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Material Selection of flywheel under optimization Environment Using Multi Criteria Decision Making: A Comparative Study

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Abstract

Flywheel attached to a rotating shaft for smooth delivery of power from motor to a machine. It is used to store rotational energy that is proportional to the square of its rotational speed. Material selection plays an important role in an effective manufacturing system for better product development. Proper decision methodology reduces personal bias and it should be coded into the software. This research venture deals with material selection of flywheel in decision environment.

Keywords: Flywheel, Material selection, TOPSIS,MOORA, Entropy, Sensitivity analysis

1. Introduction

Over the years, selection of materials plays a crucial role for value addition in production, cost optimization, better product development and improve productivity. Flywheel is an important machining component. In this paper, optimization theory is applied for right selection of flywheel manufacturing process.

1.1 Multi Criteria Decision Making (MCDM)

Multiple criteria decision making (MCDM) is the process of selecting the best alternative from a set of feasible alternatives considering multiple conflicting criteria. In precise terms criteria are considered to be 'strictly' conflicting if the increase in satisfaction of one result in a decrease in satisfaction of the other. An MCDM process always contains at least two alternatives and two conflicting criteria (Bhattacharya et al., 2003). MCDM are divided two broad categories: Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM). Several useful tools for solving of MCDM problems are

- Simple Additive Weighting method (SAW)
- Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)
- Multi Objective Optimization Ratio Analysis (MOORA)
- Analytical Hierarchy Method (AHP)
- Analytical Network Method ANP etc.

1.2 Entropy

OriginallyEntropy is a thermodynamic concept,first introducedby Shannon.It has been widely used in the engineering, socioeconomic and other fields. According to the basic principles of information theory, information is a measure of system's ordered degree, and the entropy is a measure of system's disorder degree.

Step1 Calculate p_{ij} (the i_{th} scheme's j_{th} indicator value's proportion).

$p_{ij} = r_{ij} / \sum_{j=1}^{m} = r_{ij}$, $r_{ij}$is the i_{th} scheme's j_{th} indicator value

Step2 Calculate the jth indicator's entropy value becomes

ej.ej= $-k \sum_{j=1}^{m} pij \ln p_{ij}$, k=1/ln m, m is the number of assessment schemes.

Step3 Calculate weight w_j (j_{th} indicator's weight).

$w_j=(1-e_j) / \sum_{j=1}^{m}(1-ej)$,n is the number of indicators, and $0 \le w_j \le 1$,$\sum_j^m w_j=1$

In entropy method, the smaller the indicator's entropy value ej is, the bigger the variation extent of assessment value of indicators is, the more the amount of information provided, the greater the role of the indicator in the comprehensive evaluation, the higher its weight should be.

1.3Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is an evaluation method that is often used to solve MCDM problems.
It has a number of applications in practice, such as comparison of company performances, financial ratio performance within a specific industry and financial investment in advanced manufacturing systems, etc. However, there are also some limits to it. So far,the work on how to improve original TOPSIS method has mainly emphasized on improving the weight to sensitize the *R* value. Besides, there has also been improvement on formula of the *R* value, such as the ‘Miqiezhi’ method. Because of the complexity of evaluation problems, a better and simpler method is required to understand the inherent relationship between the *R* value and alternative evaluation. In this report, a novel, modified TOPSIS (M-TOPSIS) method is described as a process of calculating the distance between the alternatives and the reference points in the *D*+ *D*−-plane and constructing the *R* value to evaluate quality of alternative.

- **Algorithm of TOPSIS method under MCDM**

The idea of TOPSIS can be expressed in a series of steps:
Step1 All the original criteria receive tendency treatment. We usually transform the cost criteria into benefit criteria, which is shown in detail as follows;
(i) The reciprocal ratio method ($X_{ij}= 1/X_{ij}$), refers to the absolute criteria;
(ii) The difference method ($X_{ij}= 1 - X_{ij}$), refers to the relative criteria.
After tendency treatment, construct a matrix

$$X' = [X'_{ij}]_{n\times m}, i = 1, 2 \ldots, n; \quad j = 1, 2 \ldots, m. \tag{2.1}$$

Step2 Calculate the normalized decision matrix A. The normalized value *aij*is calculated as

$$\mathbf{A} = [a_{ij}]_{n\times m},\ a_{ij} = X'_{ij} / \sqrt{\sum_{i=1}^{n} (X'_{ij})^2} \quad i = 1, 2 \ldots, n; \quad j = 1, 2 \ldots, m. \tag{2.2}$$

Step3 Determine the positive ideal and negative ideal solution from the matrix *A*.

$$\mathbf{A}^+ = (a_{i1}^+, a_{i2}^+, \ldots, a_{im}^+), a_{ij}^+ = \max_{1\leqslant i\leqslant n}(a_{ij}), \quad j = 1, 2 \ldots, m \tag{2.3}$$

$$\mathbf{A}^- = (a_{i1}^-, a_{i2}^-, \ldots, a_{im}^-), a_{ij}^- = \min_{1\leqslant i\leqslant n}(a_{ij}), \quad j = 1, 2 \ldots, m \tag{2.4}$$

Step4 Calculate the separation measures, using the *n*-dimensional Euclidean distance. The separation of each alternative from the positive ideal solution is given as:

$$D_i^+ = \sqrt{\sum_{j=1}^{m} W_j (a_{ij}^+ - a_{ij})^2} \tag{2.5}$$

Similarly, the separation from the negative ideal solution is given as

$$D_i^- = \sqrt{\sum_{j=1}^{m} W_j (a_{ij}^- - a_{ij})^2} \tag{2.6}$$

Step5 For each alternative, calculate the ratio Ri as:

$$R_i = \frac{D_i^-}{D_i^- + D_i^+} \quad i = 1, 2 \ldots, n \tag{2.7}$$

Step6 Rank alternatives in increasing order according to the ratio value of *Ri* in step5.

1.4Multi Objective Optimization Ratio Analysis (MOORA)

The MOORA method which was introduced by Brauers (Brauers, 2006) is such a multi objective optimization technique that can be successfully applied to solve various types of MCDM problems.

- **Algorithm of MOORA method under MCDM**

The MOORA method starts with a matrix of responses (performance measures) of different alternatives on different criteria (objectives or attributes). The matrix is shown below (Equation 1).

$$\begin{matrix} & & C_1 & \cdots & C_j & \cdots & C_n \end{matrix}$$

$$X = \begin{matrix} A_1 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix} \quad (6)$$

Where x_{ij} is the performance rating (response) to the *i*th alternative (A_i) under *j*th criterion (C_j). *m* isthe number of alternatives and *n* is the number of criteria.

The MOORA method employs a ratio system in which each response of an alternative on an attribute (criterion) is compared to a denominator. The denominator is a representative for all alternatives concerning that attribute (Brauers et al. 2007; Kalibatas and Turskis, 2008).
Brauers et al. (2008) considered various ratios such as the square root of the sum of squares of each alternative per objective, total ratios, Scharlig ratios, Weitendorf ratios, Jutter ratios, Stop ratios, Van Delft and Nijkamp ratios of maximum value, Korth ratios, Peldschus*et al*. and Peldschus ratios for nonlinear normalization. They concluded that the square root of the sum of squares of each alternative per objective is the best one for the denominator which is given below.

$$x_{ij}^* = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} \left(x_{ij}^2 \right)}} \quad (7)$$

x_{ij}^* is normalized value of response *i* with respect to attribute *j*. In the current research work, the maximum score under each attribute has also been used as the denominator of the ratio system and an effort has been made to exhibit that this ratio system is also suitable for finding the optimal solution. The following ratio system is the second best for normalization process in MOORA.

$$x_{ij}^* = \frac{x_{ij}}{\max_i \left(x_{ij} \right)} \quad (8)$$

For the computation of normalized response using the above Eq. (2b), first the maximum score under each attribute is found. Then all the scores under certain attribute irrespective of benefit or non-benefit are divided by the concerned maximum score using Eq. (2b). x_{ij}^* is a dimensionless quantity in the interval [0,1] representing the normalized score of alternative *i*on attribute *j*. However, sometimes the interval could be [-1; 1]. For example in the case of productivity growth of some factories, industries, sectors, regions or countries may be negative instead of positive thus the interval becomes [-1;1] (Brauers*et al.*, 2008).
For multi-objective optimization these normalized performances are added in case of maximization and subtracted in case of minimization. Then the optimization problem becomes

$$y_i^* = \sum_{j=1}^{g} x_{ij}^* - \sum_{j=g+1}^{n} x_{ij}^* \quad (9)$$

Where *g* is the number of benefit criteria to be maximized and *(n-g)* is the number of non-benefit criteria to be minimized. y_i^* is final score of i^{th} alternative with respect to all the attributes. In the above case it is assumed that all the attributes are of same importance.

$$y_i^* = \sum_{j=1}^{g} w_j * x_{ij}^* - \sum_{j=g+1}^{n} w_j * x_{ij}^* \quad (10)$$

Where w_j^* is the weight of jth attribute (criterion), which can be evaluated using any well-known approach either AHP or Entropy method. The value of y_i^* may be positive, negative or zero. These y_i^* values are arranged in descending order. The best alternative is one which is associated with highest y_i^* value and the worst alternative is one which is associated with the lowest y_i^* value.

1.5 Sensitivity Analysis

Introduction of sensitivity analysis

In actual situation decision-making is rather dynamic process not static. It varies in the continuous changing environment. In reality the value of decision making attitude depends upon decision maker's personal choice. Under such circumstances decision making attitude behaves as a variable that may yield different results. Keeping it in mind, the proposed model for the selection of material has been enhanced by sensitivity analysis to provide a readymade solution of the current problem under variable decision making attitude. The governing equation of the material measure (MM) is given by

$$MM_i = \alpha\left(OFM_i - SFM_i\right) + SFM_i$$

where, i = 1, 2…m.

OFM_i= Objective factor measure for the alternative i

SFM_i= Subjective factor measure for the alternative i

α = Objective factor decision weight/Coefficient of attitude

Problem Definition

An organization has got 5 different materials with different specifications for flywheel. The decision maker considered 6 selection criteria. The materials are as follows

Table-01

The selection criteria are as follows:

C1	Density (g/cm^3)
C2	Hardness (BHN)
C3	Young's modulus (GPa)
C4	Bulk Modulus (GPa)
C5	Poisson's ratio
C6	Cost (INR) Per kg

Table-2

SL NO	MATERIAL GRADE
Material-01	Carbon steel 1065
Material-02	Alloy steel AISI 4340
Material-03	Maraging steel 18NI
Material-04	Alloy steel AISI E9310
Material-05	Stainless steel

Out of 6 criteria, 4 criteria viz. C2:Hardness (Bhn), C3: Young's modulus (GPa),C4: Bulk Modulus (GPa),C5: Poisson's ratio are beneficial criteria because their higher values are desirable and remaining viz. C1: Density (g/cm^3) C7: Cost (INR) Per kg are non-beneficial criteria because their lower values are desirable.

The objective of the decision maker is to assess the performance of the materials. Counseling the above 6 criteria to ultimately select the best material. The decision maker applied TOPSIS and MOORA methods for their simplicity, adaptability, applicability and is of applications. The decision matrix for the materials with respect to the criteria shown below:

Table-3

Computational result by MATLAB:

Material	**Grade**	**Density (g/cm^3)**	**Hardness (BHN)**	**Young's modulus (GPa)**	**Bulk Modulus (GPa)**	**Poisson's ratio**	**Cost (INR) Per kg**
Material-01	Carbon steel 1065	7.85	187	210	140	0.28	55
Material-02	Alloy steel AISI 4340	7.85	217	196	140	0.29	110
Material-03	Maraging steel 18NI	8.1	290	210	160	0.30	1850
Material-04	Alloy steel AISI E9310	7.85	241	190	140	0.27	90
Material-05	Stainless steel	7.75	219	190	134	0.26	180

2.1 Entropy Method:

RESULT:

Table-4

ENTROPY METHOD						
criteria	C_1	C_2	C_3	C_4	C_5	C_6
weighted values	0.1074	0.1164	0.1097	0.1119	0.1139	0.4407

2.2 MOORA METHOD:

RESULT:

STEP 1 Determination of normalized decision matrix

0.4455	0.3584	0.4710	0.4376	0.4466	0.0295
0.4455	0.4159	0.4396	0.4376	0.4626	0.0590
0.4596	0.5558	0.4710	0.5001	0.4785	0.9920
0.4455	0.4619	0.4261	0.4376	0.4307	0.0483
0.4398	0.4198	0.4261	0.4188	0.4147	0.0965

STEP 2 Determination of weighted normalized decision matrix

0.0479	0.0417	0.0516	0.0490	0.0509	0.0130
0.0479	0.0484	0.0482	0.0490	0.0527	0.0260
0.0494	0.0647	0.0516	0.0560	0.0545	0.4372
0.0479	0.0538	0.0467	0.0490	0.0490	0.0213
0.0473	0.0489	0.0467	0.0469	0.0472	0.0425

STEP 3: Determination of weighted multi objective optimization

The value of a ......sum of all weighted normalized values for all beneficial column

0.1902
0.1934
0.2217
0.1973
0.1897

The value of b ......sum of all weighted normalized values for all non-beneficial column

0.0639
0.0787
0.4917
0.0703
0.0898

STEP 4: the value of a-b
0.1263 0.1148 -0.2700 0.1270 0.0999
STEP 5
Arranging the final value (a-b) in descending order :--------->>>M4>M1>M2>M5>M3

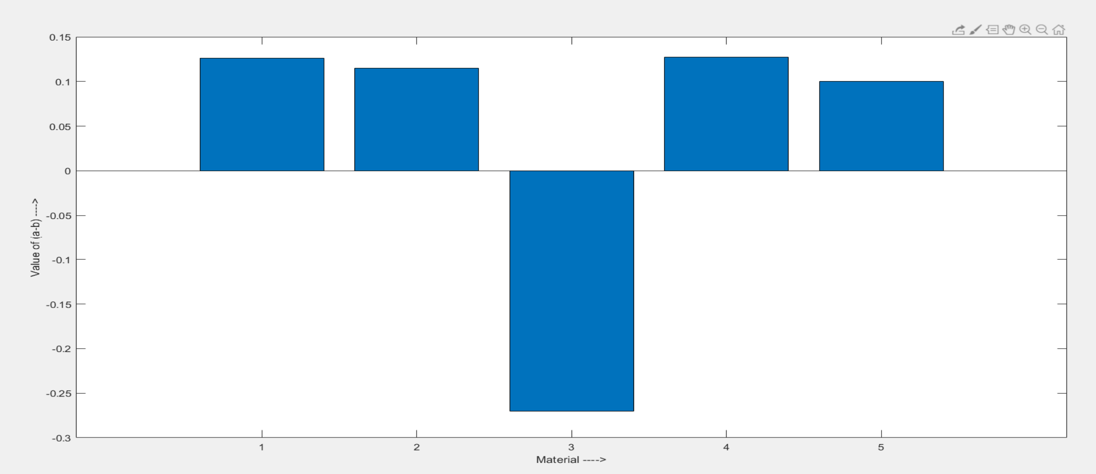

Fig:01

2.3 To determine the sensitivity analysis graph by MOORA:
The value of closeness co-efficient in MOORA method
when alpha=0 , when alpha=1

-0.0639	0.1902
-0.0787	0.1934
-0.4917	0.2217
-0.0703	0.1973
-0.0898	0.1897

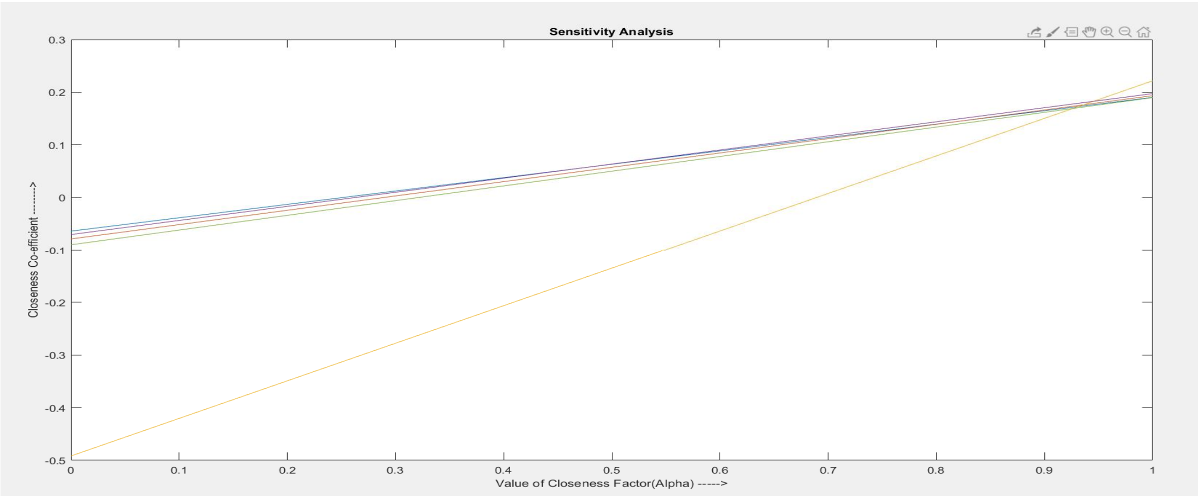

Fig:02

2.4 TOPSIS method

The weighted values are:

0.1074, 0.1164, 0.1097, 0.1119, 0.1139, 0.4407

The weighted values got from entropy method

STEP1: Determination of normalized decision matrix

0.9691	0.6448	1.0000	0.8750	0.9286	1.0000
0.9691	0.7483	0.9333	0.8750	0.8966	0.5000
1.0000	1.0000	1.0000	1.0000	0.8667	0.0297
0.9691	0.8310	0.9048	0.8750	0.9630	0.6111
0.9568	0.7552	0.9048	0.8375	1.0000	0.3056

STEP 2:

Determination of positive ideal solution: taking the maximum values of each column from the normalized decision matrix

1 1 1 1 1 1

Determination of negative ideal solution: taking the minimum values of each column from the normalized decision matrix

0.9568 0.6448 0.9048 0.8375 0.8667 0.0297

STEP 3:

Calculation of the separation measure from the positive ideal solution(di_Plus)

0.1308
0.3480
0.6457
0.2701
0.4729

Calculation of the separation measure from the negative ideal solution (di_Minus)

0.6454
0.3148
0.1372
0.3927
0.1923

STEP 3: Calculation of R_i

0.8315 0.4749 0.1753 0.5925 0.2890

STEP 4:

Arranging the final value in descending order: --------->>>M1>M4>M2>M5>M3

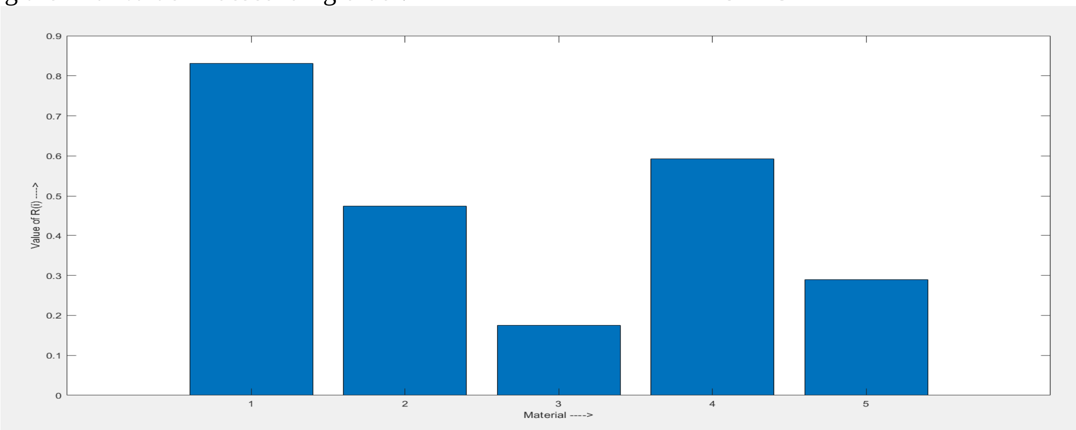

Fig:03

2.5 Comparative analysis of ranking of flywheel materials using MCDM methods

Table-5

MATERIAL	MOORA (RANK)	TOPSIS (RANK)
M1	2	1
M2	3	3
M3	5	5
M4	1	2
M5	4	4

3. Conclusion:

The use of TOPSIS and MOORA methods are inspected to be quite capable and computationally easy to appraise and select the proper material from a given set of alternatives. These methods use the measures of the considered criteria with their relative importance in order to arrive at the final ranking of the alternative flywheelMaterials. We have used the MATLAB, by this software we can also make rank of any system for any number of alternatives and criteria within a fraction of second with accuracy. Thus, these popular MCDM methods can be successfully employed for solving any type of decision-making problems having any number of criteria and alternatives in the manufacturing domain. In this study, cost is an important key issue in material selection. For a product development, cost optimization is necessary.

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