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Application model of MCDM for selection of automatic rifle

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Abstract

The paper presents a selection of the best automatic rifle of domestic production. The complexity of the problem is conditioned by the different constructional characteristics of automatic rifles, which is why the application of multi-criteria decision-making methods is necessary. The choice of the most favorable alternative was made using the AHP - VIKOR method. By applying the AHP method, the calculation of the weight coefficients of the criteria was performed, while by applying the VIKOR method, the most favorable automatic rifle, was selected. The output is a proposal for the introduction into operational use and equipping of the security forces of the Republic of Serbia.

Keywords: AHP method, VIKOR method, automatic rifle, multi-criteria decision making (MCDM)

1. Introduction

The development of weapons and military equipment experienced an expansion at the end of the 20th century, and this was influenced by various factors. Automatic rifles are the basic means of arming the world's infantry units, and according to their dimensions and manner of handling, they represent individual weapons. They achieve the best effect on the target at distances up to 400 m. Many armies of the world have different types and models of automatic rifles in their weapons, which is conditioned by the realization of different types of tasks.

Based on the stated facts, the task is set for the selection of the most efficient automatic rifle, which would meet the needs of the Serbian Army according to its characteristics. Due to the complexity of the mentioned problem, the choice of an automatic rifle conditioned the application of several methods of multi-criteria decision making, namely the methods AHP (Analytic Hierarchy Process) and VIKOR (VIšekriterijumsko KOmpromisno Rangiranje).

2. Literature review

So far, a large number of quantitative methods have been developed that help us make certain decisions (Pamučar et al, 2011a). These are the most common methods of optimization, which aim to select the optimal

[#] The initial version of the research was published at 11th DQM International conference life cycle engineering and management ICDQM -2020, Prijevor, Serbia (Radovanović et al., 2020b).

solution from the set available, using mathematical modeling of real problems and a set of mathematical tools for solving decision-making problems. Jenkins and Lowrey (2004) conduct a comparative analysis of the shooting weapons used in the U.S. Army and the proposed replacement weapons through quantitative analysis of the characteristics of the weapon "head to head". Dağdeviren et al. (2009) show the selection of optimal weapons using the AHP, TOPSIS and fuzzy TOPSIS methods. Ashari and Parsaei (2014) use ELECTRA III to optimize rifles for infantry units. Gordon et al. (2015) conducted a comparative analysis of weapons and military equipment of the U.S. army and other armies of the world, comparing basic combat characteristics. Jokić et al. (2019) using comparative analysis using the VIKOR method analyze different types of caliber for automatic rifle. Radovanović et al. (2020a) using the fuzzy AHP-VIKOR method select the most efficient procedure for rectification of the optical sight. Karimoddini et al. (2022) selects the UAV and evaluates its performances in order to support bridge inspection using the AHP method. Radovanović et al. (2020b) analyze the technical characteristics of Serbian-made automatic rifles with the aim of equipping units of the Serbian Armed Forces. Božanić et al. (2020) using a hybrid multi-criteria decision model composed of two methods: LBWA (Level Based Weight Assessment) and MAIRCA (Multi Attributive Ideal-Real Comparative Analysis method) modified by interval rough numbers – IR-MAIRCA, select the most favorable submachine gun for the needs of the army. Radovanović et al. (2021a) analyze the accuracy and precision of shooting of Serbian-made automatic rifles using the AHP method. Kowalewski (2021) compares and selects the best submachine gun for the needs of service weapons. Radovanović et al. (2021b) using a hybrid MCDM model AHP-VIKOR select the anti-armor missile systems. Dimitrov (2021) analyse a new generation of assault rifles and ammunition designed for the needs of the U.S. Military. Chemezov et al. (2021) presents the results of the ak-109 assault rifle's bullet penetration into targets made of different materials. Tesić et al. (2022) presents a modification of the DIBR and MABAC method by applying rough numbers in multi-criteria decision-making of the most effective anti-tank missile system.

3. Materials and methods

This part of the paper describes the methods used in the paper. The AHP method developed by Thomas Saaty was used to define the weighting coefficients, while the VIKOR method of multi-criteria decision-making developed by Serafim Opricović was used to select the most favorable alternative. Figure 1 shows the phases through which this model was realized.

3.1 AHP method

In the 1970s, Thomas Saaty developed the AHP method (Saaty, 1980), which is used in the analysis of multi-criteria decision making. The AHP is one of the methodological approaches for solving complex decision-making problems involving multiple alternatives and criteria. The AHP method has so far undergone a large number of modifications (Pamučar et al., 2012; Chatterjee and Stević, 2019), but in some cases it is still used in its original form in both individual (Radovanović et al., 2019) and group decision making (Janković and Popović, 2019). It is applied in decision-making analysis and decision-making in solving complex problems whose elements are goals, criteria, sub-criteria and alternatives.

It is ideal in cases when a larger number of decision makers participate in decision-making and when decision-making is based on a larger number of criteria in multiple time periods. It is realized by decomposing (structuring) problems into hierarchies, defining assigning weights to criteria, forming matrices of pair comparison, in order to determine normalized weights. Assigned weights are used to evaluate attributes at the lowest level of the overall hierarchy. The decision-making process is complex due to the emergence of competitive and conflicting goals among alternatives and criteria. The author of the method emphasized that decision-making practice most often deals with weighted alternatives, which satisfy a set of desired goals. It is necessary to choose alternatives that will best satisfy the whole set of goals. The modeling process includes four phases:

- 1 - structuring the problem,
- 2 - collecting data,
- 3 - estimating relative weights and
- 4 - determining the solution to the problem.

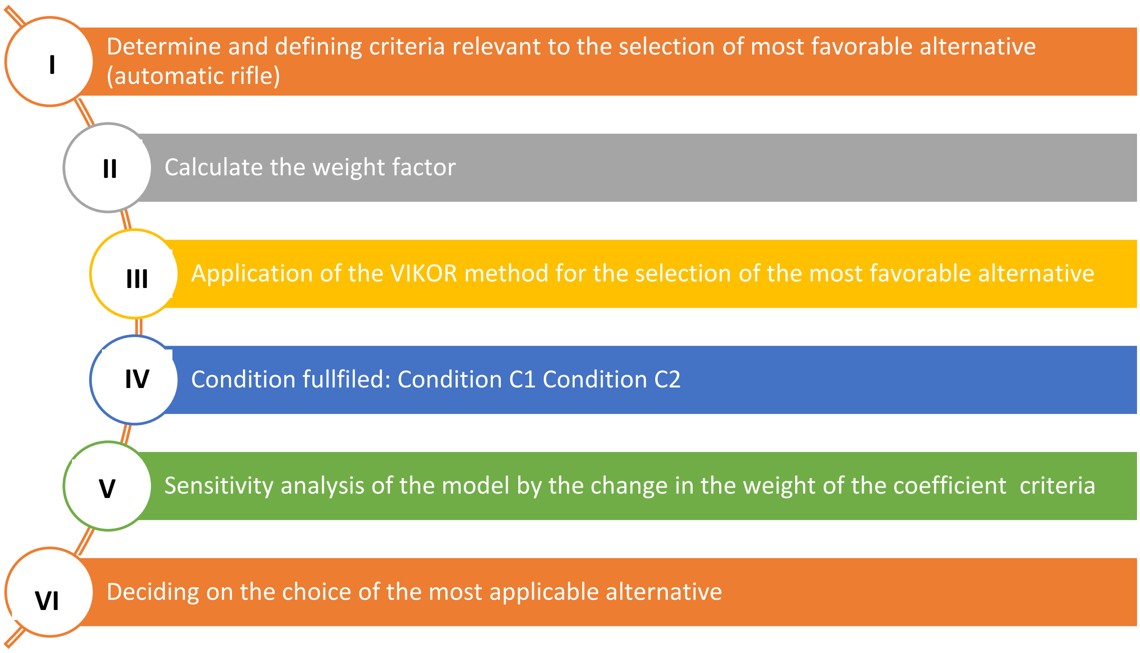

Figure 1. AHP-VIKOR model

The hierarchical structure for the general AHP model (Vujičić et al., 2018) can be seen in Figure 2.

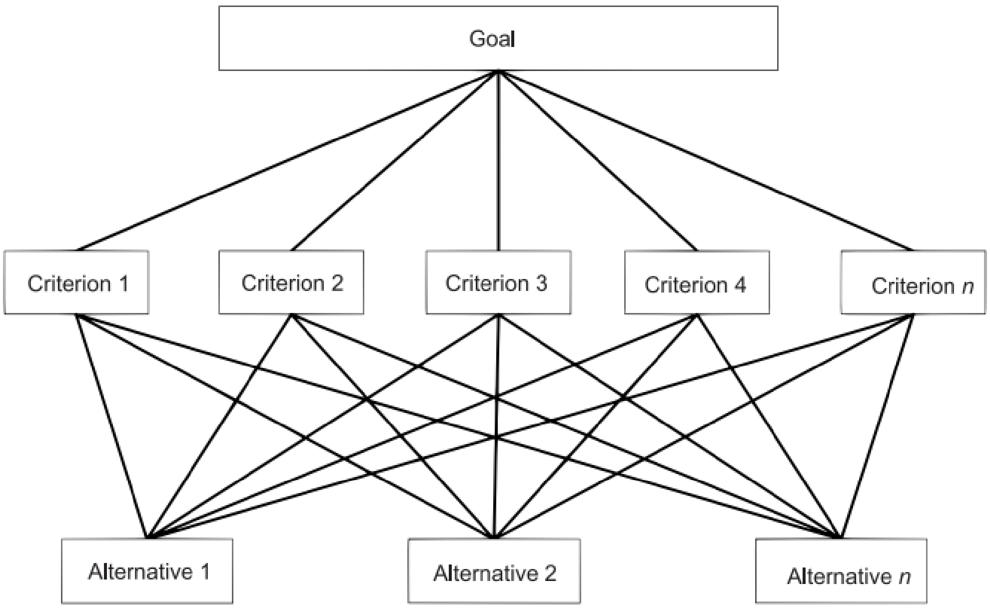

Figure 2. The AHP model

Saaty defined a scale that has a maximum value of 9, a minimum value of 1, and a division difference of 1, Table 1 (Saaty, 1994). The Satie scale is generally considered the standard for AHP, and is used for pairwise comparisons.

Table 1. Saaty's rating scale

Level	Definition	Explanation
1	equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgement strongly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Very strong importance	Activity is strongly favoured, its dominance demonstrated in practice
9	Extreme importance	Evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

The AHP method provides the possibility to decompose the realization of dependence-independence between attributes into different hierarchical levels. In order to facilitate the application of the method, software from the class of decision support systems *Expert Choice* was developed, which includes the AHP method.

3.2 VIKOR method

The VIKOR method is a method of multi-criteria ranking, the use of which is very common and is suitable for solving various decision-making problems. It is especially emphasized for situations where criteria of a quantitative nature prevail.

The VIKOR method was developed on the basis of elements from compromise programming. The method starts from the "boundary" forms of Lp - metrics (Opricović, 1986; Opricović and Tzeng, 2004; Chatterjeea and Chakrabortyb, 2016). The solution that is closest to the ideal is chosen. For measuring the distance from an ideal point the following metric is used:

$$L_p\left(F^*,F\right)=\left\{\sum_{j=1}^{n}\left[f_j^*-f_j\left(x\right)\right]^p\right\}^{\frac{1}{p}},1\le p\le\infty \quad (1)$$

The presented metric represents the distance between the ideal point *F** and the point *F(x)* in the space of criterion functions (Opricović, 1986). Minimizing this metric determines a compromise solution. According to p it has the role of a balancing factor between the total benefit and the maximum of the individual deviation. Lower values for p emphasize group benefit, while higher values for p increase the weight given to individual deviations.

When working with the method, the following terms will be used:

- n - number of criteria
- m - number of alternatives for multicriteria ranking
- f_{ij} - values of the i-th criterion function for the j-th alternative,
- w_j - weight of the j-th criterion function,
- v - weight of the strategy, meeting most of the criteria,
- i - ordinal number of the alternative, i = 1, ..., m.,
- j - ordinal number of criteria, j = 1, ..., n,
- Q_i - measure for multicriteria ranking i-th alternative

For each alternative, there are Q_i values, and then an alternative is chosen where this value is the smallest (the smallest distance from the "ideal" point). The measure for multicriteria ranking of the i-th action (Q_i) is calculated according to the expression (Opricović, 1998):

$$Q_i = v * QS_i + (1-v) * QR_i \tag{2}$$

where is:

$$QS_i = \frac{S_i - S^*}{S^- - S^*} \tag{3}$$

$$QR_i = \frac{R_i - R^*}{R^- - R^*} \tag{4}$$

$$S^* = \min_i S_i \tag{5}$$

$$R^* = \min_i R_i \tag{6}$$

$$S^- = \max_i S_i \tag{7}$$

$$R^- = \max_i R_i \tag{8}$$

By calculating the QS_i, QR_i, and Q_i values for each alternative, it is possible to form three independent rankings. QS_i value, is a measure of deviation that shows the requirement for maximum group benefit (first ranking list). QRi value is a measure of deviation that shows the requirement to minimize the maximum distance of an alternative from the "ideal" alternative (second ranking list). Q_i value represents the establishment of a compromise ranking list that combines QS_i and QR_i values (third ranking list). By choosing a smaller or larger value for v (the weight of strategies to meet most criteria), the decision maker can favor the influence of QS_i value or QR_i value in the compromise ranking list. For example, higher values for v (v> 0.5) indicate that the decision maker attaches greater relative importance to the strategy of meeting most of the criteria (Nikolić et al., 2010). Modeling the preferential dependence of the criteria usually includes the weights of individual criteria. If the given values of weights are given, the multi-criteria ranking by the VIKOR method is realized using the measure S_i and R_i. In the previous expressions, the labels used have the following meaning:

$$S_i = \sum_{j=1}^{n} W_j \frac{f_j^* - f_j}{f_j^* - f_j^-} = \sum_{j=1}^{n} w_j * d_{ij}, i = 1,2,...m \tag{9}$$

$$R_i = \max_j \left(w_j \frac{f_j^* - f_j}{f_j^* - f_j^-} \right) = \max_j \left(w_j * d_{ij} \right), i = 1,2,...m \tag{10}$$

where is:

$$f_j^* = \max_i f_{ij}, \ j = 1,2,...n \tag{11}$$

$$f_j^- = \min_i f_{ij}, \ j = 1,2,...n \tag{12}$$

Alternative a_i is better than alternative a_k according to the j^{th} criterion, if:

- $f_{ij} > f_{kj}$ (for max f_j, that is when the criterion has a request for a maximum),
- $f_{ij} < f_{kj}$ (for min f_j, that is when the criterion has a request for a minimum).

In multi-criteria ranking by the VIKOR method, alternative ai is better than alternative al (in total, according to all criteria), if: $Q_i < Q_k$. A compromise ranking list for the value v = 0.5 is taken as an acceptable ranking list according to the VIKOR method. If an alternative is in the first position on such a compromising ranking list, it still does not mean that this alternative is considered the best. In order for an alternative to be adopted as the best, according to the VIKOR method, it must be first on the compromise ranking list and meet two conditions: condition 1 and condition 2.

Condition 1

The first alternative on the compromise ranking list for the value of v = 0.5, must have a "sufficient advantage" over the action from the next position. “Advantage” is calculated as the difference of measures Q_i for the value v=0.5. Alternative a 'has a "sufficient advantage" over the following a "from the ranking list, if fulfilled:

$$Q(a`) - Q(a``) \geq DQ \tag{13}$$

$$DQ = \min\left(0.25;\ 1/(m-1)\right) \tag{14}$$

where:

- *DQ* - “sufficient advantage” threshold ,
- *m* - number of alternatives,
- 0.25 - the size of the threshold of "sufficient advantage" which limits the threshold for cases with a small number of alternatives.

Condition 2

The first alternative on the compromise ranking list for the value v = 0.5, must have a "sufficiently stable" first position with a change in weight v. The first alternative on the compromise ranking list has a "sufficiently stable" position, if it meets at least one of the following conditions:

- has the first position on the ranking list according to *QS*,
- has the first position on the ranking list according to *QR*,
- has the first position on the ranking list according to *Q* for v = 0.25 and v = 0.75.

If the first alternative from the compromise ranking list does not meet one or both conditions (1 and 2), it is considered that it is not "sufficiently" better than the alternative from the second position and possibly some more alternatives. In such cases, a set of compromise solutions is formed, which consists of the first, second and possibly some other alternatives (third, fourth ...). If the first alternative does not meet only the condition 2, then only the first and second actions are included in the set of compromise solutions. However, if the first alternative does not meet condition 1 (or both 1 and 2), then the set of compromise solutions contains alternatives from the compromise ranking list to the alternative that meets condition 1, that is to the one over which the first alternative has a "sufficient advantage" via *DQ*.

The results of the VIKOR method are:

- Ranking lists according to QS_i, QR_i and Q_i measures,
- A set of compromise solutions (in case the conditions 1 and / or 2 are not met).

These results represent the basis for deciding and adopting the final solution (multi-criteria optimal solution).

4. Problem solution

The VIKOR method was used to select the most efficient automatic rifle of domestic production, in order to equip units of the Serbian Army. The selection of the most efficient automatic rifle aims to increase the efficiency of the realization of fire tasks with an automatic rifle and optimize costs. The alternatives are:

- A1 - 7.62 mm M70 AB2 automatic rifle,
- A2 - 5.56 mm M21A automatic rifle,
- A3 - Automatic modular rifle M17.

The criterion defines the quality and represents a measure for comparison when choosing the most favorable alternative. The criterion is expressed by a criterion function that for the best variant should reach the global extreme, given the limitations that represent the possibility of achieving the goal. Eight criteria have been defined for the selection of the best alternative, based on the study of the theory of infantry weapons shooting (Kokelj and Ranđelović, 2018) and based on the experience of professional members of the Armed Forces. The following criteria are defined:

- C1 - initial bullet velocity (m / s),
- C2 - practical shooting speed (rounds / min),
- C3 - effective range (m),
- C4 - shooting accuracy at 100 m (mm),
- C5 - type of basic sight,
- C6 - automatic rifle weight (kg),
- C7 - caliber (mm),
- C8 - automatic rifle length (mm).

The weights of the criteria were determined on the basis of studying the theory of shooting and the experiences of professional members of the Armed Forces, using the AHP method (Table 2). The criterion of the type of basic sight is presented qualitatively because it is not possible to present this criterion quantitatively. Qualitative assessments are translated into quantitative ones based on the results of the AHP method. Evaluations of all alternatives according to all criteria are given in the initial decision table (Table 3), and quantified decision table (Table 4).

Table 2. Weight coefficients of criteria

criteria	C1	C2	C3	C4	C5	C6	C7	C8
Weight coefficient	0.390	0.239	0.162	0.092	0.051	0.028	0.02	0.017

Table 3. Initial decision table

criteria	C1	C2	C3	C4	C5	C6	C7	C8
extreme	max	max	max	min	max	min	min	min
A1	720	120	400	55	mechanical sight	3.7	7.62	950
A2	914	110	300	21	optical sight	4.5	5.56	998
A3	760	120	600	14	reflex sight	3.55	6.5	850

Table 4. Quantified decision table with the best and weakest alternatives for all criteria

criteria	C1	C2	C3	C4	C5	C6	C7	C8
A1	720	120	400	55	0.1	3.7	7.62	950
A2	914	110	300	21	0.25	4.5	5.56	998
A3	760	120	600	14	0.65	3.55	6.5	850
f_j^*	914	120	600	14	0.65	3.55	5.56	850
f_j^-	720	110	300	55	0.1	4.5	7.62	998

For a simpler calculation, the size *d* is introduced:

$$d_{ij} = \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \tag{15}$$

Table 5 shows the calculated values for d_{ij}, $w_j \times d_{ij}$, S_i and R_i.

Table 5. Calculated values for d_{ij}, $w_j \times d_{ij}$, S_i and R_i

C1	C2	C3	C4	C5	C6	C7	C8	Si	Ri
				wi*Dij					
0.390	0.000	0.108	0.092	0.051	0.004	0.020	0.011	0.677	0.390
0.000	0.239	0.162	0.016	0.037	0.028	0.000	0.017	0.499	0.239
0.310	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.319	0.310

The data from the last two columns of Table 5 are necessary for further calculation:

$S^* = 0{,}319$; $S^- = 0{,}677$; $R^* = 0{,}239$ $R^- = 0{,}390$;

Table 6 shows the calculated values for QS_i, QR_i, Q_i (v=0.5), Q_i (v=0.25), Q_i (v=0.75).

Table 6. Calculated values for QS_i, QR_i, Q_i

alternatives	QS_i	QR_i	Q_i (v=0,5)	Q_i (v=0,25)	Q_i (v=0,75)
A1	1.000	1.000	1.000	1.000	1.000
A2	0.503	0.000	0.251	0.126	0.377
A3	0.000	0.467	0.234	0.351	0.117

Based on the obtained values for QS_i, QR_i, Q_i for each alternative, three independent rankings can be formed (Table 7). According to the QSi criterion, the most favorable alternative is A3, and according to the QR_i criterion, the best alternative is A2. Collectively, according to Q_i (v = 0.5), the best alternative is A3.

Table 7. Ranking list based on values QS_i, QR_i, Q_i

alternatives	QS_i	QR_i	Q_i (v=0.5)
A1	3	3	3
A2	2	1	2
A3	1	2	1

In order for an alternative to be adopted as the best, according to the VIKOR method, it is necessary to meet the conditions 1 and 2. Based on the obtained results, condition 1 is not fulfilled because:

Q (A2) – Q (A3) = 0.251 -0.234 = 0.017 < DQ = 0,25

Alternative A2 enters a set of compromise solutions, as the first alternative A3 does not have a "sufficient advantage" over the second-ranked alternative A2. Analysis of the following alternative (third in rank - alternative A1):

Q (A1) – Q (A3) = 1 – 0.234 = 0.766 > DQ

Alternative A1 does not enter into a set of compromise solutions, as the alternative that occupies the first position A3 has a "sufficient advantage" over the third-ranked alternative A1.

Condition 2 is met because alternative A3 has a "sufficiently stable" first place according to two criteria:

- alternative A3 has the first position on the ranking list according to QS, and
- alternative A3 has the first position on the ranking list according to Q for v = 0.75

The final solution is defined by a set of compromise solutions that include alternatives A3 and A2. The decision maker can choose the alternative A3 - rifle automatic modular 6.5 mm M17, and as the first spare alternative is proposed alternative A2 - rifle automatic 5.56 mm M21.

6. Sensitvity analysis

Sensitivity analysis is the last step that needs to be applied. Sensitivity analysis is an important segment of the validationof results. It has been featured in a number of papers (Pamučar et al., 2011b; Božanić and Pamučar, 2010; Tešić et al., 2022). Weak results of sensitivity analysis take the whole research process to the beginning (Radovanović et al., 2021a)There are different approaches to the sensitivity analysis of models; most often authors in their papers use sensitivity analysis by changing weight coefficients of the criteria (Radovanović et al., 2021b). This analysis implies evaluation of alternatives based on different weightcoefficients of criteria, that is favoring one criterion in each scenario. In this research we defined seven scenarios, Table 8 .

Table 8. Weight coefficients of criteria in different scenarios

criteria	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
C1	0.390	0.125	0.300	0.100	0.100	0.100	0.100	0.100	0.100	0.100
C2	0.239	0.125	0.100	0.300	0.100	0.100	0.100	0.100	0.100	0.100
C3	0.162	0.125	0.100	0.100	0.300	0.100	0.100	0.100	0.100	0.100
C4	0.092	0.125	0.100	0.100	0.100	0.300	0.100	0.100	0.100	0.100
C5	0.051	0.125	0.100	0.100	0.100	0.100	0.300	0.100	0.100	0.100
C6	0.028	0.125	0.100	0.100	0.100	0.100	0.100	0.300	0.100	0.100
C7	0.020	0.125	0.100	0.100	0.100	0.100	0.100	0.100	0.300	0.100
C8	0.017	0.125	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.300

Rankings of alternatives obtained using different scenariosare shown in Table 9.

Table 9. Rankings of alternatives obtained using different scenarios

Alternative	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
A1	3	3	3	2	2	3	3	2	3	2
A2	2	2	2	3	3	2	2	3	2	3
A3	1	1	1	1	1	1	1	1	1	1

Obtained rankings, shown in Table 10, imply that favoring certain criteria affects the differences in rankings; this further implies that the developed model is sensitive to the changes of weight coefficients. The worst-ranked alternatives (A1) in a large number of scenarios kept their rankings, as well as the best-ranked (A3). However, even though the correlation between rankings seems pretty obvious, a serious analysis demands quantitative indicators. In that sense, we checked rankings correlation using the Spearman’s rank coefficient (Božanić et al., 2020).

The values of the Spearman’scoefficients range from -1 ("ideal negative correlation") up to1 ("ideal positive correlation"). In Table 10, one can see values of the Spearman’scoefficients by comparing all scenarios to each other. In thefirst row of Table 10, when comparing scenario S-0 (values ofweight coefficients obtained through research) to others wegot values compared to the final ranking.

Table 10. Rankings of alternatives obtained using different scenarios

	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
S0	1	1	1	0.5	0.5	1	1	0.5	1	0.5
S1		1	1	0.5	0.5	1	1	0.5	1	0.5
S2			1	0.5	0.5	1	1	0.5	1	0.5
S3				1	1	0.5	0.5	1	0.5	1
S4					1	0.5	0.5	1	0.5	1
S5						1	1	0.5	1	0.5
S6							1	0.5	1	0.5
S7								1	0.5	1
S8									1	0.5
S9										1

Based on the results shown in Tables 9 and 10, it is concluded that the choice of Alternative 3 is very stable. Alternative 3 takes the first place in all scenarios of changing the weighting coefficients of the criteria. Due to the small number of alternatives used in this problem, the values of the Spearman coefficient are 0.5 and 1. The results shown in Table 10 suggest that the application of the Spearman coefficient in sensitivity analysis with a small number of alternatives is not necessary because it does not give the required results, and it should be used when there is a larger number of alternatives (more than 5).

7. Conclusion

Based on the above, the conclusion is that multi-criteria analysis can be successfully applied in solving the problem of choosing the best automatic rifle, which according to its criteria best meets the tasks performed by units of the Serbian Army equipped with this type of weapon. This is shown in the example solved by the combination of the AHP method and the VIKOR method. Using the AHP method with the help of the software program Expert choice 2000, the weight coefficients of the criteria were defined, while the VIKOR method was used to select the optimal solution of a home-made automatic rifle based on the given criteria. In this way, a more objective view of the problem and its more efficient solution is achieved. It is also possible to apply other methods of multi-criteria decision-making in the selection of the most efficient automatic rifle.

Applying these methods, it was concluded that the set of compromise solutions consists of an automatic modular rifle 6.5 mm M17 and an automatic rifle 5.56 mm M21, where the alternative A3 AMR 6.5 mm M17 is a more optimal solution, and the alternative A2 AR 5.56 mm M21 is a backup alternative.

In the following research, it is possible to apply this model to solve other research problems.

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