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Implementation of Analytic Hierarchy Process (AHP) as a Decision-Making Tool for Selection of Materials for the Robot Arm

Ankit Kumar* and Manoj Kumar

Department of Mechanical Engineering, Echelon Institute of Technology, Faridabad, India.

Abstract

Material selection is the establishment of all engineering applications and structure. This selection procedure can be characterized by application requirements, possible materials, physical principles, and selection. The selection of materials is one of the most significant decisions in any project, impacts almost every aspect of a particular application. The decision maker needs to select the most suitable material for the industrial robotic arm in order to achieve the desired properties with minimum cost and specific application ability. This has turned out to be increasingly more convoluted because of expanding intricacy, propelled highlights and offices that are ceaselessly being consolidated into the robots by various makers. This paper mainly focuses on solving the selection of materials for the robotic problem using the analytic hierarchy process (AHP) method. The Analytic Hierarchy Process (AHP) is one of the widely used multi-criteria decision-making (MCDM) methods One of the main advantages of the AHP method is the relative ease with which it handles multiple criteria. In addition to this, AHP is easier to understand and it can effectively handle both qualitative and quantitative data.

Keywords: Multi-criteria decision making, Robotic materials, analytic hierarchy process (AHP)

1. INTRODUCTION

These days' robots are extremely fundamental in manufacturing industries for the enhancement of their production. The decision maker needs to select the most suitable material for the industrial robotic arm in order to achieve the desired properties with minimum cost and specific application ability. The selection of the most appropriate materials for a particular purpose is a crucial function in the design and development of products. In the development of product design, the main goal of material selection is to minimize cost while meeting product performance goals. The material selection process begins with identifying the desired attributes of the engineering problem, such as looking at the density, strength, weight or cost of the material.

The application of MCDM techniques to support engineering designers compares the performance of established materials, new materials, and hybrid materials when selecting the most appropriate materials for product design. There are three different steps involves in engineering process: selecting a suitable material for the project, specifying a shape or design for the engineering problem, and determining the necessary manufacturing processes to developed the design. Thus materials selection process is the first step of the engineering process. The materials selection process starts with identifying the desired attributes of the engineering problem, such as density, strength, or cost of the material.

2. LITERATURE REVIEW

2.1 Literature review on MCDM in the robotic area:

P.P. Bhangale et al., 2004 [1], generate and maintain a reliable and exhaustive database of robot manipulators based on their different pertinent attributes. This database can be used to standardize the robot selection procedure when the manufacturing firm has decided to use the robot for a particular operation. Arijit Bhattacharya et al., 2005 [2], an integrated model combining AHP and QFD has been delineated for the industrial robot selection problem. Seven technical requirement factors have been considered for the case study. Vijay Manikrao Athawale, 2010 [3], used VIKOR (Vlse Kriterijumska Optimizacija Kompromisno Resenje) method for solving the robot selection problem, which has already become a quite popular multi-criteria decision-making (MCDM) tool. This method can incorporate the decision maker's preferences regarding the relative importance of different robot selection attributes. Mahmood Shahrabi, 2014 [4], research is to solve a robot selection problem. For this reason, two Multi Criteria Decision Making methods, FAHP (Fuzzy Analytical Hierarchy Process) and FTOPSIS (Fuzzy Technique for Order Preference by Similarity to Ideal Solution) are used for the selection of the most convenient robot. Also, a real-life example is cited in order to demonstrate and illustrate the model. Rajani and Jawahar Babu A, 2014 [5], implemented of Analytic Hierarchy Process (AHP) as a Decision Support Tool for Selection of Robot for Spot Welding Operation. In this paper, AHP is implemented to address this MCDM problem which acts as a decision support tool to select an appropriate robot for spot welding operation based on the technical factors, because of its strong mathematical basis. Radu Eugen Breaz et al., 2017 [6], used a method based upon Analytic Hierarchy Process (AHP) for selecting the industrial robot for milling applications. Several attributes of the robots are proposed as selection criteria, and a simulation study of the milling capabilities of the robotic structure is also taken into consideration. They used load capacity, reach, weight, repeatability, power consumption, dexterity and service as selection criteria. Shashikant Tamrakar et al., 2014 [7], used the Analytical Hierarchy Process application in Industries. They show that complex decision is solved by Analytical Hierarchy Process and is validated. The AHP is an effective approach in dealing with day – to – day complex decision problems like machine shop maintenance strategy etc. Atul Sharma et al., 2015 [23], used the application of AHP and ANP methods for Selection of Best Material for an Axle in Multiple Attribute Decision Making Environments. Explores the ranking method for selecting the priority parameter for manufacturing of an axle for a motorcycle from various criteria using "Analytical Hierarchy Process (AHP)" and Analytical Network Process (ANP)".

2.2 Literature review on MCDM in material selection:

Rao and Davim, 2008 [8], used a logical system of material selection for a given engineering design while combining TOPSIS and AHP methods, and proposed a 'material selection index' to help the DM to assess and grade the alternative materials. S.R. Maity and S. Chakraborty, 2012 [9], used the fuzzy analytic network process (ANP) method to select the most appropriate material for a supercritical boiler. S.R. Maity and S.Chakraborty, 2012 [10], proposed a fuzzy analytic network process (FANP)-based approach to select the most appropriate materials for wind energy and wave energy extraction impulse turbine blades. The applicability of the fuzzy analytic network process method is demonstrated with two examples to prove its adaptability to solve industrial decision-making problems. Jahan, 2102 [11], developed the comprehensive VIKOR method and proposed a mixed 0-1 goal programming model for simultaneous material selection and design optimization. The proposed model is justified by ranking the candidate materials for a rigid pin which is implanted in the shaft of the femur and comparing the result with other methods. MousaviNasab and Sotoudeh-Anvari, 2018 [13], suggested a new MCDM methodology for a sustainable material evaluation process. Demirel, B., 2018 [14], employed an entropy-based simple additive weighting and AHP(Analytic Hierarchy Process) to determine the most appropriate material for a dental implant. Zhang et al., 2017 [15], proposed an MCDM approach that integrates DEMATEL, GRA (grey relational analysis), ANP, and TOPSIS to determine the optimal green material. Govindan et al., [16], constructed a model to select the most appropriate construction material by utilizing the DEMATEL, ANP, and TOPSIS methods. Liu et.al, 2013 [17], used VIKOR / Induced operator weighted averaging (IOWA) for Material selection in a high-temperature environment. Athawale and Chakraborty, [18], applied 10 most commonly multi-criteria decision-making methods are considered and their relative performance is compared with respect to the rankings of the alternatives while selecting suitable materials for (a) a sailing boat mast, (b) a flywheel, and (c) a cryogenic storage tank. Tramarico et al. [12] reported a trend of application of MCDM tools which was obtained from published articles in the year 1990 to 2014. From the study, AHP was the commonly applied MCDM tool and followed by TOPSIS and ANP.

3. ROBOTIC FRAME MATERIALS

For convenience, most of the engineering materials are divided into three mains or fundamental classes. These three fundamental classes of engineering materials are metallic materials, polymeric materials, and ceramic materials. In addition to the three main classes of materials, there are two additional classes i.e., composite materials and elastomer materials [19]. A combination of these fundamental types of materials makes a composite. Engineering materials grouped into six wide families as shown in ***Figure 1***.

- Metals
- Polymers
- Elastomers
- Ceramics
- Glasses
- Hybrid composite materials

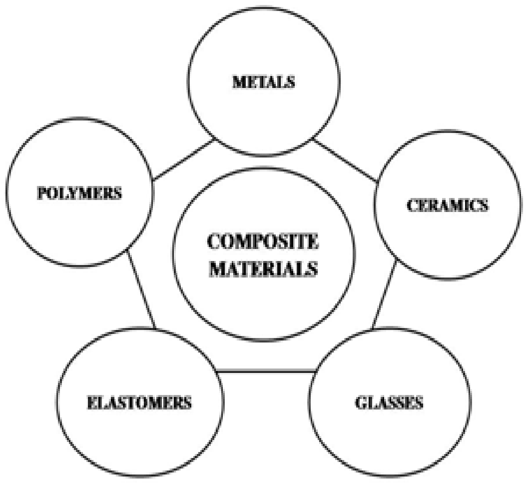

Figure 1: Classification of materials

Each material family is distinguishable by having different features or properties in common. As noted in the material selection process section, the properties of a material are what is desired, not the material itself.

Robotic frame materials can be made from a variety of materials including woods, metals, plastics, and composites [22]. These varieties of materials have their own properties, advantages, limitations, and applications. The selection process can be defined by application requirements, possible materials, physical principles, and selection. The design or function of the part/application is the application requirements. Possible Materials are defined by the application requirements. Physical principles are methods of changing the material properties of a material. When selecting a material for a given application the material properties must satisfy the function and the operating conditions of the component or the structure being designed. The properties, which directly influence the choice of material, are mechanical, physical, chemical, and manufacturing properties. In this report, only physical and mechanical properties will be discussed as these properties actually related to the properties of robotic frame materials.

The first frame material of the robot was wood. Wood is used because wood is a versatile raw material and the only renewable construction material. The main advantage of wood is: it is relatively lightweight and cheap. In general, Oak also is not widely used because of its weight and difficulty to machine [20].

The next frame material of a robot is plastic. Plastic robot frames are generally made more at manufacturing plants because it is Light in weight, better strength to weight ratio, and durable. Due to its low melting point and high malleability compared to other materials, plastic can be formed into basic and complex geometries with relative ease. The manufacturing process is easy to give the desired shape. Injection molding is the most commonly used process for making plastic frames [20].

After the plastic frame materials of the robot, another frame material comes i.e., standard metal frame. Metal tends to be a little more expensive than wood and plastic materials. Metal frames have a long life, high strength, and offer more durability and stability. The most common metal frames for robotic applications are aluminum and steel. Aluminum is a much softer metal and is easy to work with, but steel is a much stronger material.

To the selection of frame materials for the robotic arm to perform material handling tasks. After the initial selection, three materials wood, plastic, and metal were chosen for further families of the material. Thus, the selection of material for the frame of the robotic arm problem consists of four main criteria. These criteria are as follows and the hierarchy: Strength of the materials, Density of the materials, and Young's Modulus of the materials and Cost of the materials. The only materials that match this description include Wood (Ash, brich), Metal (aluminum alloys, steel) and Plastic (acrylic, polycarbonate).

4. MULTI-CRITERIA DECISION MAKING MCDM

Multi-Criteria Decision Making MCDM or MCDA stands for multi-criteria decision-making and multi-criteria decision analysis. MCDM is concerned with structuring and solving decision and planning problems involving multiple criteria. The purpose is to support decision makers facing such problems. It is a branch of a general class of Operations Research (or OR) models that deal with decision problems under the presence of a number of decision criteria. Multiple criteria decision-making (MCDM) is considered as a complex decision making (DM) tool involving both quantitative and qualitative factors. Multiple criteria decision-making (MCDM) has grown as a part of operations research, concerned with designing computational and mathematical tools for supporting the subjective evaluation of performance criteria by decision-makers.

5. THE ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchy Process (AHP) is the decision aiding method introduced by Thomas Saaty (1980), based on the use of relatively judgment matrices and may aid the decision maker to line priorities and make the best decision. By reducing difficult choices to a series of pairwise comparisons, then synthesizing the results, the AHP helps to capture every subjective and objective aspect of a selection. In addition, the AHP incorporates an effective technique for checking the consistency of the decision maker’s evaluations, therefore reducing the bias within the process.

6. IMPLEMENTATION OF THE AHP

The AHP can be implemented in the following consecutive steps:

Step-1: Define the goal or unstructured problem

Step-2: Break down the multi-criteria problem into a hierarchical structure with a number of small constituent elements, as shown in ***Figure 2.*** In ***Figure 2***, the overall goal is laid at the highest level; the evaluation criteria are gathered at the middle level and the candidate alternatives are located at the lowest level.

Step-3: A series of pair-wise comparisons are carried out among the elements at the same level in the next higher level using Saaty’s nine-point scale which is listed in ***Table 1***, and judgment matrices are formulated for all evaluation criteria. The pair-wise comparisons of various criteria generated say matrix A

Step-4: The next step involves normalization of the comparison matrix A and transforming it into matrix B. Each element of matrix B is computed as [21]

$$\boldsymbol{b_{jk}}=\frac{a_{jk}}{\sum_{l=1}^{m} a_{lk}}$$

Then calculate eigenvector w=w_j, which is known as the criteria weight vector w (that is an m-dimensional column vector) is built by averaging the entries on each row of matrix B, i.e.

$$\boldsymbol{w_j}=\frac{\sum_{l=1}^{m} b_{jl}}{m}$$

The pair wise comparisons of various criteria generated at ***step 4***, the calculate the maximum eignvalue according to following equation [21]

$$\boldsymbol{\lambda_{max}}=\frac{1}{m}\sum_{j=1}^{m}\frac{(Aw)_j}{w_j}$$

Where $\lambda \boldsymbol{max}$= maximum eigenvalue of the comparison matrix.

Step-5: The consistency of the matrix of order m is evaluated. The AHP incorporates an effective technique for checking the consistency of the evaluations when building each of the pair wise comparison matrices involved in the process. For checking the consistency of matrix, calculate the Consistency Index (CI) as [21]

$$\mathbf{CI}=\frac{\lambda_{max}-m}{m-1}$$

Step-6: Consistency ratio (CR), which can be calculated as the ratio of the consistency index (CI) of the matrix to the consistency index of a random-like matrix (RI). The value of RI takes from the Consistency indices for a randomly generated matrix ***Table 2.***

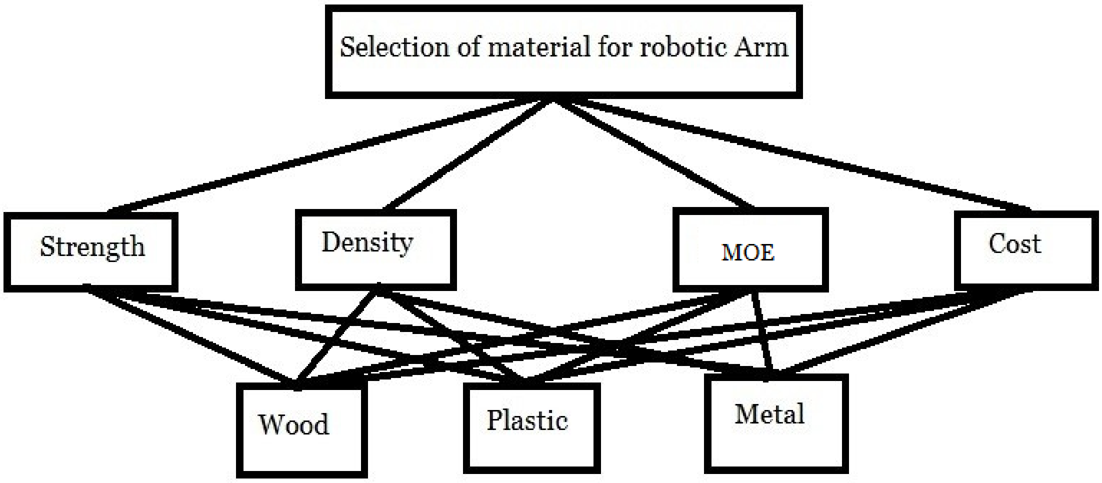

Figure 2: Decision Hierarchy for selecting material for frame of robotic Arm

Table 1: Saaty's pair wise comparison scale [21]

Verbal judgment	Numerical Value
Extremely important	9
	8
Very Strongly more important	7
	6
Strongly more important	5
	4
Moderately more important	3
	2
Equally important	1

Table 2: Consistency indices for a randomly generated matrix [21]

n	3	4	5	6
RI	0.58	0.88	1.12	1.24

Scanning the consistency of the paired comparison matrix to evaluate the decision-makers comparisons were consistent or not. If the consistency ratio (CR) is 0.10 or less is acceptable and continues the AHP analysis. If the consistency ratio is greater than 0.10 or 10%, it is necessary to revise the judgments to locate the cause of the inconsistency and correct it.

Step-7: The rating of each alternative is multiplied by the weights of the sub-criteria and aggregated to get local ratings with respect to each criterion. The local ratings are then multiplied by the weights of the criteria and aggregated to get global ratings. As the final step, option ranking is accomplished by ordering the global scores in decreasing order.

7. THE AHP FOR THE ROBOTIC ARM

The selection of material for the frame of the robotic arm problem consists of four main criteria. These criteria are as follows: Strength of the materials, Density of the materials, and Young's Modulus of the materials and Cost of the materials. The only materials that suitable for this description include Wood (Ash, brich), Metal (aluminum alloys, steel) and Plastic (acrylic, polycarbonate).

Note that the first level of the hierarchy is our goal: Selection of material for the frame of the robotic arm. The second level in the hierarchy is constituted by the criteria: Strength, Density, Young's Modulus, and Cost. The third level consists of the available alternatives. In this case: Wood, Plastic and Metal.

The advantages of this hierarchical decomposition are clear. By structuring the problem in this way it is possible to better understand the decision to be achieved, the criteria to be used and the alternatives to be evaluated. This step is crucial and this is where, in more complex problems, it is possible to request the participation of experts to ensure that all criteria and possible alternatives have been considered. Also note that in complex problems it may be necessary to include additional levels in the hierarchy such as sub-criteria.

Table 3: Pair-wise comparison matrix with intensity judgments

Selection of material	Strength	Density	Young's Modulus	Cost
Strength	1.00	2.00	3.00	2.00
Density	0.50	1.00	2.00	2.00
Young's Modulus	0.33	0.50	1.00	0.50
Cost	0.50	0.50	2.00	1.00

Table 4: Normalized Matrix

Selection of material	Strength	Density	Young's Modulus	Cost	Priority
Strength	0.429	0.500	0.375	0.364	**0.417**
Density	0.215	0.250	0.250	0.364	**0.270**
Young's Modulus	0.141	0.125	0.125	0.091	**0.121**
Cost	0.215	0.125	0.250	0.181	**0.193**

Calculation the λ_{max}

$$\boldsymbol{\lambda_{max}} = \text{average}\left\{\frac{1.704}{0.417} \quad \frac{1.105}{0.270} \quad \frac{0.489}{0.121}\frac{0.777}{0.193}\right\}$$

$$= 4.068$$

Consistency index (CI)

$$CI = \frac{\lambda_{max}-m}{m-1}$$

$$= \frac{(4.068 - 4)}{3}$$

$$= \mathbf{0.023}$$

Consistency ratio (CR)

$$CR = \frac{CI}{RI}$$

$$= \frac{0.023}{0.88}$$

$$= \mathbf{0.026}$$

Since this value of **0.026** for the proportion of inconsistency CR is less than 0.10 which is acceptable

Table 5: Comparison of Robotic arm material with respect to Strength

Strength	Wood	Plastic	Metal	Priority
Wood	1.00	0.33	0.25	**0.123**
Plastic	3.00	1.00	0.50	**0.320**
Metal	4.00	2.00	1.00	**0.557**

Table 6: Comparison of Robotic arm material with respect to Density

Strength	Wood	Plastic	Metal	Priority
Wood	1.00	0.33	0.50	**0.170**
Plastic	3.00	1.00	1.00	**0.443**
Metal	2.00	1.00	1.00	**0.387**

Table 7: Comparison of Robotic arm material with respect to Young's Modulus

Strength	Wood	Plastic	Metal	Priority
Wood	1.00	3.00	0.50	**0.320**
Plastic	0.33	1.00	0.25	**0.123**
Metal	2.00	4.00	1.00	**0.557**

Table 8: Comparison of Robotic arm material with respect to Cost

Strength	Wood	Plastic	Metal	Priority
Wood	1.00	0.25	0.20	**0.623**
Plastic	3.00	1.00	0.33	**0.239**
Metal	5.00	3.00	1.00	**0.137**

Table 9: Comparison of Local Priorities (or preferences) of the alternatives with respect to each criterion

Alternatives	Strength	Density	Young's Modulus	Cost
Wood	**0.123**	**0.170**	**0.320**	**0.623**
Plastic	**0.320**	**0.443**	**0.123**	**0.239**
Metal	**0.557**	**0.387**	**0.557**	**0.137**

Overall Priority of the Wood:
0.123x0.417+0.170x0.270+0.320x0.121+0.623x0.193= 0.26

Overall Priority of the Plastic:
0.320x0.417+0.443x0.270+0.123x0.121+0.239x0.193= 0.31

Overall Priority of the Metal:
0.557x0.417+0.387x0.270+0.557x0.121+0.137x0.193= 0.43

In other words, given the importance of each selection criteria (strength, density, Young's Modulus and cost), the Metal is preferable (overall priority = 43%) compared to the Plastic (overall priority = 31%) and Wood (overall priority = 26%).

8. RESULTS AND DISCUSSION

Based on the data from above Tables and the criteria and sub-criteria under consideration, pairwise comparison matrices have been developed for criteria versus criteria with respect to the goal, sub-criteria verses sub-criteria with respect to the respective criterion. The outcome of all these pairwise comparison matrices is to obtain a priority vector of the criteria with respect to goal and priority vectors of sub-criteria with respect to the criterion. Each selection criteria (strength, density, Young's Modulus and cost), the Metal is preferable (overall priority = 43%) compared to the Plastic (overall priority = 31%) and Wood (overall priority = 26%).

It is clear that alternative Metal has the highest priority value, and it is ranked number one.

9. CONCLUSION

The aim of this paper is to solve the selection of material for the frame of robotic arm problem using multi-criteria decision- making (MCDM) methods, AHP for a given industrial application. In conclusion, standard steel sheet metal was selected for the material of choice for the robot frame. Because the steel frame has very high strength, high modulus of elasticity, relatively lightweight and easily available in the hardware store.

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