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A Novel approach of robot selection with the help of observed and theoretical values for a given industrial application

E.S.R. Ravi Kumar* and J. Siva Ram Prasad

Faculty of Mathematics, V R Siddhartha Engineering College, Vijayawada, Andhra Pradesh, India

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Abstract

A novel appropriate technique, applied to find theoretical values (Expected Values) through decision making method (Chi-Square statistics) based, is proposed for determining of an alternative robot selection for a given problem of industrial application, and we obtain the same alternative (rank of robot-3) which is not distinguished from other existing techniques of determining alternative robots for a given industrial application problem. The non-parametric test (Chi- Square statistic) used as simple and time consuming technique to get ranks of robots for a given robot selection problem. As this technique used, looks easy to get selection of robots by ranks of robots in simple way as it compared to other existing techniques (in our point of view) and the way of obtaining theoretical values (Expected values) is also simple and novel approach with the matrix multiplication. These theoretical values (Expected values) through a non-parametric test (Chi-Square statistics), are used to determines ranks of robots for a given robot selection for a given industrial application problem. Solvers may not be able to detect, such problems on their own, a possibly big time saver in the long run in pre-processing to bring the problem into the simplest way. An example is included to illustrate the technique.

Keywords: *Robot, Theoretical Values, AHP, Non-Parametric Test (Chi-Square statistics).*

Introduction

To perform a variety of other advanced tasks an industrial robot is usually defined as a reprogrammable multifunctional unit, designed to move materials, parts, tools, or other devices by means of variable programmed motions. As per present developments in information technology and engineering sciences, utilization of robots in a variety of advanced manufacturing facilities has been increased. Robots with wide range of applications of vastly different capabilities and Engineering specifications are available in market. So, a suitable robots selection from among the large number available in the market to a particular application and production environment has become a very difficult task. When a suitable robot can be selected different aspects such as product design, production system and economics, need to be considered. Because of lack of experience of prospective users in employing a robot for required job, the selection of robot problem is particularly relevant in view of the Industry. Many precision based methods for selection of robot have been developed to date and there is need of new methods for easy selection of industrial robots under uncertainty.
Knott and Getto [1] suggested a model to evaluate different robotic systems under uncertainty, and different alternatives by computing the total net present values of cash flows of investment, labor components, and overheads. To store robot characteristics in a database and then select a robot using economic modeling, a coding and classification system was developed by Offodile *et al*.[2]. Decision models for robot selection were presented by Imang and Schlesinger [3], and compared ordinary least squares and linear goal programming methods. Topsis method for robot selection was developed by Agrawal *et al*.[4]. However, the authors had not considered the subjective attributes. A fuzzy set method for robot selection was presented by Wang *et al*.[5]. A robot selection algorithm by combining the concepts of fuzzy set theory and hierarchical structure analysis was proposed by Liang and Wang [6].

Goh [7] proposed an Analytic hierarchy process (AHP) method for robot selection. However, the authors had converted the available objective values of the robot selection attributes into fuzzy values. Also the fuzzy method was complicated and requires more computation. Moreover, only a 5- point scale was considered for the rating of robots under subjective attributes. Bhangale *et al*. [8] used TOPSIS and graphical methods and listed a large number of robot selection attributes, and ranked the robots comparing the rankings given by these methods.

*Corresponding author's ORCID ID: 0000-0002-6201-3646
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However, the weights assigned by the authors to the attributes were not consistent. Rao and Padmanabhan [9] proposed a methodology based on digraph and matrix methods for evaluation of alternative industrial robots. To ranks robots for a given industrial application a robot selection index was proposed.

A robot selection attribute is defined as a factor that influences the selection of a robot for a given industrial application. The important objective of a robot selection problem is to identify the robot selection attributes like cost, configuration, load capacity , velocity of movements, type of programming, programming flexibility, reliability, repeatability, positioning accuracy, resolution, number of degrees of freedom, number of joints, their sequence and orientation, motion transformation characteristics, ease of operation, work volume, drive system, man-machine interface, vendor's service contract, training, delivery period, maintainability, ease of assembly, ease of disassembly, types and number of sensors used, availability or assured supply, management constraints, etc. and obtain the most suitable combination of the attributes in conjunction with the real requirements of the industries. For selection of a proper robot by eliminating unsuitable robots for a given industrial application by using a logical approach, efforts need to strengthen the existing robot selection procedure to determine attributes that influence robot selection for a given industrial application.

Methodology

In this paper we aims to suggest a novel technique of obtaining theoretical values (Expected values) for simple and appropriate decision making method (Chi-Square statistics) in conjunction with AHP for industrial application problem of selecting a Robot from among the existing alternative robots. Also a ranked value judgment on a fuzzy conversion scale to represent the qualitative robot selection attribute (i.e., quantitative value is not available) is suggested. The following steps are taken in alternative robot selection.

Step (1): The pertinent attributes and the alternatives included in the decision making problem of selecting robot are to be noticed under consideration. By normalizing the objective data on the basis of beneficial attributes, determine the values of the attributes (A_i). The beneficial attribute is one of which higher attribute value is more desirable, and a non-beneficial attribute is one of which the lower attribute value is desirable. The normalized data which is taken in a matrix called normalized matrix.

Step (II): Determining relative importance (a_{ij}): Constructing a pair wise comparison matrix with the help of a scale of relative importance. The main diagonal entries of the pair wise comparison matrix are all 1,as an attribute compared with itself is always assigned the value 1. " Moderate importance", "Strong importance", "Very strong importance" and "Absolute importance" which are called the verbal judgments are given numbers 3,5,7 and 9 (the numbers 2,4,6 and 8 for compromise between these values). a_{ij} denotes the comparative importance of attribute i, with respect to attribute j by assuming m attributes, the pair wise comparison of attribute i, with attribute j yields a square matrix $B_{m \times m}$ and this matrix is called Relative importance matrix, in which $a_{ij} = 1$ for i=j and $a_{ji} = \frac{1}{aij}$.

Step (III): Defining the normalized data as observed values (O_{ij}) obtained in step(I) by normalization of attributes in the matrix and the theoretical values(Expected values) (E_{ij}) are obtained by matrix multiplication of normalized data of matrix in step(I) and Relative importance matrix in step(II). Thus by using decision making method(Chi-Square statistic) the values of the Robot selection index are determined by using $\chi^2 = \sum\sum \frac{(Oij-Eij)^2}{Eij}$, for each alternative robot.

Step (IV): Some of constraints like availability or assured supply, management constraints, political constraints, economic constraints, environmental constraints etc and all possible constraints which are likely to be experienced by the user are taken in to consideration for final decision making. However by the procedure followed, higher indexed alternative may be compromised in favour.

In this robot selection problem of industrial application, the attributes considered are Purchasing cost(pc), Load carrying capacity(lc), Repeatability error(re), Man-Machine interface(mi), Programming flexibility(pf), and these are the attributes considered in this present paper, are the same as the attributes taken by R.V. Rao and Padmanabhan KK (2006) of robot selection, identification and comparison of industrial robots using digraph and matrix methods [7], and. The appropriate fuzzy scores of linguistic terms given in Table-1 are considered same as of R.V. Rao and Padmanabhan KK (2006) Selection, identification and comparison of industrial robots using digraph and matrix methods [7]. Among these attributes, "pc, re" are non-beneficial attributes and so lower values are desirable and the other attributes are beneficial and higher values are desirable. The fuzzy scores are normalized as beneficial and non-beneficial attributes as in following table and the relative importance of attributes is also considered to find theoretical values(Expected values) of decision making method(Chi-Square statistic) for selecting robot. Let preference of decision maker (i.e. user organization) select the relative importance values of attributes as in relative matrix given below and these values are for demonstration purpose only.

By Matrix multiplication of observed values (O_{ij}) and relative matrix, we obtain the theoretical values (Expected values) E_{ij}'s where the values of the attributes (normalized matrix) are taken as observed values O_{ij}'s. We perform an appropriate decision making method (Chi-Square statistics) formula for each alternative robot. Hence the robot selection index values of different robots are given below in descending order:

Robot –III : 6.4470
Robot –I : 6.3508
Robot –II : 6.1915

It is understood that the Robot – III is the right choice under the given conditions, from these indexed values of robots. It is to be understood that the above ranking is for the given preferences of decision maker (i.e., user organization). The ranking depends upon the judgments of relative importance of attributes preferred by decision maker.

Results and discussion

To explain and validate the application of new methodology of decision making methods of robot, let us consider the following example problem. Let us consider five robot selection attributes, and three alternative robots. The objective and subjective information of the attributes is given in Table-1. Man–machine interface (mi) and programming flexibility (pf) are expressed subjectively in linguistic terms. Purchasing cost (pc), Load carrying capacity (lc), Repeatability error (re) are expressed in numeric terms.

Table 1 Robot selection attributes information of example problem.

Robot	pc ($:,000)	lc(kg)	re(mn)	mi	pf
Robot 1	73	48	0.15	A	H
Robot 2	71	46	0.18	AA	VH
Robot 3	75	51	0.14	BA	H

A: Average; AA: Above Average; BA: Below Average; H: High; VH: Very high.

The decision makers can appropriately make use of any of the eight scales suggested by Chen and Hwang (1992). For example, an 11- point scale and the corresponding crisp scores of the fuzzy numbers are given in Table-2.

Table 2 Conversion of linguistic terms into fuzzy scores

Linguistic term	Fuzzy number	Crisp score
Exceptionally low	M_1	0.045
Extremely low	M_2	0.135
Very low	M_3	0.255
Low	M_4	0.335
Below average	M_5	0.410
Average	M_6	0.500
Above average	M_7	0.590
High	M_8	0.665
Very high	M_9	0.745
Extremely high	M_{10}	0.865
Exceptionally high	M_{11}	0.955

The attributes in Table-1 are assigned objective values with respective 11-point scale in Table -2.

Table 3 Objective data of the robot selection attributes of example problem

Robot	pc($:,000)	lc(kg)	re(mn)	mi	pf
Robot 1	73	48	0.15	0.5	0.665
Robot 2	71	46	0.18	0.59	0.745
Robot 3	75	51	0.14	0.41	0.665

Normalized Matrix (O_{ij}-observed values)

$$O_{ij}'s= \begin{bmatrix} 0.9726 & 0.9412 & 0.9333 & 0.8475 & 0.8926 \\ 1 & 0.9020 & 0.7777 & 1 & 1 \\ 0.9467 & 1 & 1 & 0.6949 & 0.8926 \end{bmatrix}$$

Theoretical values (Expected values) (E_{ij}'s) can be determined with the help of Relative matrix as given below.

Here the relative matrix considered as (it is our preference) :

$$\begin{bmatrix} 1 & 0.745 & 0.5 & 0.865 & 0.745 \\ 0.255 & 1 & 0.255 & 0.59 & 0.5 \\ 0.5 & 0.745 & 1 & 0.865 & 0.745 \\ 0.135 & 0.41 & 0.135 & 1 & 0.41 \\ 0.255 & 0.5 & 0.255 & 0.59 & 1 \end{bmatrix}$$

Expected values are evaluated as follows:

$$\begin{bmatrix} 0.9726 & 0.9412 & 0.9333 & 0.8475 & 0.8926 \\ 1 & 0.9020 & 0.7777 & 1 & 1 \\ 0.9467 & 1 & 1 & 0.6949 & 0.8926 \end{bmatrix} x \begin{bmatrix} 1 & 0.745 & 0.5 & 0.865 & 0.745 \\ 0.255 & 1 & 0.255 & 0.59 & 0.5 \\ 0.5 & 0.745 & 1 & 0.865 & 0.745 \\ 0.135 & 0.41 & 0.135 & 1 & 0.41 \\ 0.255 & 0.5 & 0.255 & 0.59 & 1 \end{bmatrix} = \begin{bmatrix} 2.0212 & 3.1548 & 2.0016 & 3.5780 & 3.1305 \\ 2.0088 & 3.1363 & 1.8977 & 3.6598 & 3.1853 \\ 2.0231 & 3.1815 & 2.0497 & 3.4954 & 3.1278 \end{bmatrix} = E_{ij}'s$$

Now by Chi-Square test we have $\chi^2 = \sum \sum \frac{(Oij-Eij)^2}{Eij}$

We obtain χ_1 = 0.5440+ 1.5532+ 0.5701+ 2.0837+ 1.5998 = 6.3508

χ_2 = 0.5066 + 1.5917+ 0.6610 + 1.9330+ 1.4992 = 6.1915

χ_3 = 0.5727+ 1.4958 + 0.5375+ 2.2437 + 1.5973 = 6.4470.

Thus the order of ranking is χ_3 , χ_1 , χ_2 . That is 3 – 2 – 1.

Table 5 Comparative table of ranking of Robot selection of industrial application

Chi-square statistic approach	GTMA approach	SAW approach	AHP and its Versions	Topsis approach	Modified Topsis approach
Robot 3 (6.4470)	Robot 2 (6.1701)	Robot 3 (0.9579)	Robot 3 (0.9551)	Robot 2 (0.8088)	Robot 1 (0.6460)
Robot 1 (6.3508)	Robot 1 (5.9386)	Robot 1 (0.9429)	Robot 1 (0.9416)	Robot 1 (0.3169)	Robot 3 (0.6378)
Robot 2 (6.1915)	Robot 2 (5.7184)	Robot 2 (0.9032)	Robot 2 (0.9045)	Robot 2 (0.1912)	Robot 2 (0.3625)

Table 5 shows the indexed values of Robots. It is understood that the Robot – III is the right choice under the given conditions by many precision-based methods. It may be observed that the above ranking is for the given preferences of decision maker. The ranking depends upon the judgments of relative importance of attributes made by decision maker.

Conclusions

Even though precision-based methods, had been proposed in the past to address the issue of evaluation and selection of Robot, these methods are knowledge intensive, complicated and may so beyond the capabilities of real decision maker (i.e., user organization). There is a need for a simple and logical scientific method or mathematical tool to guide user organizations in taking a proper decision. In this paper, a relevant Technique, applied to obtain theoretical values through Relative importance and Normalized matrix and through Chi-Square Statistics based decision making method, is proposed for evaluation of alternative Robot selection and obtained the same alternative (rank of Robot-3) which not deviated from other existing techniques of evaluating ranks of Robot selection for a given Robot selection for a given Industrial application problem. The Chi-Square statistic used as simple technique to find ranks of Robots for a given Robot selection problem. We considered this approach to obtain ranks in simple way as it compared to existing methods (in our point of view) and the way of obtaining theoretical values is also simple approach with the matrix multiplication. From the values of Robot selection index from different methods of calculations, it is understood that the Robot selection of industrial application designated as Robot – 3 is the right choice under the given conditions. The procedure, we define to obtain theoretical values for Chi-Square statistic also suggests Robot – 3 is right choice.

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