C 2.3.2									
C 2.3.1	1.00	0.11		0.100	0.100	2.000	2.000	0.000	0.000	0.000	TRUE
C 2.3.2	9.00	1.00		0.900	0.900	2.000					

Table 5

Steps and results obtained for the general objective (model).

Decision matrix				Normalized matrix				W	X	CV	λ	CI	RI	CR	CR <0.1
	C 1	C 2	C 3		C 1	C 2	C 3								
C 1	1.00	9.00	1.00	C 1	0.474	0.474	0.474	0.474	0.474	3.000	3.000	0.000	0.662	0.000	TRUE
C 2	0.11	1.00	0.11	C 2	0.053	0.053	0.053	0.053	0.053	3.000					
C 3	1.00	9.00	1.00	C 3	0.474	0.474	0.474	0.474	0.474	3.000					

In figure 2 is presented the local weights of criteria from level 1 based on the general objective.

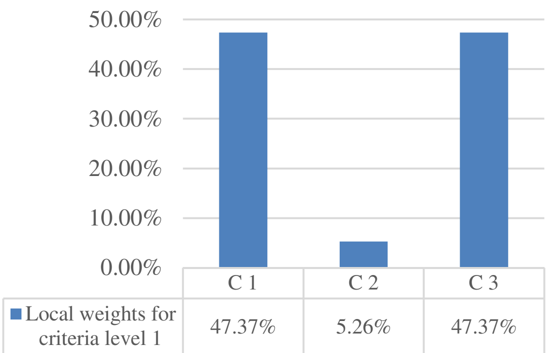


Fig. 2. The local weights of criteria from level 1

After analysis with AHP method, results that C 1 (technical criteria) and C 3 (other criteria) have obtained the greatest priority (47.37 %), followed by C 2 (size and dimensional criteria) with score (5.26 %).

This means that in order to choose the best variant of ARC welding industrial robot for the welding process of the tracked mini-robot for military applications housing, it is necessary that the technical characteristics (like working speed, repeatability) to be fulfilled, as well as other characteristics like mounting type.

From this AHP first level criteria analysis, results that for the welding process for tracked mini-robots it is necessary to acquire industrial robots with high technical performances. The low value for C 2, regarding the size of the industrial robot, can be explained by the fact that the selection of the optimal variant of robot is not constrained by the working space, in military industry spacious industrial halls are used.

In figure 3÷5 are illustrated the local weights of criteria from level 2.

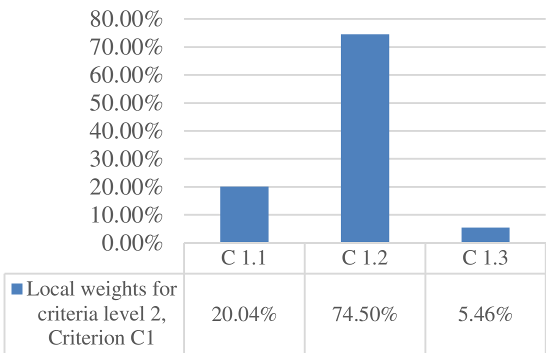


Fig. 3. The local weights of criteria from level 2, Criterion C1

In figure 3 are illustrated the local weights of criteria from level 2 with respect to technical criteria (C 1), the sub-criteria C 1.2 (repeatability) with value 74.5% has the highest ranking, followed by sub-criteria C 1.1 (motion) with 20 %, and the last ranking with 5.46 % corresponding to sub-criteria C 1.3 (allowable loading).

From this level 2 criteria classification, results that it is important for the welding robot to work repeatability in certain limits. For example, in military industry, it is necessary to perform the spot welding in a precise spot, or on a certain spot line, under identical welding conditions.

The evaluators have taken into consideration, as well, the sub-criteria C 1.1 (motion of the industrial robot), in which it was considered the speed of axis of joints of the robot, respectively the range of robot's arm features with high importance in the welding process in the military industry.

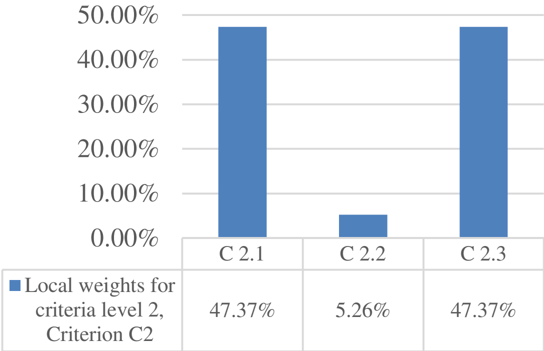


Fig. 4. The local weights of criteria from level 2, Criterion C2

In the case of main criteria C 2, the sub-criteria C 2.1 (payload) and C 2.3 (robot reach) have the highest priority (47.37 %), followed by C 2.2 (robot mass) with only 5.26 %. Analyzing the obtained weight, ensue that it is necessary that the variant of industrial robot to have a high loading capacity, respectively a maximum arm reach, to ensure an extensive workspace, in both vertical and horizontal plane.

For the last main criteria (C 3), the sub criteria C 3.2 (cost) and C 3.3 (flexibility) have the same weight (47.37 %), and for C 3.1 (power rate) have obtained only 5.26 %. In this case, both technic and economic factors are considered in the selection of the suitable industrial robot for ARC welding process in military industry.

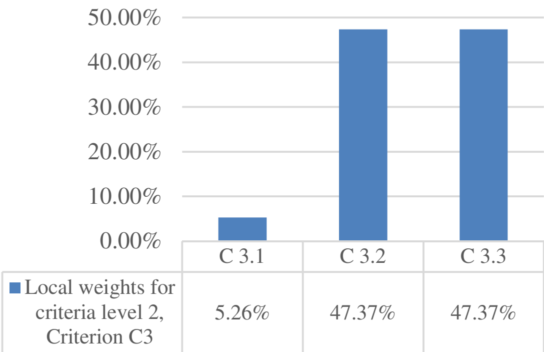


Fig. 5. The local weights of criteria from level 2, Criterion C3

Technically, the robot must offer a high flexibility, namely the possibility of reprogramming for another task in the military industry (for example pick and place task), mounting the robot in different positions (like wall, ceiling, angle), respectively setting various welding devices on the free end of the robot's arm for different welding techniques (MIG, PLASMA, ARC). On the other hand, the economical factor is equally important as the technical factor, because it is desirable that the proper robot, with the best technical performance, it is bought at an affordable price.

In figure 6 are illustrated the local weights of criterion from level 3.3.1.

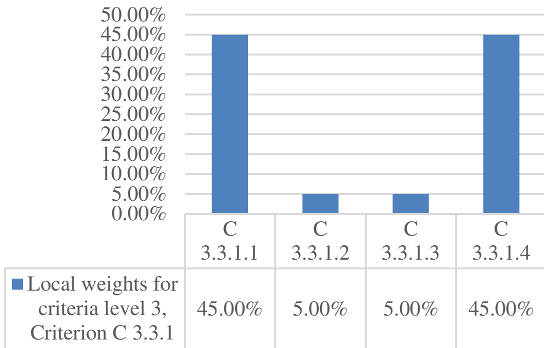
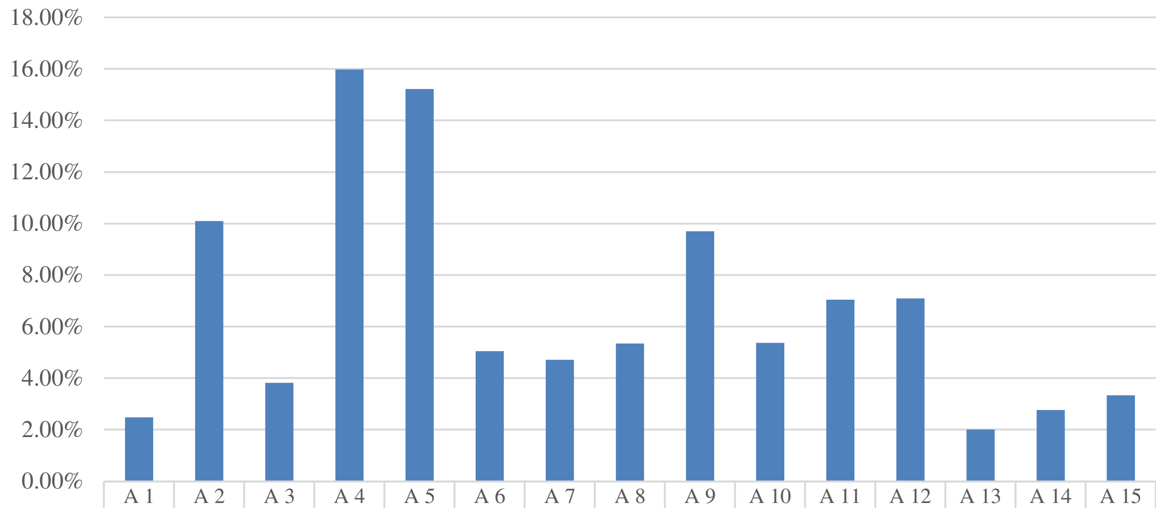


Fig. 6. The local weights of criteria from level 3, Criterion C 3.3.1

The chart from figure 6 represents the distribution of the local weights of criteria from level 3 of the sub-criteria C 3.3.1 (Mounting type). Criteria C 3.3.1.1 (Floor) and C 3.3.1.4 (Wall) have earned the highest weights (45%) thus to perform the ARC welding procedure of the tracked mini-robots housing, the chosen industrial robots, beside standard mounting on the floor, have also the mounting option on the wall, where the robot`s base is in the plane. Mounting the welding robot on the wall or on the lifting crane, makes the end-effector (the welding head) programable to execute complex paths in the work space, by using the robot`s arm extension closest to its maximum opening, to cancel the singularities in the kinematic chain, or to obtain a larger work space for the welding robot.

In figure 7 it is shown the global weights of alternatives considering each criterion.

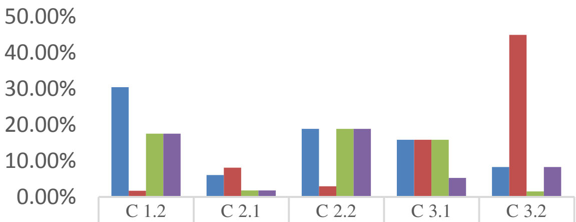


	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 9	A 10	A 11	A 12	A 13	A 14	A 15
Global weights	2.48%	10.09%	3.82%	15.98%	15.22%	5.05%	4.71%	5.34%	9.70%	5.37%	7.04%	7.09%	2.01%	2.76%	3.33%

Fig. 7. Global weights of alternatives taking into account all the criteria

Of the 15 industrial robots alternatives analyzed using the AHP method, taking into account all the identified criteria and sub criteria, respectively by the tangible and intangible characteristics, it has emerged that the alternatives that have obtained the highest weight are: on the first rank is A 4 with ≈ 16%, followed by A 5 (≈ 15%), and then next alternatives (A 2 and A 9) have the same value ≈ 10%.

The diagram from Figure 8 represents the distribution of the local weights of some criteria from level 1 for the well-ranked four alternatives.



	C 1.2	C 2.1	C 2.2	C 3.1	C 3.2
A 4	30.42%	6.06%	18.92%	15.87%	8.27%
A 5	1.76%	8.14%	2.96%	15.87%	44.92%
A 2	17.55%	1.77%	18.92%	15.87%	1.53%
A 9	17.55%	1.77%	18.92%	5.24%	8.27%

Fig. 8. The distribution of the local weights of some criteria from level 1, for the alternatives A4, A5, A2, A9

From a global analysis of the diagram presented in Figure 8, it was found that the alternative A 4 obtained the favorable weight to the criteria C 1.2 (Repeatability), C2.2 (Robot mass), C 3.1 (Power rate), compared to the other three alternatives (A5, A2, A9). Locally, the criteria C 1.2 has obtained the highest score (30.42%), followed by C 2.2 with 18.93% and the lowest scores was obtained by C3.2 (Cost) with 8.27% and C 2.1 (Payload) with 6.06%. It can be noticed that in case of alternative A5 (ranked in position 2 after analysis with AHP), the criteria Cost (C3.2) has the highest weight (44.92%), then C3.1 (15.8%), C 3.2 (8.14%), C 2.2 (2.96%). Although, for both alternatives A4 and A5, the technical criteria have comparable values, but from the cost point of view, the alternative A4 has obtained the lower score, which makes it to be the favorable choice for the proposed application.

4. CONCLUSIONS

In literature it is proven that the AHP technique is a powerful tool for selection problem solving in order to achieve the best solution from a multitude of alternatives for a specific goal (the general objective), taking into account tangible and intangible factors, respectively various criteria and sub criteria. The applicability of AHP technique is large, being successfully used in different domains with different applications, such as the military industry.

In this research paper, is presented a case study for solving a decisional problem using the AHP method. With AHP method was obtained the best variant of ARC welding industrial robot from 15 alternatives based on established general objective, respectively tangible and intangible factors (criteria and sub criteria level 1, 2 and 3). The industrial robot task considered for this case study is to carry out the ARC welding of the metal components from mechanical housing structure of the tracked mini-robots for military applications. For AHP method, the criteria and sub criteria are defined considering both technical and economic factors. Even if for this specific application the welding procedure is ARC, for AHP was taken into consideration the welding type as a sub criteria level 2. Thus, the chosen industrial robot can be also used for welding of other types of materials, such as aluminum, increasing the degree of flexibility of the chosen robot.

Also, with AHP method was obtained the ranking of the alternatives by global weights of alternatives considering each criterion. In the case of the technical criteria (C 1.2, C 2.1, C 2.2, C 3.1) the alternatives A 4, A 5 and A 9 have obtained the highest scores, but from the cost aspect, the alternative A 5 achieved the highest score and alternative A 2 the smallest value (1.53%). This expresses the fact that the industrial robot corresponding to the alternative A 5 has good technical characteristics at an acceptable cost, which makes it a good choice for the chosen application.

Future research will be performed using the AHP method results by applying a more complex decision-making process, like AHP – TOPSIS in fuzzy environment. Fuzzy TOPSIS is employed to determine the priorities of the alternatives based on the weights obtained with AHP method.

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SELECTAREA ROBOTILOR INDUSTRIALI IN INDUSTRIA MILITARĂ FOLOSIND METODA AHP: STUDIU DE CAZ

Abstract: Avand in vedere multitudinea companiilor care produc roboti industriali, configurația structurală complexă și gradul de automatizare al roboților industriali, selectarea roboților industriali pentru a îndeplini o anumită sarcină devine din ce în ce mai dificilă. În această lucrare de cerectare, s-a aplicat metoda AHP pentru a selecta cea mai favorabilă configurație a unui robot industrial care trebuie să efectueze sudarea ARC a carcaselor mini-roboţilor şenilaţi utilizaţi în aplicaţii militare. În acest scop, au fost luate în considerare mai multe companii care produc roboți industriali cu diferite specificaţii tehnice. Studiul evidențiază utilitatea aplicării metodelor de luare a deciziilor în procesele tehnologice automatizate, pentru a facilita și simplifica procesul de selecție a robotului industrial, pentru a obține varianta potrivită a robotului industrial dintr-un set de alternative, care realizează una sau mai multe sarcini specifice.

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