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Selection of Industrial Robots using Compromise Ranking Method

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Abstract

Selection of an industrial robot for a specific engineering application is one of the most challenging problems in real time manufacturing environment. This has become more and more complicated due to increasing complexity, advanced features and facilities that are continuously being incorporated into the robots by different manufacturers. The decision maker needs to select the most suitable industrial robot in order to achieve the desired output with minimum cost and specific application ability. This paper mainly focuses on solving the robot selection problem using VIKOR (Vlse Kriterijumska Optimizacija Kompromisno Resenje) method, which has already become a quite popular multi-criteria decision-making (MCDM) tool. One real time example is cited in order to demonstrate and validate the effectiveness and applicability of VIKOR method.

Keywords

Robot selection, Multi-criteria decision-making, VIKOR

1. Introduction

An industrial robot is a general purpose, reprogrammable machine with certain anthropometrical features. Its mechanical arm is the most important and vital anthropometrical component. Other less but still important features, like its decision-making capability, capability of responding to various sensory inputs and communicating with other machines make it an important tool for diverse industrial applications, including material handling, assembly, finishing, machine loading, spray painting and welding. Control resolution, accuracy, repeatability, load carrying capacity, degrees of freedom, man-machine interfacing ability, programming flexibility, maximum tip speed, memory capacity and supplier's service quality are the most important attributes to be taken into account while selecting a robot for a particular industrial application. These attributes affecting the robot selection decision can be classified as objective and subjective attributes or beneficial and non-beneficial attributes. Objective attributes can be numerically defined, such as the cost and load capacity of a robot. On the other hand, subjective attributes are qualitative in nature, e.g. vendor's service quality, programming flexibility etc. The beneficial attributes are those whose higher values are always desirable, e.g. load carrying capacity, programming flexibility and non-beneficial attributes are those whose lower values are preferable, e.g. cost, repeatability error. While selecting a robot for an industrial application, the decision maker needs to consider all these attributes, where a tradeoff between them and the robot performance measures is necessary. Selection of the best suited robot for a given industrial application from a large number of available alternatives is a typical multi-criteria decision-making (MCDM) problem. Several approaches for robot selection have already been proposed by the past researchers [1-11], which include the applications of MCDM methods, production system performance optimization models, computer-assisted models and statistical models. In this paper, a ranking of all the considered alternative robots is obtained taking into account different robot selection attributes and it is observed that the ranking obtained using the VIKOR method matches quite well with that as derived by the past researchers, which proves the applicability of this MCDM method to solve such type of complex industrial problems.

2. Literature Review

Bhangale et al. [1] developed a robot selection methodology using the technique for order performance by similarity to ideal solution (TOPSIS) and graphical methods, and compared the relative rankings of the alternative robots as obtained using these two methods. A coding system is employed for expressing various robot selection attributes and a merit value is used to rank the robots in the order of their suitability for a given industrial application. Goh et al. [2] proposed a revised weighted sum decision model that can take into account both the objective and subjective attributes while selecting the industrial robots. Khouja and Booth [3] used a statistical procedure known as robust fuzzy cluster analysis that can identify the robots with the best combination of specifications based on various performance parameters. Khouja [4] developed a two-phase decision model for solving the robot selection problems. In the first phase, data envelopment analysis (DEA) is employed for identifying the robots with the best combination of vendor specifications based on the robot performance parameters. In second phase, a multi-attribute decision-making (MADM) method is applied to select the best robot from those as identified in the first phase. Zhao et al.[5] combined a multi-chromosome genetic algorithm with first-fit bin packing algorithm for the optimal robot selection and workstation assignment problem for a computer integrated manufacturing system. Baker and Talluri [6] proposed a robot selection methodology based on cross efficiencies in data envelopment analysis (DEA) without considering the criteria weights or the decision maker's preferences. Goh [7] applied the analytic hierarchy process (AHP) for robot selection that can simultaneously consider both the objective and subjective attributes. Parkan and Wu [8] demonstrated the applications and interrelationship of the operational competitiveness rating (OCRA) and TOPSIS methods in a robot selection problem and compared their performances with other approaches. It is observed that both these methods are strongly interrelated, and their performance measurements and decision-making processes involve the same mathematical treatment though they have their apparent structural differences. Rao and Padmanabhan [9] employed the diagraph and matrix methods for evaluating and ranking of the alternative robots for a given industrial application, using the similarity and dissimilarity coefficient values. Kahraman et al. [10] developed a hierarchical fuzzy TOPSIS method to solve the multi-attribute robot selection problems. Karsak [11] introduced a decision model for robot selection based on quality function deployment (QFD) and fuzzy linear regression methods while integrating the user demands with the technical characteristics of the robots. Although a number of research works have already been presented by the past researchers on robot selection problems, but still there is a need for a simple as well as systematic approach/mathematical tool to guide the decision makers to select and identify the best suited robot from a given set of alternatives, because a wrong selection may often negatively contribute to the productivity and flexibility of the entire process. In this paper, an attempt is made to discover the potentiality and applicability of VIKOR (a compromise ranking) method while selecting the most suitable robot for a given industrial application.

3. Compromise Ranking Method

The VIKOR (the Serbian name is 'Vlse Kriterijumska Optimizacija Kompromisno Resenje' which means multi-criteria 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 MCDM problems with conflicting and non-commensurable (criteria with different units) attributes, assuming that compromise can 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 established attributes. It focuses on ranking and selecting the best alternative from a finite set of alternatives with conflicting criteria, and on proposing the compromise solution (one or more). The compromise solution is a feasible solution, which is the closest to the ideal solution, and a compromise means an agreement established by mutual concessions made between the alternatives. The following multiple attribute merit for compromise ranking is developed from the L_p-metric used in the compromise programming method [15].

$$L_{p,i} = \left\{ \sum_{j=1}^{M} (w_j \left[(m_{ij})_{max} - m_{ij}\right] \Big/ \left[(m_{ij})_{max} - (m_{ij})_{min}\right]^{p} \right\}^{1/p} \tag{1}$$

$$1 \le p \le \infty;\ i = 1,2,..., N$$

where M is the number of criteria and N is the number of alternatives. The m_{ij} values (for i = 1, 2,...,N; j = 1,2,...,M) denote the values of criteria for different alternatives. In the VIKOR method, $L_{1,i}$ and $L_{\infty,i}$ are used to formulate the ranking measure.

The procedural steps for VIKOR method are highlighted as below:

Step 1: Identify the major robot selection criteria for a given industrial application and short-list the robots on the basis of the identified criteria satisfying the requirements. A quantitative or qualitative value is assigned to each identified criterion to construct the related decision matrix.

Step 2: a) After short-listing the robots and development of the decision matrix, determine the best, $(m_{ij})_{max}$ and the worst, $(m_{ij})_{min}$ values for all the criteria.

b) The weights or relative importance of the considered criteria are estimated using analytic hierarchy process (AHP) or any other method.

c) Calculate the values of E_i and F_i.

$$E_i = L_{1,i} = \sum_{j=1}^{M} w_j \left[(m_{ij})_{max} - m_{ij}\right] / \left[(m_{ij})_{max} - (m_{ij})_{min}\right] \tag{2}$$

$$F_i = L_{\infty,i} = \text{Max}^m \text{ of } \left\{ w_j \left[(m_{ij})_{max} - m_{ij}\right] / \left[(m_{ij})_{max} - (m_{ij})_{min}\right] \right\} \qquad j = 1,2,\ldots, M \tag{3}$$

Eqn. (2) is only applicable to beneficial attributes (whose higher values are desirable). For non-beneficial attributes (whose lower values are preferable), the term $[(m_{ij})_{max} – m_{ij}]$ in Eqn. (2), is to be replaced by $[m_{ij} – (m_{ij})_{min}]$. Hence, for non-beneficial attributes, Eqn. (2) can be rewritten as:

$$E_i = L_{1,i} = \sum_{j=1}^{M} w_j \left[(m_{ij}) - (m_{ij})_{min}\right] / \left[(m_{ij})_{max} - (m_{ij})_{min}\right] \tag{4}$$

d) Calculate P_i values.

$$P_i = v((E_i – E_{i\text{-}min})/(E_{i\text{-}max} – E_{i\text{-}min})) + (1 – v)((F_i – F_{i\text{-}min})/(F_{i\text{-}max} – F_{i\text{-}min})) \tag{5}$$

where $E_{i\text{-}max}$ and $E_{i\text{-}min}$ are the maximum and minimum values of E_i respectively, and $F_{i\text{-}max}$ and $F_{i\text{-}min}$ are the maximum and minimum values of F_i respectively. v is introduced as weight of the strategy of 'the majority of attributes' (or 'the maximum group utility'). The value of v lies in the range of 0 to 1. Normally, the value of v is taken as 0.5. The compromise can be selected with 'voting by majority' ($v > 0.5$), with 'consensus' ($v = 0.5$) or with 'veto' ($v < 0.5$).

e) Arrange the alternatives in the ascending order, according to the values of P_i. The compromise ranking list for a given v can be obtained by ranking with the P_i measure. The best alternative is the one having the minimum P_i value.

The VIKOR method is an effective MCDM tool, specifically applicable to those situations when the decision maker is not able, or does not know to express his/her preference at the beginning of the decision-making process. The resulting compromise solution can be accepted by the decision maker because it provides a maximum group utility of the 'majority' and a minimum individual regret of the 'opponent'. The compromise solutions can be the base for negotiations, involving the decision maker's preference on criteria weights. The VIKOR results depend on the ideal solution, which stands only for the given set of alternatives. Inclusion (or exclusion) of an alternative can affect the VIKOR ranking of the new set of alternatives.

4. Illustrative Example

In order to demonstrate and validate the application of the above-mentioned MCDM method for solving the robot selection problem, a real time example is cited. This example [1] deals with the selection of the most suitable robot for some pick-n-place operations where it has to avoid certain obstacles. Performance of an industrial robot is often specified using different attributes. Repeatability, accuracy, load capacity and velocity are observed to be the most important attributes affecting the robot selection decision. Among these, repeatability and accuracy are the most confusing attributes. Repeatability is the measure of the ability of a robot to return to the same position and orientation over and over again, while accuracy is the measure of closeness between the robot end effectors and the target point, and can usually be defined as the distance between the target point and the center of all points to which the robot goes on repeated trials. It is easier to correct poor accuracy than repeatability and thus, repeatability is generally assumed to be a more critical attribute. Load capacity is the maximum load that a manipulator can carry without affecting its performance. Load capacity of a robot is related to its acceleration and speed, and is a function of manipulator acceleration and wrist torque. Maximum tip speed is the speed at which a robot can move in an inertial reference frame. Memory capacity of a robot is measured in terms of number of points or steps that it can store in its memory while traversing along its predefined path. Manipulator reach is the maximum distance that can be covered by the robotic manipulator so as to grasp the objects for the given pick-n-place operation. Although it is usually assumed that the specified robot selection attributes are mutually independent, in general, performance parameters provided by different robot manufacturers are not simultaneously achievable. Furthermore, it is quite difficult to establish the functional relationship between those robot selections attributes. Hence, making this assumption introduces a risk of selecting a robot that may fail to provide the required performance. In this example [1], five different robot selection attributes are considered as load capacity (LC), maximum tip speed (MTS), repeatability (R), memory capacity (MC) and manipulator reach (MR), among which load capacity, maximum tip speed, memory capacity and manipulator reach are the beneficial attributes, whereas, repeatability is a non-beneficial attribute. Thus, the robot selection problem consists of five criteria and seven alternative robots, as given in Table 1.

Table 1: Quantitative data for different robots [1]

Sl. No.	Robot	LC (kg)	MTS (mm/s)	R (mm)	MC	MR (mm)
1.	ASEA-IRB 60/2	60	2540	0.40	500	990
2.	Cincinnati Milacrone T3-726	6.35	1016	0.15	3000	1041
3.	Cybotech V15 Electric Robot	6.8	1727.2	0.10	1500	1676
4.	Hitachi America Process Robot	10	1000	0.20	2000	965
5.	Unimation PUMA 500/600	2.5	560	0.10	500	915
6.	United States Robots Maker 110	4.5	1016	0.08	350	508
7.	Yaskawa Electric Motoman L3C	3	177	0.10	1000	920

The problem of selecting the best suited industrial robot for the given pick-n-place operation is solved using the VIKOR method. At first, the best and the worst values of all the criteria are identified. Rao [15] estimated the criteria weights as $w_{LC} = 0.036$, $w_{MTS} = 0.326$, $w_R = 0.192$, $w_{MC} = 0.326$ and $w_{MR} = 0.120$ using analytic hierarchy process (AHP) and these weights are used here for the VIKOR method-based analysis. Now, the values of E_i and F_i are calculated using Eqns. (2) or (4) and (3) respectively, as given in Table 2. Table 2 also shows the values of P_i for $v = 0.5$ and the compromise ranking list of the considered alternative robots. The candidate robots are arranged in ascending order, according to the values of P_i. The best choice of robot for the given pick-n-place operation is robot 3 (Cybotech V15 Electric Robot). Cincinnati Milacrone T3-726 is the second choice and the last choice is robot 7 (Yaskawa Electric Motoman L3C). Rao [15] obtained a ranking of the alternative robots as 3-2-7-1-4-6-5 using the TOPSIS method, whereas, VIKOR method derives a compromise ranking of robots as 3-2-4-1-5-6-7 (Spearman's rank correlation coefficient = 0.8333). It is observed that in VIKOR method, the first and second best choice of robots remain the same.

Table 2: E_i, F_i and P_i values for alternative robots

Robot	E_i	F_i	P_i	Rank
1	0.5700	0.3075	0.7473	4
2	0.3511	0.2103	0.1034	2
3	0.3420	0.1845	0	1
4	0.5118	0.2125	0.3314	3
5	0.7069	0.3075	0.9348	5
6	0.6910	0.3260	0.9782	6
7	0.6974	0.3260	0.9870	7

While calculating P_i values, the value of v is usually taken as 0.5 [15], but actually its value lies between 0 and 1. Table 3 shows the comprise rankings of the alternative robots for two extreme values of $v = 0.1$ and $v = 0.9$. In both the cases, the best choice of robot (Cybotech V15 Electric Robot) does not change, although the ranking of the alternative robots changes slightly.

Table 3: Rankings of robots for different values of *v*

P_i ($v = 0.1$)	Robot/Rank	P_i ($v = 0.9$)	Robot/Rank
0.8451	ASEA-IRB 60/2 (4)	0.6494	ASEA-IRB 60/2 (4)
0.1661	Cincinnati Milacrone T3-726 (2)	0.0407	Cincinnati Milacrone T3-726 (2)
0	Cybotech V15 Electric Robot (1)	0	Cybotech V15 Electric Robot (1)
0.2242	Hitachi America Process Robot (3)	0.4387	Hitachi America Process Robot (3)
0.8826	Unimation PUMA 500/600 (5)	0.9870	Unimation PUMA 500/600 (7)
0.9956	United States Robots Maker 110 (6)	0.9608	United States Robots Maker 110 (6)
0.9974	Yaskawa Electric Motoman L3C (7)	0.9766	Yaskawa Electric Motoman L3C (5)

5. Conclusions

The cited example demonstrates the potentiality, applicability and simplicity of the compromise ranking method in solving robot selection decision-making problems. The method can incorporate the decision maker's preferences regarding the relative importance of different robot selection attributes. As the measures of the quantitative as well as qualitative attributes and their relative importance are used together to rank the alternatives, the VIKOR method provides a better evaluation of the alternatives. It can make a compromise ranking of the alternative robots from a finite set of alternatives for a given problem. The results derived using this MCDM method almost match with those as obtained by the past researchers. This compromise ranking method can also be used for any type of decision-making problems, involving any number of quantitative and qualitative attributes, and any number of alternatives. In order to facilitate the application of VIKOR method for solving various MCDM problems, the related flow logic presenting its implementation module may be developed.

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