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Applications of Modified Simple Additive Weighting Method in Manufacturing Environment

T. K. Biswas, S. Chaki*

Automobile Engineering Department, MCKV Institute of Engineering, Liluah, Howrah, West Bengal, India

P A P E R I N F O	*A B S T R A C T*
	Multiple criteria decisions making (MCDM) techniques are employed widely by decision-makers for ranking the potential alternatives under conflicting environments to select the best one for different industrial problems. Present work employed a modified Simple Additive Weighting (SAW) method to solve different decision-making problems in the manufacturing industry such as industrial robot selection, flexible manufacturing systems selection and, non-traditional machining processes selection respectively. The proposed methodology is simple and involves lesser mathematical complexity. The ranking obtained by the proposed modified SAW method corroborates well with other popular MCDM methods like MOORA, MABAC, TOPSIS and AHP for solving similar problems. It indicates the robustness of the proposed method. However, the proposed method is better compared to those methods through its simplicity, lesser computational complexity, and lesser computational time. Further, sensitivity analysis indicates the stability of the method. Being generic the method can be applied for solving problems related to ranking and selection in any societal segment.

1. INTRODUCTION

Multi-criteria decisions making (MCDM) is a popular method for making decision in daily lives or complex engineering problems under multiple conflicting criteria. It helps in evaluating and determining the best possible alternative and precise ranking preorders of the considered alternatives. Such approaches are useful for an organization in reduction of the product cost, enhancement of productivity, up-gradation of product quality, and improvement of sales volume in the market. Since the inception of the concept, several popular MCDM methods are evolved and been employed in almost every domain of engineering and management [1-4].

The recent trend towards increased productivity and maintaining uniform quality has incorporated computer-based automation within the manufacturing domain. To cater to that need large applications are being observed on non-traditional machining (NTM) processes,

industrial robots, additive manufacturing along flexible manufacturing systems (FMS) etc. However, those processes or equipment are generally dependent on several variables or attributes that bear complex relationships among themselves, and selecting an appropriate process or equipment from available alternatives always processes a challenge to the practicing engineers. The industrial robot selection problem has been investigated in the recent past through various MCDM approaches like MOORA [5], COPRAS [6], Fuzzy Delphi method, TOPSIS [7], VIKOR [8], Best-worst method [9], etc. Along with, the development of robot prototype [10], controller [11], and optimization of motors in powertrain [12] has been also studied by the researchers.

The FMS selection is another prominent MCDM problem, where methods like MOORA [5], fuzzy AHP, PROMETHEE [13], AHP-TOPSIS [14], TOPSIS [15] have been incorporated by researchers. Determining a suitable nontraditional machining (NTM) process from

*Corresponding Author Institutional Email: chaki.s@mckvie.edu.in (S. Chaki)

several alternatives has been also evaluated by researchers through TOPSIS-AHP [16], MOORA [7], fuzzy AHP [17] methods.

Literature indicates the application of a number of MCDM techniques for the selection of robots, FMS, and NTM processes. But those methods bear complex mathematical steps and are computationally expensive. However, robustness and stability are found adequate for almost all the above-mentioned processes. The simple Additive Weighting (SAW) method, a comparatively simple and computationally inexpensive method has been already used in different application domains [18,19]. The present work proposed and envisaged working of a less critical approach of MCDM i.e. modified Simple Additive Weighting (SAW) method that incorporates a simple process of scaling during computation of normalized decision matrix. It simplifies the further computation. In this process, a negative performance score never appears during computation and it always remains greater than one during ranking evaluation, which is advantageous.

The present work has investigated the efficacy of the modified SAW method through three different modern-day manufacturing problems that include selecting industrial robots, FMS, and NTM processes. A comparative study of the ranking by proposed modified SAW method and other popular techniques like MOORA (Multi-objective optimization by ratio analysis) and MABAC (Multi-Attribute Border Approximation Area Comparison) method is determined and presented for each of the problems. Finally, the stability of the proposed method is investigated through sensitivity analysis.

2. MODIFIED SAW METHOD:

Modification of conventional Simple additive weighting (SAW) method [19] has been detailed as follows:
Step 1. Establishment of the initial decision matrix

$$\mathbf{X} = \left[x_{ij}\right]_{m \times n} \tag{1}$$

Step 2. The decision matrix is normalized as

$$\mathbf{N} = \left[r_{ij}\right]_{m \times n} \tag{2}$$

In this step, dimensions of criteria are converted into non-dimensional forms.
For Benefit type criteria, r_{ij},

$$r_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \tag{3}$$

For non-beneficial type criteria, r_{ij},

$$r_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{4}$$

Here, x_{ij}, x_i^+ and x_i^- are the elements from the initial decision matrix (X), where $x_i^+ = \max(x_1, x_2, \ldots, x_m)$ and $x_i^- = \min(x_1, x_2, \ldots, x_m)$.

Step 3. For sets of beneficial and non-beneficial criteria, each normalized criterion r_{ij} is computed on a scale of 0-1 where 0 corresponds to the minimum and 1 to the maximum assigned value for the corresponding indicator. Now, r_{ij} is classified into five scale values ranging from 1-5 where 5 is the extreme importance, 4 is very strong importance, 3 is strong importance, 2 is moderate importance and 1 is the equal importance. During computation, when the normalized value of criteria are in the interval of (>0.80, 1.00), then the scale value is taken as g=5, If the criteria value lies in the interval of (>0.60, 0.80), then g=4, if the normalized value of all criteria lies in the interval of (>0.40, 0.60) then g=3, (>0.20,40) then g=2 and (>0.00,0.20) and finally g=1. This scaled normalized decision matrix is identified by (V_{ij}).

Step 4. The elements of the weighted scale value (Q) are calculated based on the expression:

$$Q_{ij} = w_i \cdot v_{ij} \tag{5}$$

Step 5. Finally, the overall score (S_i) of the alternatives is computed using Equation (6), and rank the alternatives are determined based on the descending value of S_i.

$$S_i = \sum_{j=1}^{n} q_{ij} \tag{6}$$

3. PERFORMANCE EVALUATION OF MODIFIED SAW METHOD:

To show the applicability and efficacy of the modified SAW method in solving MCDM problems following examples are considered in the manufacturing environment.

3. 1. Case Study1: Industrial Robot Selection   In this example, seven different industrial robots are analyzed based on five different criteria such as load capacity (LC), repeatability (RE), maximum tip speed (MTS), memory capacity (MC), and manipulator reach (MR) to find out the best robot among them. Here, except repeatability other criteria are of beneficial types. The decision matrix and criteria weights determined by Bhangale et al. [20] have been used and given in Table 1.

The normalized decision matrix has been determined using Equations (2)- (4). Scaling of normalized decision matrix has been done using step 3 explained in section 2 (Table 2). Table 3 indicates weighted scaled values (Q) computed using Equation (4).

Finally, the overall score S_i of alternatives has been computed using Equation (6) and subsequent ranking is determined (Table 3).

TABLE 1. Decision matrix of industrial robot selection [20]

Sl. No	Alternatives	Criteria				
		LC	RE	MTS	MC	MR
1	ASEA-IRB 60/2	60	0.4	2540	500	990
2	Cincinnati Milacrone T3-726	6.35	0.15	1016	3000	1041
3	Cybotech V15 Electric Robot	6.8	0.1	1727.2	1500	1676
4	Hitachi America Process Robot	10	0.2	1000	2000	965
5	Unimation PUMA 500/600	2.5	0.1	560	500	915
6	United States Robots Maker 110	4.5	0.08	1016	350	508
7	Yaskawa Electric Motoman L3C	3	0.1	177	1000	920
Weight considered (Wi)		0.1574	0.1825	0.2385	0.2172	0.2043

TABLE 2. Scaled Normalized decision matrix, V

Sl. No.	Alternatives	Criteria				
		LC	RE	MTS	MC	MR
1	ASEA-IRB 60/2	5	1	5	1	3
2	Cincinnati Milacrone T3-726	1	4	2	5	3
3	Cybotech V15 Electric Robot	1	5	4	3	5
4	Hitachi America Process Robot	1	4	2	4	2
5	Unimation PUMA 500/600	1	5	1	1	2
6	United States Robots Maker 110	1	5	2	1	1
7	Yaskawa Electric Motoman L3C	1	5	1	2	2

TABLE 3. Weighted scale value matrix, Q, Overall score Si and corresponding rank

Sl. No	Alternatives	Criteria					S_i	Rank
		LC	RE	MTS	MC	MR		
1	ASEA-IRB 60/2	0.787	0.183	1.193	0.217	0.613	2.992	3
2	Cincinnati Milacrone T3-726	0.157	0.730	0.477	1.086	0.613	3.063	2
3	Cybotech V15 Electric Robot	0.157	0.913	0.954	0.652	1.022	3.697	1
4	Hitachi America Process Robot	0.157	0.730	0.477	0.869	0.409	2.642	4
5	Unimation PUMA 500/600	0.157	0.913	0.239	0.217	0.409	1.934	7
6	United States Robots Maker 110	0.157	0.913	0.477	0.217	0.204	1.968	6
7	Yaskawa Electric Motoman L3C	0.157	0.913	0.239	0.434	0.409	2.151	5

3. 2. Case Study2: FMS Selection   In this example the decision matrix developed by Karsak and Kuzgunkaya [21] on Flexible Manufacturing Systems (FMS) selection is given in Table 6 and has been solved using the modified SAW method. The chosen problem has eight alternatives and seven criteria. Out of these, all the five criteria such as reduction in labor cost (LC), reduction in WIP (RWIP), reduction in setup cost (RSC), increase in market response (IMR), improvement in quality (IQ) are beneficial attributes and others two i.e. capital and maintenance cost (CMC), and floor space used (FSU) are non-beneficial attributes. The criteria weights determined through AHP method for the same problem by Rao and Parnichkun [22] have been employed here for analysis (Table 4).

The normalized decision matrix, weighted scale value matrix, and the overall score are determined through stepwise computation by using Equations (2)-(5) of the modified SAW method. Table 5 indicates the final rank of alternatives obtained through the modified SAW method.

TABLE 4. Decision matrix for FMS selection [21,22]

Alternative FMS	Criteria						
	RLC (%)	RWIP (%)	RSC (%)	IMR	IQ	CMC ($ 000)	FSU (ft²)
1	30	23	5	0.745	0.745	1500	5000
2	18	13	15	0.745	0.745	1300	6000
3	15	12	10	0.5	0.5	950	7000
4	25	20	13	0.745	0.745	1200	4000
5	14	18	14	0.255	0.745	950	3500
6	17	15	9	0.745	0.5	1250	5250
7	23	18	20	0.5	0.745	1100	3000
8	16	8	14	0.255	0.5	1500	3000
Weight considered (Wi)	0.1129	0.1129	0.0445	0.1129	0.2861	0.2861	0.0445

3. 3. Case Study3: Non-traditional Machining (NTM) Process Selection

In this example, the best NTM process is selected from nine different unconventional machining processes with ten important criteria for each of the processes. Among ten criteria, material removal rate (MR1), efficiency (η), safety (S), work material (WM), and shape feature (SF) are considered as the beneficial criteria and surface finish (TSF), power requirement (PR), cost (C), tooling and fixtures (TF), tool consumption (TC), are the non-beneficial criteria. The decision matrix and corresponding criteria weights computed using the AHP method by Chakladar and Chakraborty [16] are used in the present computation (Table 6).

The overall score (S_i) for different processes is computed by the modified SAW method through Equations (2)-(6). Ranking obtained by modified SAW method for alternatives is given in Table 7.

TABLE 5. Comparative study of ranking for FMS selection

FMS Alternative	1	2	3	4	5	6	7	8
S_i	3.59	3.29	2.53	4.07	3.89	2.38	4.15	1.27
Rank	4	5	6	2	3	7	1	8

TABLE 6. Decision matrix for NTM process selection [16]

Alternatives	Criteria									
	TSF	PR	MR₁	C	η	TF	TC	S	WM	SF
Ultrasonic machining (USM)	1	10	500	2	4	2	3	1	5	5
Water jet machining (WJM)	2.5	0.22	0.8	1	4	2	2	3	5	4
Abrasive jet machining (AJM)	2.5	0.24	0.5	1	4	2	2	3	5	4
Electrochemical machining (ECM)	3	100	400	5	2	3	1	3	1	1
Chemical machining (CHM)	3	0.4	15	3	3	2	1	3	3	1
Electric discharge machining (EDM)	3.5	2.7	800	3	4	4	4	3	1	5
Wire electrical discharge machining (WEDM)	3.5	2.5	600	3	4	4	4	3	1	5
Electron beam machining (EBM)	2.5	0.2	1.6	4	5	2	1	3	5	5
Laser beam machining (LBM)	2	1.4	0.1	3	5	2	1	3	5	5
Weight considered (Wi)	0.0783	0.0611	0.1535	0.1073	0.0383	0.0271	0.0195	0.0146	0.2766	0.2237

TABLE 7. Comparative study of ranking for NTM process selection

Alternatives	USM	WJM	AJM	ECM	CHM	EDM	WEDM	EBM	LBM
S_i	4.584	3.871	3.87	1.498	2.295	3.141	2.988	3.829	4.015
Rank	1	3	4	9	8	6	7	5	2

4. RESULTS AND DISCUSSION

It has been observed from Table 3 that, Cybotech V15 electric robot is considered as the best alternative according to the Modified SAW method for the robot selection problem. That robot is specifically suitable for multiple purposes including welding, drilling, routing, assembly, and many other operations.

While solving the FMS selection problem, Table 5 indicates FMS7 as the best alternative with a considerably high percentage reduction of labor cost, work in process, and set up costs along with high improvement in quality and considerable improvement in market response. It has been observed to be achieved at considerably low capital and maintenance costs which is beneficial from a managerial point of view.

During NTM process selection, Ultrasonic Machining (USM) has been determined as the best alternative based on the criteria chosen for analysis and given in Table 7. The USM process is particularly useful for machining high precision parts from hard and brittle difficult-to-machine materials.

Further, the sensitivity of the solution to a change in the criteria weight obtained through the modified SAW method was evaluated to estimate the stability of the method. This analysis has been conducted with case study 1 for industrial robot selection. There are five criteria (C1-C5) and the possible interchanges are ten (5_{C_2}) as shown in Figure 1. During analysis, weights of a pair of criteria are interchanged for all alternatives, i.e., all industrial robots under study. But from the sensitivity plot given in Figure 1, the ranking of the robots does not observe to vary to a great extent even after interchanging the criteria weights. Moreover, in all the cases, the Cybotech V15 Electric robot always outperforms others. It indicates the high stability of the modified SAW method.

The study of sensitivity for the modified SAW method has been further extended by comparing the ranking of industrial robot selection problems with four other popular MCDM methods such as MABAC, MOORA, TOPSIS, and AHP. It can be observed from

Figure 2 that, the Cybotech V15 Electric robot is ranked as the best alternative for all methods understudy while other alternatives have placed in different positions. It establishes the robustness of the proposed method. Similar results have been obtained with the other two case studies.

A comparative study between the proposed modified SAW method with other MCDM methods, like MABAC, AHP, TOPSIS, COPRAS, ELECTRE, PROMETHEE, etc in terms of computational time, simplicity, mathematical calculations involved, stability, robustness, and type of information obtained has been shown in Table 8. The simplicity of the modified SAW method is high and it is easy to implement. The computational time is very less. The involvement of very less mathematical calculation causes ease in implementation. The superiority of the proposed method compared to other MCDM methods will surely encourage decision-makers to employ it in practical applications. Comparison of modified SAW method with other MCDM methods for Industrial Robot Selection problem is shown in Figure 2.
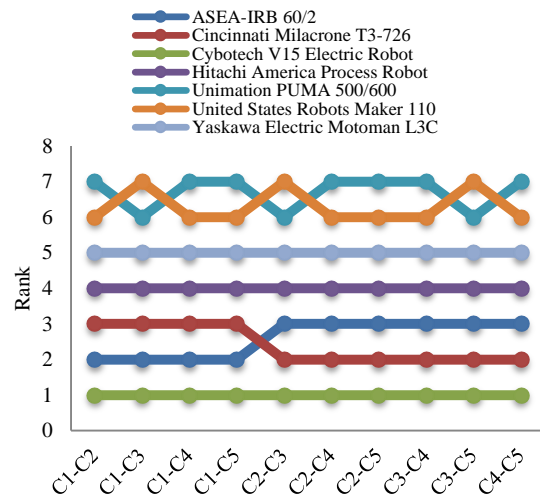

Figure 1. Sensitivity analysis of modified SAW method for Industrial Robot Selection problem

TABLE 8. Comparative performance of some popular MCDM method

MCDM method	Computational time	Simplicity	Mathematical calculation involved	Stability	Robustness	Information type
MODIFIED SAW	Very less	Very simple	Minimum	Good	High	Quantitative
MABAC	less	Simple	Moderate	Good	High	Quantitative
AHP	Very high	Very critical	Maximum	Poor	Less	Mixed
TOPSIS	Moderate	Moderately critical	Moderate	Medium	Moderate	Quantitative
COPRAS	Moderate	Moderately critical	Moderate	Medium	Moderate	Quantitative
ELECTRE	High	Moderately critical	Moderate	Medium	Moderate	Mixed
PROMETHEE	High	Moderately critical	Moderate	Medium	Moderate	Mixed
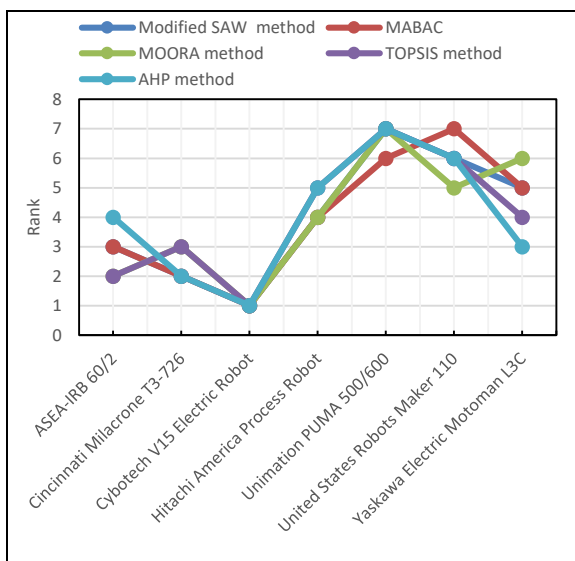
Figure 2. Comparison of modified SAW method with other MCDM methods for Industrial Robot Selection problem

- The method is robust as the best ranking obtained through the modified SAW method is found to corroborate well with that has been obtained by other popular MCDM methods.
- Compared to other available methods, the proposed method is simple, easy to understand, involves minimum mathematical calculation with low computation time, and is quantitative in nature.
- With such advantages, the modified SAW method may be effectively employed for solving ranking and selection problems in any sector of society.

5. CONCLUSION

Present work proposed a modified SAW method for decision making under conflicting environments from a significant number of available alternatives for a complex engineering problem. The efficacy of the proposed method was tested for three case studies based on robot selection, FMS selection, and non-traditional machining process selection, respectively.

- For the robot selection problem, Cybotech V15 electric robot is considered as the best alternative which is specifically suitable for multiple purposes including welding, drilling, routing, assembly, and many other operations
- For FMS selection problem, FMS7 is selected as the best alternative with a considerably high percentage reduction of labor cost, work in process, and set up costs along with improvement in quality and market response while capital and maintenance costs remained quite low.
- For the NTM process selection problem, Ultrasonic Machining has been determined as the best alternative which is useful for providing high precision parts from hard and brittle difficult-to-machine materials.
- The proposed method employed a concept of forming a scaled normalized decision matrix that simplified further computation resulting in non-occurrence of negative performance score during the evaluation of ranking.
- The method is stable during sensitivity analysis, as ranks obtained for the alternatives remained almost unchanged even with interchanging the criteria weights.

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Persian Abstract

چکیده

تکنیک‌های تصمیم‌گیری چند معیاره (MCDM) به طور گسترده توسط تصمیم‌گیرندگان برای رتبه‌بندی گزینه‌های بالقوه در محیط‌های متضاد به کار گرفته می‌شوند تا بهترین گزینه برای مشکلات صنعتی مختلف انتخاب شود. کار حاضر از روش وزن‌دهی افزودنی ساده (SAW) برای حل مشکلات مختلف تصمیم‌گیری در صنعت تولید مانند انتخاب ربات صنعتی، انتخاب سیستم‌های تولید انعطاف‌پذیر و انتخاب فرآیندهای ماشین‌کاری غیر سنتی استفاده می‌کند. روش پیشنهادی ساده است و شامل پیچیدگی ریاضی کمتری است. رتبه‌بندی به‌دست‌آمده با روش پیشنهادی اصلاح‌شده SAW به خوبی با روش‌های رایج MCDM مانند MOORA، MABAC، TOPSIS و AHP برای حل مسائل مشابه تأیید می‌شود. این نشان دهنده اعتبار و پایداری روش پیشنهادی است. با این حال، روش پیشنهادی به دلیل سادگی، پیچیدگی محاسباتی کمتر و زمان محاسباتی کمتر در مقایسه با آن روش‌ها بهتر است. علاوه بر این، تجزیه و تحلیل حساسیت نشان دهنده پایداری روش است. از آنجایی که روش عمومی است، می توان برای حل مسائل مربوط به رتبه بندی و انتخاب در هر بخش اجتماعی استفاده کرد.