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Material selection on countermeasure flare systems by multi criteria decision making methods

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Abstract – The material is one of the main important factors that should be considered in the design. The right material selection allows the design, on which is studied, to show the best performance. For this reason, this study aims to determine the best material for countermeasure flare systems with multi-criteria decision-making (MCDM) methods. In our study, a MCDM method called best worst based simple additive weighting (BWSAW) is proposed for material selection problem. AHP, SAW, TOPSIS, ELECTRE and BWSAW MCDM methods are also used. Cost, tensile strength, melt point, thermal conductivity, density, and thermal expansion have been taken into consideration as criteria and titanium diboride, alumina (95), chromium, silicium carbide, carbon fiber, and stainless steel as material alternatives. Carbon fiber is the best material for the AHP, SAW and BWSAW methods while stainless steel is the best material for ELECTRE and TOPSIS method. Given all methods together, it has been decided that the best material to be used for the countermeasure flare system is carbon fiber. This proposed MCDM method can be used by decision makers for all multi criteria decision making problems for future works. This study is intended to analyse the problem of the material selection of the dispenser systems used in the production of Countermeasures Dispenser Systems. In this research, a hybrid MCDM technique based on the combination of the BWM and SAW is utilized to solve the problem of selecting suitable material of the countermeasures dispenser systems in the literature.

Keywords – Material Selection, Design, Multi Criteria Decision Making, AHP, SAW, TOPSIS, ELECTRE, BWSAW, Countermeasure Flare system.

I. Introduction

In today's complex and modern battlefield, the biggest threat for low altitude flying aircraft is heat-seeking-missiles. Systems such as infrared-seeking and radar guided missiles, anti-aircraft guns, rockets, and small weapons as well as heat-seeking-missiles are among the major threats for aircraft. These aircraft are required to flight at low altitude in order to carry out their duty, accordingly being under the threat of the weapons named above. That aircraft can carry out their duty effectively and survive in battlefield depend on developing and practicing of tactics, technique and electronic-war countermeasures against all weapon systems. Today, the heat-driven missiles, which can be carried easily and be used from a shoulder, have been highly developed and widespread. These systems can also easily separate the real targets and countermeasure systems like flares. Therefore, all armed forces that use aircraft must use well-developed countermeasure systems for protecting their aircraft and personnel. Aircraft and all of its hot parts emit energy at the same wavelength that corresponds to the IR spectrum. This increases the effectiveness of surface-to-air heat-seeking missiles and makes aircraft a soft target. The higher the sensitiveness of the missile sensors, the higher their ability to select heat sources on aircraft. This would increase the effectiveness of the heat-seeking missiles in their effective range against any aircraft without countermeasures or protection systems. To prevent this, countermeasure systems that emit heat at the same wavelength as an aircraft and are integrated with the aircraft have been developed. The mission of these systems is to distract the sensors of heat-seeking missiles. Thus, aircraft security is ensured with the misdirection of sensors of heat-seeking-missiles by means of pseudo heat sources.

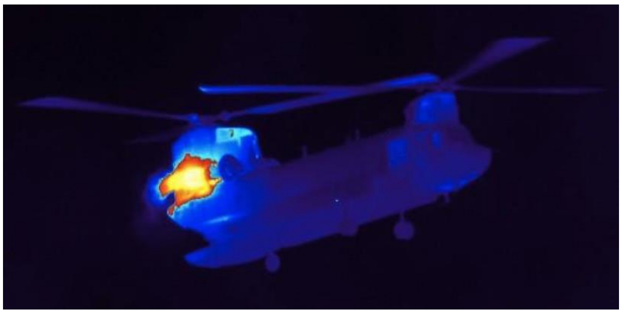

Fig. 1 Image of a helicopter taken by a thermal camera

All systems and procedures that protect aircraft from enemy's missiles before they are launched prevent missiles from reaching make a shot difficult and briefly, protect aircrafts from missiles which are called 'countermeasures'. The countermeasures cover methods are those that have physical use (Chaff and flare), electronic measures, and jammer systems and manoeuvre methods. Flares are used against heat-seeking missiles are materials or systems which are produced of magnesium, start burning after ejection from aircraft and emitting high heat. Their mission is to distract heat-seeking missiles from an aircraft by drawing the heat-seeking missiles onto themselves with their emitted high heat. Sometimes, they may be ejected before heat-seeking missiles are launched. They are used against infrared–seeking anti-aircraft missiles (SAM), especially in low-altitude attacks. It is hard to escape from missiles by only ejecting one or multi ejecting flares. Flares are generally ejected away in multiple numbers. For instance, 30 flares can be loaded onto an aircraft such as an F-16. The ejection period can be either set by the pilot or set automatically. There are also systems in the tail of some new age aircraft which automatically eject flares following the detection of these missiles.

Fig. 2 Countermeasure Dispenser Systems that are integrated with different angles in a Helicopter

Fig. 3 Countermeasure Dispenser System integrated in a Helicopter (close view)

The material is one of the main important factors that should be considered in the design. The right material selection allows the design, on which is studied, to show the best performance. In the present study, five alternative materials have been selected using the CES 2015 Edupack program and the best material among them has been decided applying MCDM method. The main material to be used in a Countermeasure Dispenser Systems (CMDS) should have the following properties.

1) It is a big advantage that the materials to be used in the production of the CMDS are lightweight. For this reason, the density of the material should be as low as possible.

2) While an aircraft is in flight, there is a high possibility that various stresses will occur on the systems. Therefore, the CMDS should be as durable as possible against these stresses and the yield point of the materials are used in the production of these systems should be as high as possible.

3) High temperatures occur in during dispense. Therefore, the melting point of these systems should be high so as they should be able to show resistance against these high temperatures.

4) Heat occurring in the CMDS should be transferred into the environment promptly. Thus, the CMDS systems will have a lower surface temperature, and the detection of the system by heat-seeking missiles will be more difficult. Therefore, the thermal conductivity coefficient of the material to be used should be as high as possible.

5) Thermal shock resistance of the material to be used should be as high as possible against unexpected heat changes. Consequently, the thermal expansion coefficient should be as low as possible.

6) The unit price of the material to be used should be low. However, this criterion is not as important as the others.

The selection of the right material is a vital decision in any design and material selection is a decision-making problem. A decision-making problem is a selection making process from within alternative decisions. In literature, that more than one decision maker (DM) gives the best decision by considering more than one criteria among more than one alternative is called MCDM problem. There are a lot of available MCDM methods that are used in the solution of MCDM problems. Analytical Hierarchical Process (AHP), Simple Additive Weighting (SAW), the best worst method (BWM), a new weighting method that was recently introduced to deal with pairwise comparisons (BWSAW) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) can be given as examples of these methods. These methods are intuitional methods and do not guarantee an optimal solution. Therefore, results of these methods may be different from each other and prevent the decision maker from making the best decision. We proposed the best worst based simple additive weighting (BWSAW) as a MCDM method. It was aimed to have the best material selection with AHP, SAW, TOPSIS, ELECTRE and BWSAW from the MCDM methods, to address the material selection of the dispenser systems used in the production of CMDS. The CMDS is a system that can be integrated with aircraft and are developed in order to protect aircraft from air-to-air and surface-to-air heat-seeking missiles. MCDM is a decision-making process that uses more than one alternative and takes changeable importance criteria the criteria according to the DM into consideration. The reason for taking the criteria weights into consideration is to calculate the importance of each criterion according to the other criteria. The weights calculated based on the assessment criteria's importance allow the definition of the variation of various values that each criteria has according to these weights and takes different numerical values depending on these variations [1]. There are many MCDM methods available in literature. Şenyiğit and Demirel [2] used the AHP, TOPSIS and SAW techniques in the selection of the material to be used in carbonated soft drink packaging in their study. Yılmaz and Evci [3] have a study in which they investigated the position of the aerospace and defence industry in the composite materials market by literature review. In their study, they discussed developing composite material technology that is possible to be used in the aerospace and defence sector in the future and put forward a novel technology assessment method addressed to determine technological development. Pehlivanoğlu [4], in his paper, explained with concrete examples why honeycomb structures were preferred in the aerospace industry. Belevi and İnançer [5], in their study, investigated the effect of atmospheric conditions such as temperature, humidity, and salt on the mechanical properties of carbon, glass and aramid fiber reinforced composites. Yurdakul et al. [6] developed a computer program by using the data obtained for the selection of high strength aluminium alloys used in the aerospace industry. Through this program, desired properties can be set according to the data that a user gives and the appropriate material among the alloys in the database is selected [6]. Şenyiğit and Demirel [7] proposed an entropy-based SAW and AHP to decide the best material for a dental implant. Öztürk and Kaçar [8] published a study summarizing magnesium alloy applications in aeronautics, reasons for preference and future work. Sun and Gollnick [9] proposed an index to measure the performance of a technique for the method selection approach. Sun [10] proposed an improved multi-criteria decision analysis method to collect the multiple design criteria into one composite and solved the specification problem of weighting factors. Sennaroğlu and Çelebi [11] proposed a location selection problem for a military airport using MCDM techniques in their study. They proposed a real-world decision problem. They offered the decision criteria to determine alternative locations. The objective of the paper was to determine the most suitable location among alternatives. They reviewed the literature of MCDM techniques. Babu et al. studied [12] on the choice of best matrix material for Aluminium Hybrid Metal Matrix Composites (AHMMCs) by AHP. They focused on AHMMCs. Kumar et al. [13] focalized on a computational outline for identifying the best applicant cloud service by integrating AHP and TOPSIS. Finally, they proposed a new methodology. Kabak and Keskin [14] proposed a mixed methodology of a mathematical model, AHP) and geographical information systems for the resolution of Hazardous Materials Warehouse Location Selection problem. Asadabadi [15] studied on MCDM techniques which need the DM to estimate candidates with respect to decision criteria and also to detect importance weightings to the criteria. He proposed the application of MCDM techniques by addressing possible fluctuations in the criteria weightings. There are a lot of review studies on MCDM techniques, recently. First of all, Sitorus et al. [16] focused on a wide survey of the exercises and streams of MCDM techniques for the choice problem in mining and mineral processing. Khedrigharibvand et al. [17] look at MCDM techniques that have the potential to be applied in sustainable rangeland management. They discussed how different MCDM techniques can be used and which techniques are well matched to determine suitable livelihood alternatives. Finally, Ghasempour et al. [18] presented studies about determining selection of solar plants sites and solar plants technologies with using MCDM techniques.

The BWM has been evolved recently, and, for this reason there are few studies that have used this method [19-24]. One of the hybrid MCDM method as BWSAW in our study is proposed by Yücenur and Subaşı [25]. Yücenur and Subaşı proposed a new hybrid method. The SWARA method is used in the first phase of the solution for determining criteria's importance weights. Finally, the WASPAS method was used for selecting the best alternative [25]. There is only one study using both BWM and SAW methods together [26]. BWM was used to gain the criteria weights and SAW was employed to rank the locations regarding the decision factors in their study. According to the best of our knowledge, there are no studies using BWSAW in the area of material selection. This is another contribution of this paper.

II. MATERIALS AND METHOD

The problem of decision making is most general and can be defined as a selection of the most appropriate option from a set of options for at least one purpose or criteria. Accordingly, the elements of a decision problem constitute priorities of DMs, options, criteria, environmental outcomes and DMs. MCDM, one of the most famous substations of decision making, can be described as a decision making problem under the existence of a decision criteria group [9,10]. This study is intended to analyse the problem of the material selection of the dispenser systems used in the production of Countermeasures Dispenser Systems. In this research, a hybrid MCDM technique based on the combination of the BWM and SAW is utilized to solve the problem of selecting suitable material of the countermeasures dispenser systems. As yet, many mathematical methods have been proposed and used for solving material selection problems. The major problem about current decision analysis attempts is that determining a suitable MCDM method is indeed an MCDM problem itself because different techniques might yield different results for a given problem.

The newest trend in regard to MCDM technique use is to mix two or more techniques to make up for lacks in any single particular technique. For example, Şenyiğit and Demirel [7] determined the best material for a dental implant by combining between entropy method and SAW as Yücenur and Subaşı [25]. This work tries to use a hybrid MCDM model that mixes BWM with SAW to solve the constraints of conventional decision techniques. Subsequently, BWM is applied to calculate weights of criteria, changed from those variables, via the pairwise comparison calculated by method of linear programming (LP). Eventually, SAW is manipulated to rank from the most to least alternative materials. The nomenclature is shown in Table-1.

1) It is a big advantage that the materials to be used in the production of the CMDS are lightweight. For this reason, the density of the material should be as low as possible.

2) While an aircraft is in flight, there is a high possibility that various stresses will occur on the systems. Therefore, the CMDS should be as durable as possible against these stresses and the yield point of the materials used in the production of these systems should be as high as possible.

3) High temperatures occur in during dispense. Therefore, the melting point of these systems should be high so as they should be able to show resistance against these high temperatures.

4) Heat occurring in the CMDS should be transferred into the environment promptly. Thus, the CMDS systems will have a lower surface temperature, and the detection of the system by heat-seeking missiles will be more difficult.

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The selection of the right material is a vital decision in any design and material selection is a decision-making problem. A decision-making problem is a selection making process from within alternative decisions. In literature, that more than one decision maker (DM) gives the best decision by considering more than one criteria among more than one alternative is called MCDM problem. There are a lot of available MCDM methods that are used in the solution of MCDM problems. Analytical Hierarchical Process (AHP), Simple Additive Weighting (SAW), the best worst method (BWM), a new weighting method that was recently introduced to deal with pairwise comparisons (BWSAW) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) can be given as examples of these methods. These methods are intuitional methods and do not guarantee an optimal solution. Therefore, the outcomes that these methods find may be different from each other and prevent the decision maker from making the best decision. We proposed the best worst based simple additive weighting (BWSAW) as a MCDM method. It was aimed to have the best material selection with AHP, SAW, TOPSIS, ELECTRE and BWSAW from the MCDM methods, to address the material selection of the dispenser systems used in the production of CMDS. The CMDS is a system that can be integrated with aircraft and are developed in order to protect aircraft from air-to-air and surface-to-air heat-seeking missiles.

Table 1 Nomenclature

a_{ij}	=	The output of alternative *i* in terms of criteria *j*.
r_{ij}	=	Normalized decision matrix
w_j	=	Weight of j^{th} criteria
y_{ij}	=	Weighted normalized decision matrix
A^*	=	Positive ideal solution
A^-	=	Negative ideal solution
S_i^*	=	The distance between performance scores from the positive ideal for each alternative
S_i^-	=	The distance between performance scores from the negative ideal for each alternative
C_i^*	=	Relative closeness value of alternative *i*
C_{ij}	=	Concordance matrices
D_{ij}	=	Discordance matrices
C	=	Concordance matrices
D	=	Discordance matrices
F	=	Predominance concordance matrices
G	=	Predominance discordance matrices
J	=	The class of benefit criteria
J`	=	The class of cost criteria
m	=	The number of decision points
ξ^L	=	Consistency index for linear model
aB_j	=	The option of the most suitable criteria for the criteria *j*
a_{jw}	=	The option of criteria *j* for the most unsuitable criteria

The nomenclature of the study is shown in table 1.

A. *Best Worst Based Simple Additive Weighting Method (BWSAW)*

Best Worst Based Simple Additive Weighting Method is a new MCDM method [26]. This method depends on BWM method which is a weighting technique that uses two vectors of pairwise comparisons to determine the weights of criteria. The DM firstly determines the best and the worst criteria. Secondly, the most suitable criterion is compared to the other criteria and finally, the other criteria are compared to the worst criteria.

BWM determines the weights of criteria according to the LP model proposed by Rezaei [20] as below:

$$\begin{aligned} &\text{Min } \xi^L \\ &\text{s.t.} \\ &\left|w_B - aB_j w_j\right| \le \xi^L, \text{ for all j} \\ &\left|w_j - a_{jW} w_W\right| \le \xi^L, \text{ for all j} \\ &\sum_j w_j = 1 \\ &w_j \ge 0, \text{ for all j} \end{aligned} \quad (1)$$

The steps of BWSAW are shown as below:

Step 1: Define the set of decision criteria.

Step 2: Define the worst and best criteria.

Step 3: Define the option of the best and the worst criteria over all the other criteria.

Step 4: Define the weights of criteria (wn) by the LP model of BWM which was proposed by Rezaei [20].

Step-5: Each alternative (aij) is normalized according to the benefit (Equation 2) or cost (Equation 3) criteria.

$$r_{ij} = \frac{a_{ij}}{Max\ a_{ij}} \quad (2)$$

$$r_{ij} = \frac{Min\ a_{ij}}{a_{ij}} \quad (3)$$

Step-6: The weighted values of the criteria are multiplied by the normalized values of each criteria value of each alternative. The total values (Ti) of each alternative are found by Equation (4). The sum of these values for each alternative is calculated. The alternative with the highest overall value is the best alternative.

$$T_i = \sum_{j=1}^{N} w_n r_{ij} \quad (4)$$

B. *TOPSIS*

TOPSIS is a MCDM method developed by Yoon and Hwang in 1980. In essence, the solution is to ensure that the positive ideal solution is at the shortest distance and the negative ideal solution is at the farthest distance Şenyiğit and Demirel [2].

Step 1: Objective is determined, criteria are defined and a decision matrix is formed.

Step 2: The decision matrix is normalized by the vector normalization method. The evaluation matrix R of alternative *i* under evaluation criteria *j* is a_{ij}. There are *m* alternatives and *n* criteria.

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \quad (5)$$

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (6)$$

Step 3: The obtained normalized values in step 2 are multiplied by the weight values to form a weighted normalized decision matrix.

$$\sum_{j=1}^{n} w_j = 1 \quad (7)$$

$$Y_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_n r_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_n r_{mn} \end{bmatrix} \quad (8)$$

Step 4: Ideal (A*) and negative ideal (A−) solutions are determined.

$$A^* = \left\{ (\max_i v_{ij} \mid j \in J), (\min_i v_{ij} \mid j \in J^{'} \right\} \quad (9)$$

$$A^- = \left\{ (\min_i v_{ij} \mid j \in J), (\max_i v_{ij} \mid j \in J^{'} \right\} \quad (10)$$

Step 5: Separation measures are calculated.

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \quad (11)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad (12)$$

Step 6: The relative closeness values are calculated according to the ideal solution.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad (13)$$

Step 7: The best alternative is the alternative that has the highest score of relative closeness value [11].

C. ELECTRE

The ELECTRE (Elimination and Choice Translating algorithm) method was introduced by Benayoun, Roy and Sussman in 1968. The first three steps of TOPSIS and ELECTRE methods are same. For this reason, we began the steps of the ELECTRE method from Step 4.

Step 4: The concordance (C_{kl}) and discordance sets (D_{kl}) are determined.

$$C_{kl} = \{j, y_{kl} \geq y_{lj}\} \quad (14)$$

$$D_{kl} = \{j, y_{kl} < y_{lj}\} \quad (15)$$

Step 5: Concordance (C) and Discordance (D) matrices are calculated. The elements of C matrix are calculated by means of the relationship shown in the formula as below.

$$c_{kl} = \sum_{j \in C_{kl}} w_j \quad (16)$$

$$d_{kl} = \frac{max|y_{kj} - y_{lj}| \; for \; j \in D_{kl}}{max|y_{kj} - y_{lj}| \; for \; j} \quad (17)$$

Step 6: Predominance Concordance (F) and Discordance (G) matrices are calculated. F matrix is mxm dimensional and elements of this matrix are determined by the comparison of concordance threshold value ($\underline{c}$) with the elements of the concordance matrix (c_{kl}). The concordance threshold value ($\underline{c}$) is obtained as below:

$$\underline{c} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} c_{kl} \quad (18)$$

The elements of F matrix are shown by f_{kl}. It takes a 0 or 1 value. The discordance threshold value ($\underline{d}$) is obtained as below:

$$\underline{c} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} d_{kl} \quad (19)$$

Step 7: Net concordance and discordance indexes are calculated.

Step 8: The best alternative is determined.

III. RESULTS

The goal of this work is to decide the best material to be used in the design of the chaff/flare launch system. The cost (Cr1), tensile strength (Cr2), melting temperature (Cr3), thermal conductivity (Cr4), density (Cr5) and thermal expansion (Cr6) criteria have been taken into account to achieve this goal. In the MCDM problem, criteria are classified as benefit or cost criteria. The basic reason of this classification is that while benefit criteria are being maximized, cost criteria are being minimized. While cost, density and thermal expansion criteria are cost criteria, other criteria are benefit criteria. Because, we desire low cost and thermal expansion values in design. Of course, we desire high tensile strength, melting temperature, density and thermal expansion values in design [27].

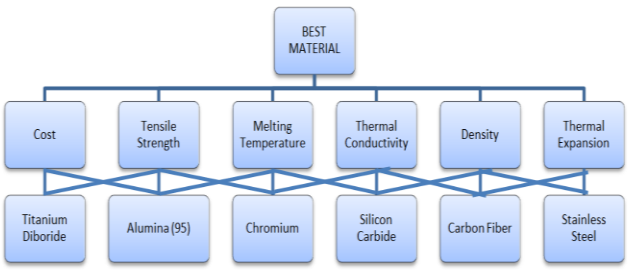

Fig. 4 The decision hierarchy of best material selection

The decision hierarchy of material selection for AHP is shown in Figure-4.

Table 2 Decision matrix

Materials	Cost (Cr1)	Tensile Strength (Cr2)	Melting Temperature (Cr3)	Thermal Conductivity (Cr4)	Density (Cr5)	Thermal Expansion (Cr6)
	Criteria					
Titanium Diboride(MA1)	42	360	2970	25	4.5	7
Alumina (95) (MA2)	30	207	2100	23	3.7	6.95
Chromium (MA3)	25	700	1850	89	7.15	6.5
Silicon Carbide (MA4)	32	500	2400	80	3.18	5
Carbon Fiber(MA5)	61.2	4000	3750	140	1.82	0.3
Stainless Steel (MA6)	5	670	1500	25	7.5	10

The decision matrix is shown in Table-2. The material alternatives are titanium diboride (MA1), alumina (95) (MA2), chromium (MA3), silicon carbide (MA4), carbon fiber (MA5) and stainless steel materials (MA6). The data for these alternatives were obtained from ECHIP-7 software.

Table 3 BTO and OTW pairwise comparison vectors

Best to Others	Cr1	Cr2	Cr3	Cr4	Cr5	Cr6
Cr1 (BEST)	1	2	2	9	3	5

Others to the worst	Cr4 (WORST)
Cr1	9
Cr2	6
Cr3	4
Cr4	1
Cr5	3
Cr6	2

The most important criteria according to the DMs (authors) is the cost criteria while the least important criteria is the thermal conductivity criteria for the BWSAW method. The most important criteria in a design is cost, for this reason the Cr1 criteria is determined as the most important criteria. Best to others (BTO) and others to the worst (OTW) pairwise comparison vectors are shown in Table-3.

Table 4 Criteria weights according to the BWM

Cr1	Cr2	Cr3	Cr4	Cr5	Cr6
0.37	0.20	0.18	0.04	0.13	0.08

The weights of criteria are calculated by BWM. Criteria weights according to the BWM are shown in Table-4.

Table 5 Normalized Decision Matrix for the BWSAW method

	CRITERIA					
ALTERNATIVES	**Cr1**	**Cr2**	**Cr3**	**Cr4**	**Cr5**	**Cr6**
MA1	0.12	0.09	0.79	0.18	0.40	0.04
MA2	0.17	0.05	0.56	0.16	0.49	0.04
MA3	0.20	0.18	0.49	0.64	0.25	0.05
MA4	0.16	0.13	0.64	0.57	0.57	0.06
MA5	0.08	1.00	1.00	1.00	1.00	1.00
MA6	1.00	0.17	0.40	0.18	0.24	0.03

Normalized decision matrix is another step of BWSAW method. A normalized decision matrix for the BWSAW method is shown in Table-5.

Table 6 Results of the BWSAW method

Ranking	Materials	Scores
1	**MA5**	0.66
2	**MA6**	0.52
3	**MA4**	0.30
4	**MA1**	0.27
5	**MA3**	0.26
6	**MA2**	0.25

The results of the BWSAW method are shown in Table-6. According to the results, MA5 is the best material alternative.

Table 7 Criteria weights according to the AHP method

Cr1	Cr2	Cr3	Cr4	Cr5	Cr6
0.38	0.25	0.15	0.04	0.11	0.07

According to the DMs, the determined criteria weights by considering the AHP method are shown in Table-7.

Table 8 Results of the AHP method

Ranking	Materials	Scores
1	**MA5**	0.26
2	**MA6**	0.20
3	**MA3**	0.18
4	**MA4**	0.15
5	**MA2**	0.11
6	**MA1**	0.10

The obtained results by following the steps of the AHP method are shown in Table-8. According to these results, the best material alternative is the MA5 alternative. The second best alternative is MA6 [27].

Table 9 Results of the SAW method

Ranking	Materials	Scores
1	**MA5**	0.65
2	**MA6**	0.52
3	**MA4**	0.28
4	**MA3**	0.25
5	**MA1**	0.24
6	**MA2**	0.22

Table-9 shows the results obtained by following the SAW method. According to these results, it was determined that the best material is the MA5 alternative as it is in the AHP method results.

Table 10 Normalized Decision Matrices

	CRITERIA					
ALTERNATIVES	**Cr1**	**Cr2**	**Cr3**	**Cr4**	**Cr5**	**Cr6**
MA1	0.11	0.09	0.48	0.13	0.30	0.04
MA2	0.16	0.05	0.34	0.12	0.36	0.04
MA3	0.19	0.17	0.30	0.47	0.19	0.05
MA4	0.15	0.12	0.39	0.42	0.42	0.06
MA5	0.08	0.96	0.60	0.74	0.73	0.99
MA6	0.95	0.16	0.24	0.13	0.18	0.03

Table-10 shows the normalized decision matrix for the TOPSIS and ELECTRE methods.

Table 11 Weighted Normalize Decision Matrix

	CRITERIA					
ALTERNATIVES	**Cr1**	**Cr2**	**Cr3**	**Cr4**	**Cr5**	**Cr6**
MA1	0.04	0.02	0.07	0.01	0.03	0.00
MA2	0.06	0.01	0.05	0.01	0.04	0.00
MA3	0.07	0.04	0.04	0.02	0.02	0.00
MA4	0.06	0.03	0.06	0.02	0.04	0.00
MA5	0.03	0.24	0.09	0.03	0.08	0.07
MA6	0.37	0.04	0.04	0.01	0.02	0.00

Table-11 shows the weighted normalization decision matrix by multiplying the weight values of the criteria by the normalized values obtained in Table-9.

Table 12 Ideal (A^*) and negative ideal (A^-) solutions

	CRITERIA					
	Cr1	**Cr2**	**Cr3**	**Cr4**	**Cr5**	**Cr6**
A^*	0.37	0.24	0.09	0.03	0.08	0.07
A^-	0.03	0.01	0.04	0.01	0.02	0.00

Table 12 shows the ideal and negative ideal solutions for the TOPSIS technique.

Table 13 Display of sorting by the TOPSIS method

ALTERNATIVES	S^*_i	S^-_i	C^*_i
MA1	0.40	0.04	0.09
MA2	0.39	0.04	0.09
MA3	0.37	0.05	0.13
MA4	0.38	0.05	0.11
MA5	0.34	0.25	0.42
MA6	0.22	0.34	**0.60**

Table-13 shows the order of the alternatives according to the TOPSIS method, taking into account the closeness values according to the ideal solution. The best material alternative to this order is stainless steel, which is the sixth material alternative.

Table 14 Presentation of the Concordance Matrix

	MA1	MA2	MA3	MA4	MA5	MA6
MA1	-	0.40	0.26	0.15	0.39	0.26
MA2	0.60	-	0.17	0.39	0.39	0.33
MA3	0.74	0.83	-	0.67	0.39	0.61
MA4	0.85	0.61	0.33	-	0.63	0.37
MA5	0.61	0.61	0.61	0.37	-	0.22
MA6	0.74	0.67	0.39	0.63	0.83	-

Table 14 shows the concordance matrix considered for the ELECTRE method and Table 15 shows the discordance matrix.

Table 15 Presentation of the Discordance Matrix

	MA1	MA2	MA3	MA4	MA5	MA6
MA1	-	0.82	1.00	0.98	1.00	1.00
MA2	1.00	-	1.00	1.00	1.00	1.00
MA3	0.92	0.63	-	1.00	1.00	1.00
MA4	1.00	0.22	0.65	-	0.31	1.00
MA5	0.06	0.14	0.22	1.00	-	1.00
MA6	0.11	0.06	0.05	0.08	0.20	-

Table 16 Sorting by the Net Concordance index (CP)

ALTERNATIVES	CP	Ranking
MA1	-2,09	6
MA2	-1,25	5
MA3	**1,49**	**1**
MA4	0,58	3
MA5	-0,19	4
MA6	1,47	2

According to the net concordance index in Table-16, the order of the alternatives according to the net discordance index is shown in Table-17. Among the alternatives according to the ELECTRE method, the net concordance index is the highest and the net discordance index is the lowest, which is considered as the best alternative.

Table 17 Sorting by the Net Discordance index (DP)

ALTERNATIVES	DP	Ranking
MA1	1.72	5
MA2	3.12	6
MA3	1.63	4
MA4	-0.89	3
MA5	-1.08	2
MA6	-4.50	1

Table 18 Display of sorting by the ELECTRE method

ALTERNATIVES	Ranking
MA6	1
MA3	2
MA4	3
MA5	4
MA1	5
MA2	6

Table-18 shows the final ranking according to the ELECTRE method. As a result, it is determined that the best alternative material is stainless steel (MA6) in the ELECTRE method as well as in the TOPSIS method. When these results are examined, it can be seen that the MA3 and MA6 alternatives are the two best alternatives and the MA1 and MA2 alternatives are the two worst alternatives (see Table-18).

Table 19 Comparison of results according to the multi-criteria methods

Ranking	AHP	SAW	TOPSIS	ELECTRE	BWSAW
1	MA5	MA5	MA6	MA6	MA5
2	MA6	MA6	MA5	MA3	MA6
3	MA3	MA4	MA3	MA4	MA4
4	MA4	MA3	MA4	MA5	MA1
5	MA2	MA1	MA1	MA1	MA3
6	MA1	MA2	MA2	MA2	MA2

In Table 19, net concordance values of the MA3 (1.49) and MA6 (1.47) materials are close to each other. Therefore, the net discordance values are taken into consideration in the selection of the best material according to the ELECTRE method. It has been decided that the MA6 material which has the lowest net discordance value is the best material alternative. Table-19 presents the comparison of the results of all the methods considered in the study. It was determined that the second best material alternative in the TOPSIS method is the MA6 material and the second best alternative material in the ELECTRE method is the MA3 material. The MA5 material alternative has been determined to be the best alternative material for the AHP and SAW methods. The MA6 alternative is the second best alternative material in these methods.

Table 20 Display of Spearman rank correlation coefficient values

Methods	AHP	SAW	TOPSIS	ELECTRE	BWSAW
AHP	-	0.89	0.89	0.60	0.66
SAW		-	0.89	0.60	0.78
TOPSIS			-	0.83	0.54
ELECTRE				-	0.79
BWSAW					-

Table-20 presents the spearman rank correlation coefficients of the alternatives in which the methods used in the study, are determined. The Spearman's rank correlation coefficient measures the relation among ranks are determined by other MCDM methods. The Spearman's rank correlation coefficient takes values between -1 and +1. When table 20 is examined, it is determined that the order in which the methods are determined is significant. When this table is examined, there is a strong positive correlation between AHP-SAW (0.89), AHP-TOPSIS (0.89), TOPSIS-SAW (0.89) and TOPSIS-ELECTRE (0.83). There is a medium positive correlation between ELECTRE-BWSAW (0.79), SAW-BWSAW (0.78), AHP-BWSAW (0.66) AHP-ELECTRE (0.60), SAW-ELECTRE (0.60) and TOPSIS-BWSAW (0.54). The order in which the methods are determined is in an acceptable range.

IV. DISCUSSION

Selecting materials requires exploring the best equivalent between design needs and the features of the materials that might be used. Each material has different performance for each feature. There is no material that fulfilled all the suitable features. Incorrect selection of a material often results in early defects of the product in the practical area. Thus, DMs must specify and choose the optimum material. To make the material selection easy and to make the right decision, a methodical and sufficient method is required. The material selection procedure can be assumed as a MCDM problem. MCDM methods have been developed in order to solve material selection problems. A new MCDM method is used in this paper as a contribution to literature.

V. CONCLUSION

In this paper, the AHP, SAW, TOPSIS, ELECTRE and BWSAW methods were utilized for the determination of the best material for countermeasure flare systems. Literature in the area of materials selection and MCDM was reviewed. The criteria (cost, tensile strength, melt point, thermal conductivity, density, and thermal expansion) weighting was performed by compromised weighting method composed of AHP and BWM. The candidate materials (titanium diboride, alumina (95), chromium, silicium carbide, carbon fiber, and stainless steel) were ranked by using these methods and the results obtained by each method were compared in this study. As a result of the study, it was decided that the best material to be used in designing the chaff/flare launch system is carbon fiber (MA5) or stainless steel (MA6). Carbon fiber is the best material for the AHP, SAW and BWSAW methods while stainless steel is the best material for ELECTRE and TOPSIS method. Finally, we recommend using carbon fiber as the best material for countermeasure flare systems.

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