A Comparative Analysis of TOPSIS & VIKOR Methods in the Selection of Industrial Robots

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CERTIFICATE OF APPROVAL

This is to certify that the thesis entitled *A Comparative Analysis of TOPSIS & VIKOR Methods in the Selection of Industrial Robots* Submitted by *Sri Nirmal Patel* has been carried out under my supervision in partial fulfillment of the requirements for the Degree of Bachelor of Technology (B. Tech.) in Mechanical Engineering at National Institute of Technology, NIT Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma.

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Abstract

Now-a-days robots are very essential in manufacturing industries for the optimization of their production. So selection of an industrial robot for a particular application is one of the most vital problems in real time manufacturing environment. The decision maker needs to choose the most suitable and applicable industrial robot in order to get the required output with minimum cost and having the specific abilities. This paper mainly focuses to compare the different multiple criteria decision making (MCDM) methods such as TOPSIS and VIKOR Method for selection of alternative industrial robots. Both the methods are based on an aggregating function that represents closeness to the ideal solution. VIKOR method is based on linear normalization whereas TOPSIS method used vector normalization to eliminate the units of criterion functions. A solution obtained by TOPSIS method has the shortest distance from the ideal one and farthest from the negative ideal solution. VIKOR method helps to determine a compromise solution that gives a maximum group utility for the majority and minimum for opponents.

CONTENTS

1. Introduction

An industrial robot is a widely used, reprogrammable machine having anthropometrical features. It has mechanical an arm which is most important and highly anthropometrical component. It has some other important features such as decision making capability, easily communicate with other machines and enable to reply to various sensory inputs. Industrial robot is a wonderful tool for every manufacturing industry for different purpose such as material handling, loading to the machine, finishing, painting with spray, welding, accuracy in work, repeatability and easily carry heavy loads. It has some other capabilities like various degrees of freedom, user friendly, and flexibility in programming, large memory capacity etc. So for an industry, it is a most important task of selecting a robot for a particular application. Selection of robot depends upon the different attributes which are classified into subjective and objective attributes or beneficial and non-beneficial attributes. Subjective attributes are qualitative in nature. Some examples are programming flexibility, vendor's service quality etc. whereas objective attributes are numerical values such as load capacity, cost etc. The beneficial attributes mean which provide us some profit so its higher value is always preferable. Some examples are load carrying capacity, arm movement distance and flexibility in programming. Non-beneficial attributes mean which makes us in loss so its lower value is preferable. Some examples cost, maintenance cost, error done by the robot etc. During the selection of a robot for an industrial application, the decision makers have to consider all attributes explained above. Whereas we have to sacrifice some features or attributes depending upon the requirement due to some reason that's why we need to optimize the selection of industrial robots. That's why we approach to different multiple criteria decision making (MCDM) methods such as Weighted Sum Method (WSM), Weighted Product Method (WPM), Analytic Hierarchy Process (AHP) Method, Revised Analytic Hierarchy Process (RAHP) Method, and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Method, Compromise Ranking Method (VIKOR) for the solving of this type of industrial problems which are shown in the Fig.1.

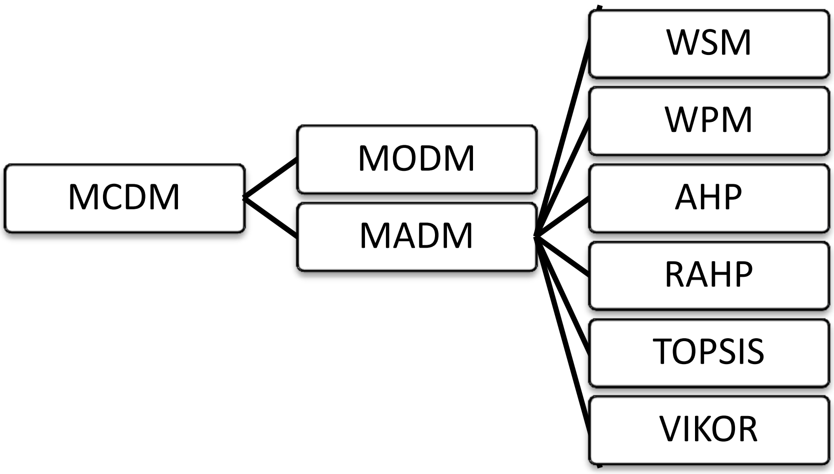

Fig. 1: Classification of MCDM methods

There are a large number of papers have proposed analytical models to give a suggestion in conflict management situations. Among the various approaches available to conflict management, one of the most appropriate is multicriteria decision making. Multicriteria decision making (MCDM). It may be considered as a complex and dynamic process including one manager level and one engineering level [1].

The main steps of multicriteria decision making are the following:

a) Obtaining system evaluation attributes that related system capability to achieve the goals;
b) Developing possible number of alternative systems for achieving the goals (generating alternatives);
c) Obtaining the alternatives in terms of different criteria (the values of the criterion functions);
d) Applying a normative multicriteria to the analysis method;
e) Accepting one alternative as optimal which is to be preferred;

f) If the final solution is not satisfied, gather new information about the model and go to the next iteration of multicriteria optimization technique.

Steps (a) and (e) are done at the upper level, where decision makers have the main role, and the other steps are mostly done by the engineers. For step (d), a decision maker expresses his/ her requirements in terms of the relative importance of different attributes and that's why needs to introduce criteria weights. These weights in MCDM do not have a perfect economic significance, but their use provides the chance to model the actual aspects of decision making i.e. preference structure.

The main efforts are given in the engineering level to generate and evaluate the alternatives in steps (b) and (c); these efforts are depends on the project of the person since projects depending to the needs. Generating alternatives can be a very complex process, since there is no general procedure or mathematical procedure that can replace human creativity in generating and evaluating alternatives.

In this paper, two methods of MCDM such as VIKOR and TOPSIS are compared and focusing on construction of aggregating function and then normalization of attribute in order to compare the procedural basis of these two methods. A comparative analysis is illustrated with a numerical example “selection of Industrial robots”.

2. Literature Review

The purpose of this literature review is to provide background information on the issues to be considered in this thesis and give importance to the relevance of the present study. This treatise embraces about the importance of industrial robots in different application and selection of this robot by comparing two multiple criteria decision making (MCDM) methods, TOPSIS and VIKOR.

Every industry needs industrial robots to fulfill their demand and to optimize their production as well as quality. Hence selecting an industrial robot for a particular engineering application is a great task which needs good reasoning, ideas, experience and lots of brainstorming thinking to select an appropriate robot before its application in the necessary industries.

Rao et al. [2] compared digraph and matrix method for the selection of industrial robots. He robot proposed a selection index that evaluates and ranks robots for a given industrial application and that index is obtained from a robot selection attributes function, obtained from the robot selection attributes digraph. Goh et al. [3] Proposed a decision weighted sum magazine that we can take into account both the objective and subjective characteristics during the selection of industrial robots. Khouja and Booth [4] used a statistical procedure known as robust fuzzy cluster analysis that can identify the robot with the best combination of specifications based on various performance parameters. Khouja [5] developed a decision model two stages to solve the problems of selection robot. In the first phase, the data envelopment analysis (DEA) is used to identify the robot with the best combination of the manufacturer's specifications on the basis of the performance parameters of the robot. In the second phase, a multi-attribute decision making (MADM) method is applied to select the best robot from those identified in the first phase. Zhao et al. [6] Combined a multi-chromosome genetic algorithm with first-fit bin packing algorithm for the optimal selection of the robot and assignment problem workstation of an integrated production system of the computer.

Baker and Talluri [7] proposed a methodology for the selection of the robot on the basis of cross-efficiencies in data envelopment analysis (DEA), without considering the criteria weights or the preferences of the decision maker. Goh [8] applied the Analytic Hierarchy Process (AHP) for the selection of robots that can simultaneously consider both objective and subjective characteristics. Parkan and Wu [9] demonstrated the applications and interrelations of the operational competitiveness rating (OCRA) and methods in a problem of robot selection TOPSIS and compared their performances with other approaches. It is observed that both of these methods are strongly correlated, and their performance measures and decision involve the same mathematical treatment even if they have their structural differences apparent. Kahraman et al. [10] Developed a method of hierarchical fuzzy TOPSIS to solve the problems of multi-attribute selection robot. Karsak [11] introduced a decision-making model for selection of robot based on Quality Function Deployment (QFD) and fuzzy linear regression methods, integrating the user requests, with the technical characteristics of the robots. Although a number of research works have been presented by researchers in the past on issues of selection of robots, but still there is a need for a simple and systematic approach / mathematical tool to guide decision-makers to select and identify the best robot suitable for a given set of alternatives, because a wrong choice can often contribute negatively to the productivity and flexibility of the whole process. In this work, an attempt is made to discover the potential and applicability of Vikor (a ranking compromise) method while selecting the most suitable robot for a particular industrial application. VIKOR (the Serbian name is 'Vlse Kriterijumska Optimizacija Kompromisno Resenje' which means multicriteria optimization (MCO and compromise solution) method was mainly Established by Zeleny [12] and later advocated by Opricovic and Tzeng [13-14]. This method is developed to solve the Attributes MCDM problems with conflicting and non-commensurable (different units criteria), assuming that compromise may be acceptable for conflict resolution, when the decision maker wants a solution that is the closest to the ideal solution and the alternatives can be evaluated with respect to all the attributes set. It focuses on the classification and selection of the best alternative from a finite set of alternatives with conflicting criteria, and on proposing a compromise solution (one or more).

The compromise is a viable solution that is the closest to the ideal solution and a compromise means an agreement established by mutual concessions made between alternatives. The following multiple attribute merit for compromise ranking is developed from the L-metric used in compromise programming method [15]. Knott and Getto [16] suggested a model to evaluate different robotic systems under uncertainty and the different alternatives were evaluated by calculating the total net present value of the cash flows of investment, job components and overhead. Offodile et al. [17] developed a coding and classification system which is used to store the characteristics of the robot in a database, and then selects a robot using economic modeling. While the intent provides valuable help in the final selection stage, an exercise of this type will be prohibitive in the initial selection phase in which the number of robots is great potential and many other considerations have to be taken into account. Imang and Schlesinger [18] presented the decision models for robot selection and comparison of ordinary least squares and the method of linear goal programming.

3. TOPSIS Method

TOPSIS (technique for order preference by similarity to ideal solution) method was firstly developed by Hwang and Yoon in 1981. The basic approach of this method is choosing an alternative that should have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution. The positive ideal solution maximizes the benefit criteria and minimizes conflicting criteria, whereas the negative ideal solution maximizes the conflicting criteria and minimizes the benefit criteria. For the calculation of TOPSIS values, we have to go through the following steps

Step 1: In the first step, we have to determine the objective and to identify the attribute values for each alternative.

Step 2: This step involves the development of matrix formats. The row of this matrix is allocated to one alternative and each column to one attribute. The decision making matrix can be expressed as:

$$D = \begin{bmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2n} \\ x_{31} & x_{32} & x_{33} & \cdots & x_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & x_{m3} & \cdots & x_{mn} \end{bmatrix}$$

Step 3: Then using the above matrix to develop the normalized decision matrix with the help of the formula given below:

$$X_{ij}^{*} = X_{ij} / \sum_{i=1}^{n} X_{ij}$$

Step 4: Depending upon the relative importance of different attributes obtain weight for each attributes using the formula given below and the sum of the weights should be 1.

$$W_j = V_j / \sum_{i=1}^{m} V_j \quad \& \quad \sum_{j=1}^{m} w_j = 1$$

Where v_j is the variance of each attribute which can be calculated by the formula given as $V_j = (1/n) \sum_{i=1}^{n} (X_{ij}^{*} - (X_{ij}^{*})_{mean})^2$

Step 5: Then obtain the weighted normalized matrix V_{ij} by multiplying W_j with all the values $X_{ij.}^*$ such as

$$V_{ij} = W_j X_i \,.$$

Step 6: This step determines the ideal (best) and negative ideal (worst) solutions. The ideal and negative ideal solution given as:

a) The Ideal solution

$$A^+=\{v_1^+, \ldots\ldots, v_m^+\} \quad = \{(max v_{ij}|j\in I'), (min\ v_{ij}|j\in I'')\}$$

b) The negative ideal solution

$$A^-=\{v_1^-, \ldots\ldots, v_m^-\} \quad =\{(min v_{ij}|j\in I'), (max\ v_{ij}|j\in I'')\}$$

Here,

I'={j=1,2,…n|j }: Associated with the beneficial attributes

I''= {j=1,2,…n|j }: Associated with non-beneficial adverse attributes

Step 7: Obtain separation (distance) of each alternative from the ideal solution and negative ideal solution which is given by the Euclidean distance given by the equations.

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

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

Step 8: Calculate the relative closeness to the ideal solution of each alternative which is given by the formula :

$$C_i^* = D_i^-/(D_i^+ + D_i^-), \quad i=1,\ldots\ldots\ldots, n$$

Step 9: A set of value is generated for each alternative. Choose the best alternative having largest closeness to ideal solution. Arrange the alternative as an increasing order of C_j*.

4. VIKOR Method

VIKOR (Vlse Kriterijumska Optimizacija Kompromisno Resenje), also known as Compromise Ranking Method is a possible solution that is closest to the ideal solution and the meaning of compromise is agreement generated by mutual concession. The calculation of VIKOR values, we go through the following steps:

Upto **step 4** is same that of TOPSIS method as given above.

Step 5: Obtain the value of the criterion function for all the alternative f_{ij}. f_{ij},is the ^{jth} criterion function of X_i alternative .

Here , i=1,2,….,n : the number of alternatives.

j=1,2,….,m: the number of criteria.

Step 6: Obtain the maximum criterion function f j* and the minimum criterion function f j- , where j = 1. . . . . . m.

$$f_j^* = \max_i f_{ij} = max\ [(f_{ij}\ )|\ i = 1, 2, ...,n]$$

$$f_j^- = \min_i f_{ij} = min\ [(fij)\ |\ i = 1, 2, ...,n]$$

Step 7: Calculate the utility measure and regret measure for all the alternatives given as:

a) Utility measure

$$S_i = \sum_{j=1}^{m} W_j (f_j^* - f_{ij}) / (f_j^* - f_j^-)$$

b) Regret measure

$$R_i = \max_j\ [W_j(f_j^* - f_{ij}) / (\ f_j^* - f_j^-)$$

Step 8: calculate the value of VIKOR index for each alternative expressed as follows:

$$Q_i = v(S_i - S^*)/(S^- - S^*) + (1 - v)(R_i - R^*)/(R^- - R^*)$$

Where,

Q_i represents the VIKOR index value of i^{th} alternative. I=1,2,……,n.

$$S^* = \min_i S_i = \min [(S_i) \mid i = 1, 2, \ldots\ldots, n]$$

$$S^- = \max_i S_i = \max [(S_i) \mid i = 1, 2, \ldots\ldots, n]$$

$$R^* = \min_i R_i = \min [(R_i) \mid i = 1, 2, \ldots\ldots, n]$$

$$R^- = \max_i R_i = \max [(R_i) \mid i = 1, 2, \ldots\ldots, n]$$

v is the weight for the maximum value of group utility and 1 – v is the weight of the individual regret. v is generally set to 0.5.

Step 9: Rank of the alternatives is done by observing the Qi value. The less the value indicates a better quality.

5. Problem Specification

A problem of selecting an industrial robot is very important to an industry for the optimization of his production. The selection of industrial robots depends on various attributes considered same as Rao et al. [2].and these are (i) load capacity (LC), (ii) repeatability error (R), (iii) vertical reach (VR), and (iv)degrees of freedom (DF). All the attributes except repeatability error (R) are beneficial and objective which is to be normalized as explain above Section 3.

Quantitative data for the selection of industrial robot:

Table1: Attributes for robot selection

Alternative freedom	Load capacity (kg) LC	Repeatability error (mm) R	Vertical reach (cm) VR	Degrees of freedom DF
Robot 1	60	0.4	125	5
Robot 2	60	0.4	125	6
Robot 3	68	0.13	75	6
Robot 4	50	1	100	6
Robot 5	30	0.6	55	5

6. Result & Discussion

Both the TOPSIS and VIKOR methods were utilized in finding the ranking of industrial robots using variances and weights as given below. By TOPSIS method, using the relative closeness coefficient ranking was found to be in the order 3, 1, 2, 5 and 4. In VIKOR, by observing the VIKOR index value, ranking was done as 3, 1, 2, 5 and 4. Hence, for selection of industrial robots , both the results affirmed robot 3. It clearly satisfies all the attributes like load capacity (LC), repeatability error (R), vertical reach (VR), and degrees of freedom (DF). Final ranking in both the methods was found to be same with the preference material remaining same for all cases. The TOPSIS method used for selecting an industrial robot involved many lengthy calculations to get the positive and negative ideal solution, the separation and closeness coefficients of all the alternatives. Besides from that, it does not take the relative distances from reference points and solution may not be consider as closest to the ideal. The VIKOR method had less number of comparisons and evaluations compared to TOPSIS method. Although both the methods provided same preferential-ordered solution to this problem, VIKOR stood out the best reducing computation time and providing desirable result. The detail calculation of TOPSIS and VIKOR method are given as:

(a) TOPSIS Method

Table 2: Normalized decision matrix ($X_{ij}{}^{*} = X_{ij} / \sum_{i=1}^{n} X_{ij}$)

Alternative freedom	Load capacity (kg)	Repeatability error (mm)	Vertical reach (cm)	DF
Robot 1	0.2239	0.1581	0.2604	0.1786
Robot 2	0.2239	0.1581	0.2604	0.2143
Robot 3	0.2537	0.0514	0.1563	0.2143
Robot 4	0.1866	0.3953	0.2083	0.2143
Robot 5	0.1119	0.2372	0.1146	0.1786

Table 3: Variance of different attributes ($V_j=(1/n)\sum_{i=1}^{n}(X_{ij}^{*}-(X_{ij}^{*})_{mean})^2$)

Load capacity (kg)	Repeatability error (mm)	Vertical reach (cm)	DF
0.0035	0.0141	.0044.	0.0014

Table 4: Weights of different attributes ($W_j= V_j/\sum_{i=1}^{m} V_j$)

Load capacity (kg)	Repeatability error (mm)	Vertical reach (cm)	DF
0.1496	0.6025	0.188	0.0599

Table 5: Weighted normalized matrix ($v_{ij} = W_j X_{ij}^{*}$)

Alternative freedom	Load capacity (kg)	Repeatability error (mm)	Vertical reach (cm)	DF
Robot 1	0.03349544	0.09525525	0.0489552	0.01069814
Robot 2	0.03349544	0.09525525	0.0489552	0.01283657
Robot 3	0.03795352	0.0309685	0.0293844	0.01283657
Robot 4	0.02791536	0.23816825	0.0391604	0.01283657
Robot 5	0.01674024	0.142913	0.0215448	0.01069814

Table 6: Ideal and negative ideal solution

Solution	Load capacity (kg)	Repeatability error (mm)	Vertical reach (cm)	DF
A^+	0.03795352	0.23816825	0.0489552	0.01283657
A^-	0.01674024	0.0309685	0.0215448	0.01069814

Table 7: Separation of each alternative from the ideal solution and negative ideal solution

Robot	1	2	3	4	5
D_j^+	0.14299851	0.14298252	0.20812197	0.01402508	0.10138772
D_j^-	0.07186691	0.07189872	0.02271641	0.20825826	0.1119445

Table 8: Relative closeness to the ideal solution $(C_i^* = D_i^- / (D_i^+ + D_i^-))$

Robot	1	2	3	4	5
C_j^*	0.3344740	0.33459748	0.09840831	0.93690451	0.5247426

Preference of selecting industrial robot by TOPSIS method : 3 , 1 , 2 , 5 and 4

(b) VIKOR Method

Table 9: Maximum criterion functions $(f_j^* = \max_i f_{ij})$

Load capacity (kg)	Repeatability error (mm)	Vertical reach (cm)	DF
0.2537	0.3953	0.2604	0.2143

Table 10: Minimum criterion function ($f_j^- = \min_i f_{ij}$)

Load capacity (kg)	Repeatability error (mm)	Vertical reach (cm)	DF
0.1119	0.0514	0.1146	0.1786

Table 11: Utility measure ($S_i = \sum_{j=1}^{m} W_j (f_j^* - f_{ij})/(f_j^* - f_j^-)$)

Robot	1	2	3	4	5
S_i	0.506905	0.4470048	0.73673	0.137971	0.6744853

Table 12: Regret measure ($R_i = \max_j [W_j(f_j^* - f_{ij}) / (f_j^* - f_j^-)]$)

Robot	1	2	3	4	5
R_i	0.415565571	0.41556557	0.6025	0.07079097	0.276985315

Table 12: VIKOR index value Q_i

Robot	1	2	3	4	5
Q_i	0.808	0.758	1.271	0	0.747

Preference of selecting an industrial robot by VIKOR method :3 , 1 , 2 , 5 and 4

7. Conclusion

This paper examines two popular multi-criteria decision making algorithms such as VIKOR and TOPSIS for solution quality when applied to a benchmarking problem in industrial robot selection. All the MCDM methods estimate criteria weights proposed Rao and Patel [19] so that human judgment can be avoided by assigning weights to different attributes. Both the methods result in same preference of selecting an industrial robot. But VIKOR method stands out to be the best due to elegant method and computational easiness.

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