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Supplier Selection in A Supply Chain Using Multi-Criteria Decision Making Methods

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ABSTRUCT: *Supplier evaluation and selection has been a vital issue of strategic importance in a supply chain. Different Multi-criteria decision making (MCDM) approaches namely Simple Additive Weighing (SAW), Multi Objective Optimization on the basis of Ratio Analysis (MOORA), Technique of Ordered Preference Similarity to Ideal solution (TOPSIS) have been proposed by the researchers in past, to solve the supplier evaluation and selection problem. The Ranking performances of the three methods are analyzed and compared to find the most prevalent approach in the articles and thereby present the future scope of arriving at an optimal solution to the problem, based on the specification, the strategies and the requirements of the buyers. Sensitivity analysis is also carried out for the three methodologies for in depth analysis. It is carried out by varying the individual weights of the criteria and by using normalized weights of the criteria. The results obtained using these three methods are observed to be almost similar to those derived by the past researchers. The projects work concludes that all the three methodologies are highly robust in nature.*

Keywords: *MCDM, SAW, MOORA, TOPSIS, Sensitivity Analysis*

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I. INTRODUCTION

Traditionally organization has been divided into operative function such as marketing, planning, purchasing, financing etc. Supply chain is a strategy that integrates these functions to create a general plan for an organization to satisfy the service policy, maintaining the lowest possible cost level due to incredible competitive environment that they are exposed to. Supply chain development is guided by the decisions made about the five supply chain drivers namely Production, Inventory, Facility Location, Transportation, and Information. Among all these Supplier plays the major role as it is seen that it is related to each other of the others drivers. In case of Information, supplier transfers the information in the form of material flow or information to the manufactures to direct the procedure for producing the customer specified product in a correct manner. Supplier is the mediator in every field of information; it can also transfer the feedback given by the customers to the manufactures. For the production process, supplier provides the necessary information about the raw material in stock. It takes care of the inventory and works according to demand of the product in the market by the customers. Supplier also takes care of the facility or location that is engrossed for the requirement of the production. Transformation is also a part of supply chain which is impossible without the influence of supplier for the best results to produce the products of best quality and optimum price as per the customer demands.

1.1 Definition of a Supplier: A Supplier can be defined in many ways in which some of definitions are as follows:
1.1.1 The definitions of a supplier is a person or entity that is source for goods or services.
1.1.2 A company that provides microprocessors to a major computer business is an example of a supplier.
1.1.3 Independent sellers at e-commerce giants like Amazon.

Supplier evaluation and selection involve decisions that are critical to the profitability, growth and survival of manufacturing organizations in the increasingly competitive global scenario. Such decisions are often complex, because they require the identification considering and analysis of many tangible factors. Choosing the supplier involves much more than scanning a series of price list. How we weigh up the importance of these different factors will be based on one’s business priorities. Kao [4] postulated that inappropriate decisions will affect the entire supply chain since the position of supplier selection and its related tasks are at the front end in the supply chain process. Some of the major factors affecting supplier selection are as shown below in Fig 1.1.

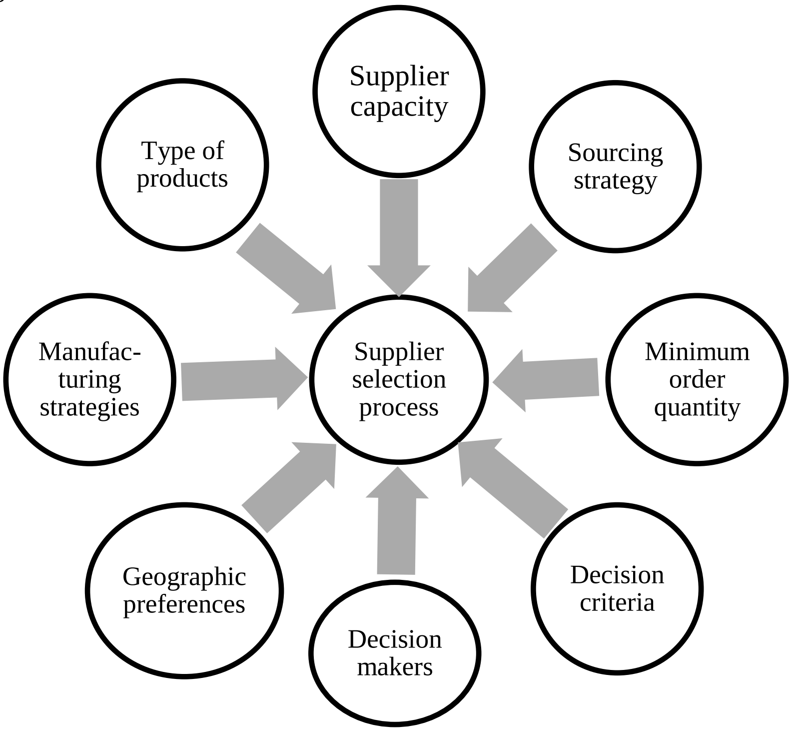

Figure 1: Supplier Selection Process

1.2 Multiple Criteria Decision Making (MCDM): MCDM is a sub-discipline of operation research that involves the analysis of a finite set of alternatives described in the terms of evaluating criteria based on the values and preferences of the decision maker. Cost or price is usually one of the main criteria. Some measure of quality is typically another criterion that is in conflict with the cost. In purchasing a car, cost, comfort, safety, and fuel economy may be some of the main criteria we consider. It is unusual that the cheapest car is the most comfortable and the safest one. In portfolio management, we are interested in getting high returns but at the same time reducing our risks. Again, the stocks that have the potential of bringing high returns typically also carry high risks of losing money. Therefore, the difficulty of the problem originates from the presence of more than one criterion. There is no longer a unique optimal solution to an MCDM problem that can be obtained without incorporating preference information. The concept of an optimal solution is often replaced by the set of non-dominated solutions. A non-dominated solution has the property that it is not possible to move away from it to any other solution without sacrificing in at least one criterion. Therefore, it makes sense for the decision-maker to choose a solution from the non-dominated set. Otherwise, she/he could do better in terms of some or all of the criteria, and not do worse in any of them. Generally, however, the set of non-dominated solutions is too large to be presented to the decision-maker for his final choice. Hence we need tools that help the decision-maker focus on his preferred solutions (or alternatives). A major distinction between MCDM problems is based on whether the solutions are explicitly or implicitly defined.

1.2.1 Multiple Attribute Decision Making (MADM) Problems: These problems consist of a finite number of alternatives, explicitly known in the beginning of the solution process. Each alternative is represented by its performance in multiple criteria. The problem may be defined as finding the best alternative for a decision-maker (DM), or finding a set of good alternatives. One may also be interested in sorting or classifying alternatives. Sorting refers to placing alternatives in a set of preference-ordered classes (such as assigning credit-ratings to countries), and classifying refers to assigning alternatives to non-ordered sets (such as diagnosing patients based on their symptoms). Some of the MCDM methods in this category have been studied. [1]

1.2.2 Multiple Objective Decisions Making (MODM) Problem: In these problems, the alternatives are not explicitly known. An alternative (solution) can be found by solving a mathematical model. The number of alternatives is either infinite or not countable (when some variables are continuous) or typically very large if countable (when all variables are discrete).Whether it is an evaluation problem or a design problem, preference information of DMs is required in order to differentiate between solutions. The solution methods for MCDM problems are commonly classified based on the timing of preference information obtained from the DM. There are methods that require the DM's preference information at the start of the process, transforming the problem into essentially a single criterion problem. These methods are said to operate by "prior articulation of preferences." Methods based on estimating a value function or using the concept of "outranking relations," analytical hierarchy process, and some decision rule-based methods try to solve multiple criteria evaluation problems utilizing prior articulation of preferences. Similarly, there are methods developed to solve multiple-criteria design problems using prior articulation of preferences by constructing a value function. Perhaps the most well-known of these methods is goal programming. Once the value function is constructed, the resulting single objective mathematical program is solved to obtain a preferred solution. Some methods require preference information from the DM throughout the solution process. These are referred to as interactive methods or methods that require progressive articulation of preferences. These methods have been well-developed for both the multiple criteria evaluation [2]. Multiple criteria design problems typically require the solution of a series of mathematical programming models in order to reveal implicitly defined solutions. For these problems, a representation or approximation of efficient solutions may also be of interest. This category is referred to as posterior articulation of preferences, implying that the DM's involvement starts posterior to the explicit revelation of interesting solutions (see [3]). MCDM includes both MADM and MODM. To use decision making, using MCDM techniques we face with two types of problems: Qualitative and quantitative

TABLE 1: DIFFERENCE BETWEEN MADM AND MODM

MADM	MODM
1. It stands for Multiple Decision Making 2. It has a higher level of transparency 3. In MADM, it ends up knowing which alternative you like most (ranking approach) 4. It is used for making decisions in a qualitative problem	1. It stands for Multiple Objective Decision Making 2. It has a lower level of transparency 3. In MODM, it ends up knowing what alternative you would need to build (Design approach) 4. It is used for making decisions in a quantitative problem

II. METHODOLOGY:

The purpose of the study is to analyze the approach of SAW, MOORA, TOPSIS for the evaluation and selection of suppliers from the basis of various criteria. The case company is active in manufacturing industry in eastern India. To collect the research data, six experts in the case company was interviewed. Based on their opinion, most commonly used criteria that are used in almost every manufacturing company has been shorted out. It is known that the criteria considered in supplier evaluation are industry specific and based on each case and the criteria are changed and replaced. Here the individual weights are calculated using SAATY'S 1 (equal)-9 (extreme) of pair-wise comparison method [5]. In order to apply the combined approach of SAW, TOPSIS, MOORA techniques, this paper proposes five main stages.

TABLE 2: SELECTING CRITERIA FOR SUPPLIER SELECTION AND WEIGHTS

CODE	CRITERIA	WEIGHT
E	Product Price	0.225
F	Transportation Cost	0.394
G	Delivery Lead Time	0.047
H	On Time Delivery	0.107
I	Material Quality	0.034
J	Technical Capability	0.164

Furthermore, a decision matrix is developed using numerical values indicating the performance rating of each supplier with respect to each criteria, as shown in Table: 3. The Cost Criteria considered are Product price; Transportation & Delivery lead time while the Benefit Criteria are On-time delivery, Material quality & Technical capability.

Table 3: Decision Matrix Considered For Following Mcdm Methods

ALTERNATIVES	E (₹)	F (₹)	G (DAY)	H (%)	I (%)	J (%)
A1	2200	700	10	39	93	89
A2	2900	570	13	40	95	91
A3	3400	490	16	54	92	96
A4	3000	530	12	45	96	93

III. ILLUSTRATION OF THE CASE PROBLEM APPLYING SAW METHOD:

Each performance rating is normalized using the formula as in equation (1, 2) for example.
In case of a cost criteria,

$$r_{1E} = \left\{ \frac{Min_i x_{ij}}{x_{ij}} \right\} = 92/93 = 0.9892.$$

While in case of a benefit criteria,

$$r_{1H} = \left\{ \frac{x_{ij}}{Max_i x_{ij}} \right\} = 700/700 = 1.$$

TABLE 4: NORMALIZED MATRIX FOR SAW METHOD

ALTERNATIVES	E (₹)	F (₹)	G (DAY)	H (%)	I (%)	J (%)
A1	1.0000	0.7000	1.0000	0.7222	0.9688	0.9271
A2	0.7586	0.8596	0.7692	0.7407	0.9896	0.9479
A3	0.6471	1.0000	0.6250	1.0000	0.9583	1.0000
A4	0.7333	0.9245	0.8333	0.8333	1.0000	0.9688

Calculation of weighted normalized decision matrix is done using the equation (3), as for example

$$\lfloor V_{ij} \rfloor = \lfloor w_j \times r_{ij} \rfloor_{m \times n}$$

= 1.000× 0.255 = 0.2550

Where w_j is the weight of the j^{th} criterion.

Furthermore, Preference value and subsequent ranking is calculated using the equation (4), as for example

$$Q_i = \sum_{j=1}^{n} w_j r_{ij} = \{(0.9892 \times 0.255) + \text{............} + (0.7222 \times 0.164)\} = 0.9400.$$

TABLE 5: WEIGHTED NORMALIZED DM SHOWING PREFERENCE VALUE AND RANKING

ALTERNATIVES	E (₹)	F (₹)	G(DAY)	H (%)	I (%)	J (%)	E (₹)	RANK
A1	0.2550	0.2758	0.0470	0.0773	0.0329	0.1520	0.8401	3
A2	0.1934	0.3387	0.0362	0.0793	0.0336	0.1555	0.8367	4
A3	0.1650	0.3940	0.0294	0.1070	0.0326	0.1640	0.8920	1
A4	0.1870	0.3643	0.0392	0.0892	0.0340	0.1589	0.8725	2

IV. ILLUSTRATION OF MOORA METHOD:

Each performance rating is normalized using the equation (5), as for example

$$\overset{*}{x}_{ij} = x_{ij} \Big/ \sqrt{\sum_{i=1}^{m} x_{ij}^{\ 2}} \quad (j=1,2,\ldots\ldots,n)$$ where $\overset{*}{x}_{ij}$ represents the normalized performance of the i^{th} alternative on the j^{th} criterion and is obtained by the ratio of individual performance rating and the square root of summation of squares of each performance rating on the j^{th} criteria.

TABLE 6: MATRIX OBTAINED BY SQUARING EACH OF PERFORMANCE MATRIX

ALTERNATIVES	E (₹)	F (₹)	G(DAY)	H (%)	I (%)	J (%)
A1	4840000	490000	100	1521	8649	7921
A2	8410000	324900	169	1600	9025	8281
A3	11560000	240100	256	2916	8464	9216
A4	9000000	280900	144	2025	9216	8649
SUMMATION	33810000	1335900	669	8062	35354	34067
SQUARE ROOT SUMMATION	5814.6367	1155.8114	25.8650	89.7886	188.0266	184.5725

Calculation of weighted normalized matrix is done using the equation (3), in similar way and total score benefit and cost criteria is calculated using the equation (6, 7)

$$(TS_B)_i = \sum_{j \in B}^{n} w_j \times \overset{*}{x}_{ij} = 0.0465+0.0168+0.0791= 0.1424, \text{for supplier A1}$$

$(TS_C)_i = \sum_{j \in C}^{n} w_j \times x_{ij}^{*}$ = 0.0965+0.23860.0182 = 0.3533,for supplier A1

TABLE 7: TOTAL SCORE COST AND BENEFIT CRITERIA

ALTERNATIVES	E (₹)	F (₹)	G(DAY)	H (%)	I (%)	J (%)	COST	BENEFIT
A1	0.3784	0.6056	0.3866	0.4344	0.4946	0.4822	0.3533	0.1424
A2	0.4987	0.4932	0.5026	0.4455	0.5052	0.4930	0.3451	0.1457
A3	0.5847	0.4239	0.6186	0.6014	0.4893	0.5201	0.3452	0.1663
A4	0.5159	0.4586	0.4639	0.5012	0.5106	0.5039	0.3340	0.1536

The Net Score is calculated by using equation (8),

$$NS_i = (TS_B)_i - (TS_C)_i = \sum_{j \in B}^{n} w_j \times x_{ij}^{*} - \sum_{j \in C}^{n} w_j \times x_{ij}^{*}$$

= (0.0648+0.0131+0.0712)-(0.1261+0.1900+0.0178) = -0.1847

TABLE 8: NET SCORE AND RANK OBTAINED BY MOORA METHOD

ALTERNATIVES	E (₹)	F (₹)	G(DAY)	H (%)	I (%)	J (%)	NET	RANK
A1	0.0965	0.2386	0.0182	0.0465	0.0168	0.0791	-0.2109	4
A2	0.1272	0.1943	0.0236	0.0477	0.0172	0.0809	-0.1994	3
A3	0.1491	0.1670	0.0291	0.0644	0.0166	0.0853	-0.1789	1
A4	0.1316	0.1807	0.0218	0.0536	0.0174	0.0826	-0.1804	2

V. ILLUSTRATION OF TOPSIS METHOD

The decision matrix as shown in Table :4 is normalized by using equation (5),

TABLE 9: CONVERTED COST CRITERIA TO BENEFIT CRITERIA

ALTERNATIVES	E (₹)	F (₹)	G(DAY)	H (%)	I (%)	J (%)
A1	0.6285	0.3986	0.6112	0.4345	0.4946	0.4827
A2	0.4768	0.4895	0.4702	0.4457	0.5052	0.4932
A3	0.4066	0.5695	0.3820	0.6016	0.4892	0.5202
A4	0.4609	0.5265	0.5093	0.5014	0.5106	0.5040

Now the weighted normalized decision matrix is calculated by calculating normalized decision matrix by using equation (3),

TABLE 10: WEIGHTED NORMALIZED MATRIX

ALTERNATIVES	E (₹)	F (₹)	G(DAY)	H (%)	I (%)	J (%)
A1	0.1603	0.1571	0.0287	0.0465	0.0131	0.0712
A2	0.1216	0.1929	0.0221	0.0477	0.0171	0.0731
A3	0.1037	0.2244	0.0180	0.0644	0.0210	0.0986
A4	0.1175	0.2074	0.0239	0.0491	0.0158	0.0822

Now the calculation of positive ideal solution is done using the following equation (9)

$PIS = \{(\max\ v_{ij} \mid j \in P)\} = \{ v_j^{*} \mid j = 1, 2... n\}$

Where P is associated with the positive criteria (benefit criteria).

TABLE 11: POSITIVE IDEAL SOLUTION

PIS	0.1603	0.2244	0.0287	0.0648	0.0210	0.0986

Now the calculation of positive ideal solution is done using the following equation (10)

$NIS = \{(\min\ v_{ij} \mid j \in P)\} = \{ v_j^{-} \mid j = 1, 2... n\}$

Where P is associated with the positive criteria (benefit criteria).

TABLE 12: NEGATIVE IDEAL SOLUTION

NIS	0.1037	0.1571	0.0180	0.0454	0.0131	0.0712

The separation measures ($\overset{*}{D_i}$ and $\overset{-}{D_i}$) of each alternative from the PIS and NIS is calculated using the m-dimensional Euclidean distance equation (11)

$$\overset{*}{D_i} = \sqrt{\sum_{j=1}^{n}(v_{ij} - \overset{*}{v_j})^2} \qquad (j=1, 2... n)$$

$$\overset{-}{D_i} = \sqrt{\sum_{j=1}^{n}(v_{ij} - \overset{-}{v_j})^2} \qquad (j=1, 2... n)$$

TABLE 13: SPERATION MEASURE

D^*	D
0.0731	0.0608
0.0578	0.0412
0.0608	0.0731
0.0518	0.539

The relative closeness to the ideal solution or the closeness of alternative A_i with respect to PIS is calculated using equation (12)

$$CC_i = \frac{\overset{-}{D_i}}{(\overset{*}{D_i} + \overset{-}{D_i})}$$

TABLE 14: CLOSENESS COEFFICIENT OF THE ALTERNATIVES

CC_1	*0.4540*
CC_2	*0.4157*
CC_3	*0.5460*
CC_4	*0.5100*

Upon obtaining the closeness coefficient, respective rank is allotted to the suppliers

TABLE 15: MATRIX SHOWING RANKING

ALTERNATIVES	E (₹)	F (₹)	G(DAY)	H (%)	I (%)	J (%)	CC	RANKING
A1	0.1603	0.1571	0.0287	0.0648	0.0131	0.0712	0.4540	3
A2	0.1216	0.1929	0.0221	0.0528	0.0171	0.0731	0.4157	4
A3	0.1037	0.2244	0.0180	0.0454	0.0210	0.0986	0.5460	1
A4	0.1175	0.2074	0.0239	0.0491	0.0158	0.0822	0.5100	2

The results and discussion evolved as an outcome of using these three proposed methodologies is stated below.

VI. SENSIBILITY ANALYSIS:

Sensitivity analyses are commonly used and the reader is referred to Clemen [6] for a perspective on different approaches to sensitivity analyses in multi-criteria decision making. The goal of sensitivity analyses is to investigate the impacts of the uncertainties to the model.

In this paper the quantitative multiple criteria decision making methods and sensitivity analysis methods usage in SAW analyzed. The weight with the least value is varied to check the proportional change in the rankings of the alternatives. Here the least value among all the weights is 0.034 with the criteria Material Quality. This value of weight is varied consecutively up to 35% and the respective change in the index values and the ranking of the alternatives of all the three methodologies is carefully observed.

The observation of sensitivity analysis is shown in a tabulated manner below:

TABLE 16: SENSIVITY ANALYSIS OF SAW METHOD

TOTAL SCORE					WEIGHTS						RANKING
CASE	A1	A2	A3	A4	W1	W2	W3	W4	W5	W6	
1	0.840	0.836	0.892	0.872	0.255	0.394	0.047	0.107	0.034	0.164	A3>A4>A1>A2
2	0.840	0.837	0.892	0.872	0.255	0.394	0.047	0.107	0.034	0.1643	A3>A4>A1>A2
3	1.143	1.146	1.191	1.185	0.255	0.394	0.047	0.107	0.034	0.164	A3>A4>A1>A2
4	0.841	0.837	0.893	0.874	0.255	0.394	0.047	0.107	0.0350	0.164	A3>A4>A1>A2
5	0.841	0.838	0.893	0.874	0.255	0.394	0.047	0.107	0.0353	0.164	A3>A4>A1>A2

TABLE 17: SENSIBITY ANALYSIS OF MOORA METHOD

TOTAL SCORE					WEIGHTS						RANKING
CASE	A1	A2	A3	A4	W1	W2	W3	W4	W5	W6	
1	-0.21	-0.19	-0.17	-0.18	0.255	0.394	0.047	0.107	0.034	0.164	A3>A4>A1>A2
2	-0.21	-0.19	-0.17	-0.18	0.255	0.394	0.047	0.107	0.0343	0.1643	A3>A4>A1>A2
3	-0.05	-0.04	-0.02	0.02	0.255	0.394	0.047	0.107	0.0346	0.164	A3>A4>A1>A2
4	-0.21	-0.19	-0.17	0.17	0.255	0.394	0.047	0.107	0.0350	0.164	A3>A4>A1>A2
5	-0.21	-0.19	-0.17	0.17	0.255	0.394	0.047	0.107	0.0353	0.164	A3>A4>A1>A2

TABLE 18: SENSIBILITY ANALYSIS OF TOPSIS METHOD

TOTAL SCORE					WEIGHTS						RANKING
CASE	A1	A2	A3	A4	W1	W2	W3	W4	W5	W6	
1	0.454	0.415	0.546	0.510	0.255	0.394	0.047	0.107	0.034	0.164	A3>A4>A1>A2
2	0.453	0.415	0.546	0.510	0.255	0.394	0.047	0.107	0.0343	0.1643	A3>A4>A1>A2
3	0.454	0.415	0.546	0.510	0.255	0.394	0.047	0.107	0.0346	0.164	A3>A4>A1>A2
4	0.453	0.415	0.546	0.510	0.255	0.394	0.047	0.107	0.0350	0.164	A3>A4>A1>A2
5	0.453	0.415	0.546	0.509	0.255	0.394	0.047	0.107	0.0353	0.164	A3>A4>A1>A2

The observation show that the top ranking alternatives changes negligibly with each percentage increment in the least weight value of the criteria chosen as Material Quality (I). It is noticed that the alternative A3 is robust enough to handle the variation up to 35% change in its initial value of the least weight in all the three methodologies. Only twice, that is on 2% and 24% change in the initial value of the least weight, it is observed that the alternative A4 is optimal based on the MOORA method, the ranking of the other two methods remains the same with some small change in the index values of the three respective methodologies.

After ascertaining the rank orders for all the alternatives as well as the sensitivity analysis the following comparison between the different MCDM techniques is shown below

TABLE 19: COMPARION BETWEEN SAW, MOORA, TOPSIS

DECISION PARAMETERS	SAW	MOORA	TOPSIS
1.CORE PROCESS	HIGH	MODERATE	HIGH
2. MATHEMATICAL CALCULATION	LESS	LESS	MODERATE
3. FINAL RESULT	GLOBAL RANKING ORDER	GLOBAL RANKING ORDER	GLOBAL RANKING ORDER
4. COMPUTATION TIME	VERY LESS	VERY LESS	MODERATE

VII. CONCLUTION

Supply chain is a system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer. Supply Chain Management includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. Suppliers plays a major role in a supply chain to get the best outcomes in every aspect, which definitely calls for Multiple criteria decision making methods for the evaluation and selection of suppliers because in today's competitive world, one has got many alternatives as different suppliers from different firms or companies to choose from on the basis of many criterion such as product price, transportation cost, delivery lead time, on time delivery, material quality, technical capability and ordering cost etc. In this paper we analyze the quantitative multiple criteria decision making methods and sensitivity analysis methods usage in decision support systems. It is submitted analysis sensitivity of methods SAW, MOORA and TOPSIS. The paper is also intended to the problem of determining sensitivity of quantitative methods SAW, MOORA and TOPSIS. The final conclusion that can be summed up after the alternatives evaluation and sensitivity analysis with respect to initial data:

1. The ranking of the alternatives in both SAW and TOPSIS remains the same i.e. A3 is optimal; where as in MOORA A4 is optimal.
2. If the initial least weight of the criteria differs by 2% and 24% of the initial value MOORA method is more sensitive than SAW and TOPSIS.
3. Sensitivity analysis is important and it must be performed in decision making methods with respect to the initial data, which may be not sufficiently accurate. This applies both to the values and weights of the criteria used. The final decision should be provided alongside with the results of sensitivity analysis. It must be taken into account when developing decision support systems.

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