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12th GLOBAL CONGRESS ON MANUFACTURING AND MANAGEMENT, GCMM 2014

Design, Development and Implementation of a Robust Decision Support Expert System (branDEC) in Multi Criteria Decision Making

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Abstract

In today's dynamic business scenario, in order to sustain within the global turmoil, decision plays a pivotal role. Today's market is completely driven with the choice of the consumer or the end user and toprolong this unprecedented uproar an adroit, firm and stable decision has to be taken. To acclimatize with the changing scenario, the situation demands for development of an expert system to expedite the decision making activity. Advent in MCDM (Multi Criteria Decision Making) techniques diffused with high end mathematical sub-layers isserving this purpose for the past decade. Literature survey reveals lack of availability of a robust expert system encompassing a numerous MCDM techniques, normalization techniques and weight determination techniques. Therefore this project is to mitigate this paucity and to develop a decision support expert system **branDEC-V:1R:1** [bran is an eponym derived by taking the first letter of the authors name and DEC is short form of"decision"]which can simultaneously harness all the existing offline MCDM methods and which make a decision avoiding time and computational complexity.
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*Keywords:*MCDM techniques;decision support expert system; aggregated/group decision making.

1. Introduction

For the couple of years MCDM has become the thrust area of research for dealing with complex decision making problems. The MCDM methodology can be envisaged as a non-linear recursive process comprising the

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doi:10.1016/j.proeng.2014.12.339

following steps [1]: a) structuring the decision problem, b) articulating and modelling the preferences, c) aggregation of the alternative's preferences and d) making recommendations.

Structuring the DMS (decision making situation) appears to be an important step to infer a decision. This step includes the determination and the assessment of the stakeholders, the different alternatives, the consequences, the important aspects (criteria), the quality and the quantity of the information, etc. Existing methodologies pertinent to MCDM techniques in primarily based on twofold steps: construction and exploitation [2].

1.1. Philosophy and elements of MCDM

Multi-Criteria Decision Making (MCDM) is one of the most well known branches of decision making. MCDM is primarily divided into multi-objective decision making (MODM) and multi-attribute decision making (MADM)[3]. However, very often the terms MADM and MCDM are used to mean the same class of models. MODM studies decision problems in which the decision space is continuous having an objective function. On the other hand, MCDM/MADM concentrates on problems with discrete decision spaces in which the set of decision alternatives are predetermined [4]. Although different MCDM methods may have diverse protocols and stature; they all posed with certain common features. These common features include alternatives and attributes (decision criteria) [5].Usually alternatives entail a spectrum of different choice of desire duly available to the decision maker. For the present investigation the alternatives is assumed to be finite,ranging from several to hundreds wherein they all are supposed to be assessed, evaluated, and eventually ranked.Criteria represent the different adjudging measure with respect to which alternatives are adjudged from the suitability point of view. Decision weights play a pivotal role in MCDM problems, since the ultimate adjudging means (score, closeness coefficient, selection index etc.) is a function of weights of criteria present in the decision making problem. One can easily make the decision making problem biased by imparting more weightages to the intended criteria. Now a day's many emergent techniques have evolved to generate criteria weights from the discrete data.Decision matrix refers to an array which entails elements corresponding to performance of an alternative with respect to a particular criterion. Usually this is static in nature, for dynamic decision making problems the elements become time variant and eventually the choice of alternative may vary from time to time. The scope of the present project does not cover up the online decision making rather it deals with the static or offline counterpart. The constructional feature of a decision matrix has been addressed in.

1.2. Decision making framework

The present work encompasses design and implementation of an expert system which can cope and handle simultaneously a number of alternatives, criteria (ordinal and cardinal), available normalization techniques, weight determination techniques (singular, integrated and customized). In addition to these, to yield singular decision as well as group decision provisions have been made. The entire frame work has been shown in Fig.1.

1.3. Objective

Literature survey reveals that for individual decision making method, application software are readily available in both online and offline modes. Application software mostly lagging with a platform, where the decision maker can select a particular method to solve decision making problems. Therefore the objective of the present investigation is to develop a computer assisted decision aiding tool encompassing standard decision making methodologies to make decision by avoiding time and computational complexity. To achieve the same the following steps are followed:

- To extract and formulate decision making problems under deterministic utopian condition.
- To formulate and generate alternatives with regard to particular problem and to implement it.
- To Formulate and generate criteria which are either ordinal or cardinal in nature and to implement it.
- To formulate and implement suitable normalization techniques pertaining to different decision making methodologies.
- To implement different intelligent techniques to find out criteria weights as well as to make provision for customized (user driven) weights.
- To provide the option for decision making by individual method.
- To provide the option for group decision making through combination of decision outcomes of individual method.

- To validate the consistency of ranks achieved by one method by the others.

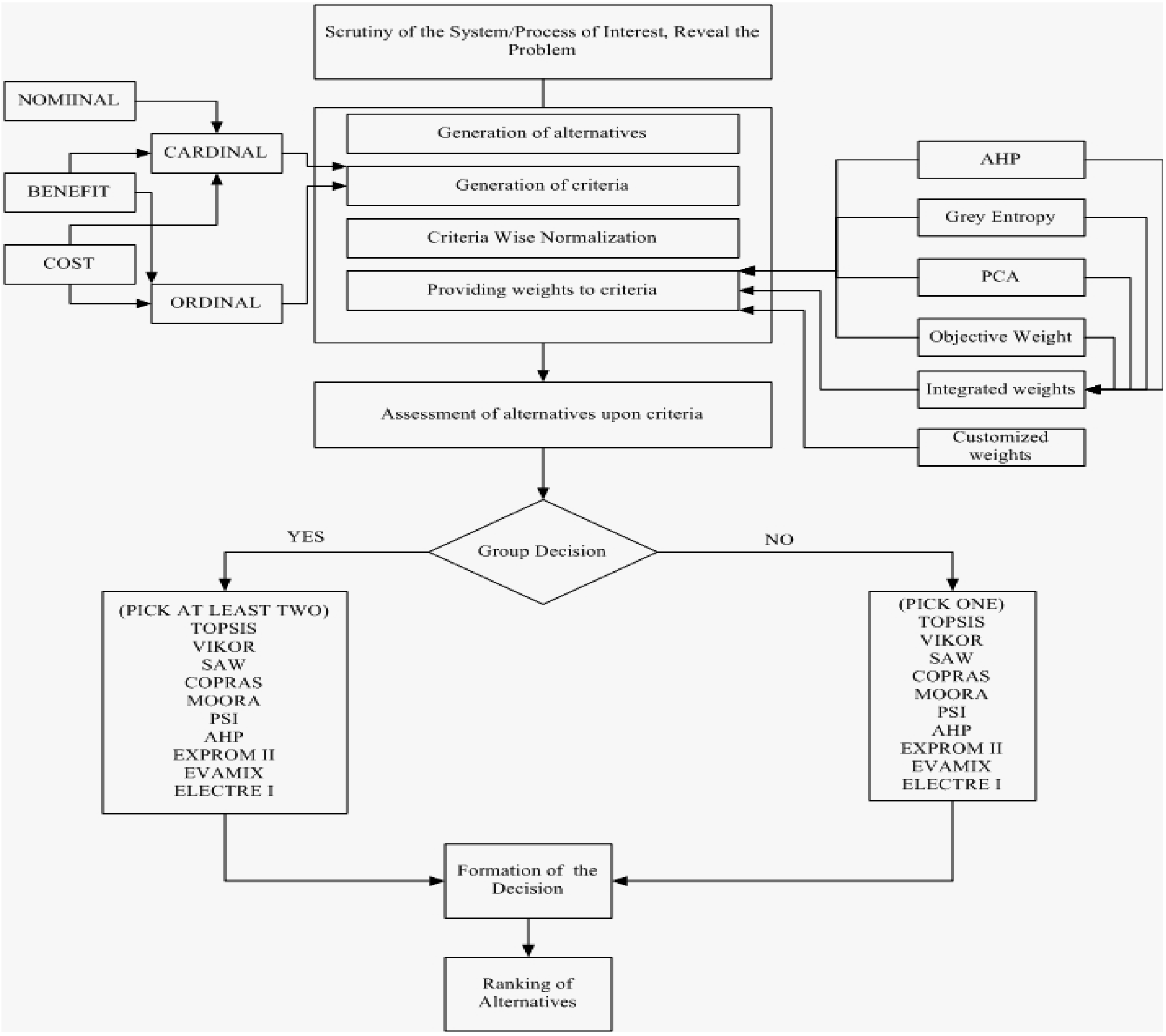


Fig. 1.Framework of the expert system.

2. MCDM problem formulation

2.1. Decision matrix

For MCDM problem, let $\boldsymbol{A} = \{A_1, A_2........A_m\}$ $(m \geq 2)$ be a discrete set of ***'m'*** feasible Alternatives, and **C** $= \{C_1, C_2........C_n\}$ be a finite set of Criteria's. Let, $M = \{1,2,..i,..., m\}$, $N = \{1,2,...j,..,n\}$; $i \in M$, $j \in N$. If *'m'* alternatives are evaluated with respect to the *'n'* Criteria, whose values constitute a decision matrix is denoted the following decision matrix as shown in accordance with Eq.(1).

$$\begin{array}{c|ccccc} & C_1 & \cdots & C_j & \cdots & C_n \\ \hline A_1 & x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ A_i & x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ A_m & x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{array} \quad (1)$$

Over the past three decades researchers over the globe have contributed significantly to developed different methodologies to solve multi criteria decision making problems. For the present investigation the authors have made an attempt to develop an expert system, obviously encompassing the existing methodologies by harnessing them in a nutshell to mitigate the computational time and related ambiguities. This paper encompasses design, development, implementationand validation of a decision aiding software which includes decision making methods like, AHP[6],TOPSIS[5,7,8],VIKOR[9,10,11,12,13,14,15], SAW[16], COPRAS[17,18,19],MOORA[20], PSI[21],EXPROM-II[22,23], EVAMIX[18,24] and ELECTRE-II[25] followed by different normalization as well as weight determination techniques at all possible combinations under the same platform.

2.2. Criteria weight determination techniques

To determine the relative weightages for different criteria several weight determination techniques were adopted. Weights were generally achieved through:*a)*analytical hierarchy process[6]*b)* entropy method [23]*c)* principal component analysis [26,27,28]*d)* grey entropy method[29]*e)* variance based objective weight[30] and *f)*weights by aggregation orintegration [23]. In order to find the relative importance through analytical hierarchy process pair-wise comparisons of the criteria are done abiding a scale of relative importance that measures intangible aspects in relative terms [6].Also it can measure the inconsistency and improve the judgments.Entropy measures the randomness and uncertainty in the information using probabilistic approach. This yields to a notion that, broad distribution fetches more uncertainty than a narrow variation and owes to more weightages [23]. Principal component analysis is an adroit statistical tool to convert multi indicators to several composite ones [26, 27]. PCA can simplify this phenomenon by dimension reduction to find out uncorrelated composite factors that reflect original information as much as possible to represent all the original variables[28].Wen et al. [29] proposed the mapping function in grey entropy and defined a monotonic increasing mapping function for grey entropy measure. The statistical variance is the backbone for determination of the objective weights of importance of the attributes in MCDM problem as revealed in[30].

2.3. Normalization methods

In the initial decision matrix, the elements $\mathbf{x_{ij}}$[Eq. (1)] are subjected to different units as well as scales of magnitudes. In order to mitigate the problems associated with different units and scales they are intended to make unit less by normalization and comparable sequences are generated. There are several pre-processing techniques adopted by different researchers over the globe according to their convenience to solve MCDM problems.

2.4. Quantization of ordinal criteria

In order to decipher the linguistic terms to their corresponding fuzzy numbers, an 11- point (eleven) scale was adopted by Rao and Patel [30], for better understanding and representation of the qualitative or ordinal criteria values, which has been shown in Table 1.

Table 1. Eleven-point fuzzy linguistics conversion scale [30]

Linguistic Quality factors	Assigned values
Exceptionally low	0.045
Extremely low	0.135
Very low	0.255
Low	0.335
Below average	0.410
Average	0.500
Above average	0.590
High	0.665
Very high	0.745
Extremely high	0.865
Exceptionally high	0.955

3. Software featuresand implementation

Owing to the objective and scope of the present work and relevant methodologies along with their pre-processing techniques which have already been addressed earlier, it is quite evident that, to implement the same, a proper object oriented technique is required to illustrate the user interface and outcomes in a synergistic manner in the design architecture which has already been addressed in Fig.1.The Expert System has been designed on PHP platform in view of web applications. In order to resolve and ascertain a decision in MCDM problems, the user has to provide the initial credentials i.e. number of alternatives, number of criteria. Among the criteria, some criteria are ordinal (qualitative) and other are cardinal (quantitative). Again the nature of the criteria may be beneficial (higher the best), pernicious (lower the best) and seldom targeted one (nominal the best). This nominal nature is not applicable for ordinal criteria. The option for way in of number of alternatives, number of criteria (both qualitative and quantitative) has been made in the expert system as illustrated in Fig.2.

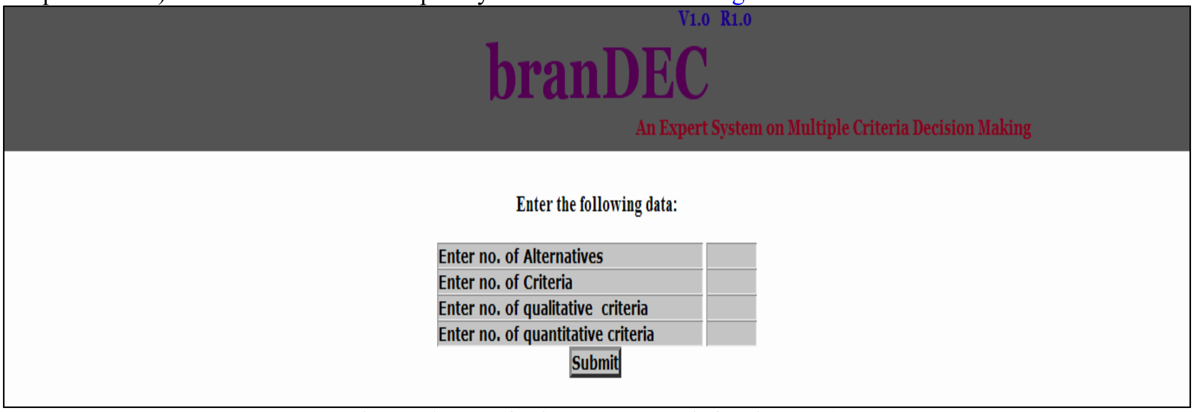


Fig. 2. Index page for the expert system (before data entry).

For better understanding of the employability of the expert system the authors adopted a MCDM problem cited by Jahan and Edward [32] for material selection during knee implantations. The material property criteria considered by them include Density, Tensile strength, Modulus of elasticity, Ductility, Corrosion resistance, Wear resistance and Osseo-integration ability. The target criteria are density and modulus of elasticity that is determined base on nearing to human bone. The other criteria are beneficial one that the higher is the better. This decision making problem encompasses ten (10) alternatives and seven (7) criteria. To form the decision matrix these two things seems to be the prerequisites. Again, out of the criteria three (Corrosion resistance, Wear resistance and Osseo-integration ability) belong to ordinal (qualitative) and four (Density, Tensile strength, Modulus of elasticity, Ductility) belong to cardinal (quantitative category). Furthermore, out of the quantitative criteria two (Density and Modulus of elasticity) demands for targeted value and the other two (Tensile strength, Modulus of elasticity, Ductility) are akin to benefit criteria. All the qualitative criteria belong to benefit criteria. Once the MCDM problem is scrutinized the user had to submit the numbers of alternatives and numbers and nature of criteria in the index page to generate the matrix to encompass the crisp values of the elements as shown in Fig 3.

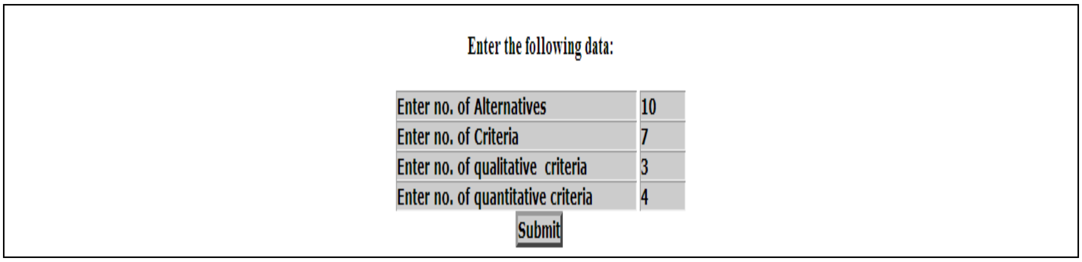


Fig. 3. Provision for ingresses in defining the decision matrix through expert system.

Provision has been made so that the user can change the name of the alternatives as well as criteria [Fig.4]. Once this part is over the imminent action is to define the nature of criteria for which options are available for both qualitative and quantitative criteria. For qualitative criteria options are categorized into either of higher-the-better (benefit) or lower-the-better (cost) illustrated in Fig.4. Whereas, for quantitative criteria three provisions are available; they are i) higher-the-better (benefit), ii) lower-the-better (cost) and iii) Target /nominal-the-better which have been depicted in Fig. 5.If any quantitative criteria deserves nominal-the-best feature then obviously the user has to incorporate the nominal or targeted value which has been shown in Fig 6.Once the natures of all criteria are finalized then the qualitative elements in the decision matrix are selected following the eleven point scale [Article 2.4]. This provision is made through a uni-select dropdown menu shown in Fig.7.

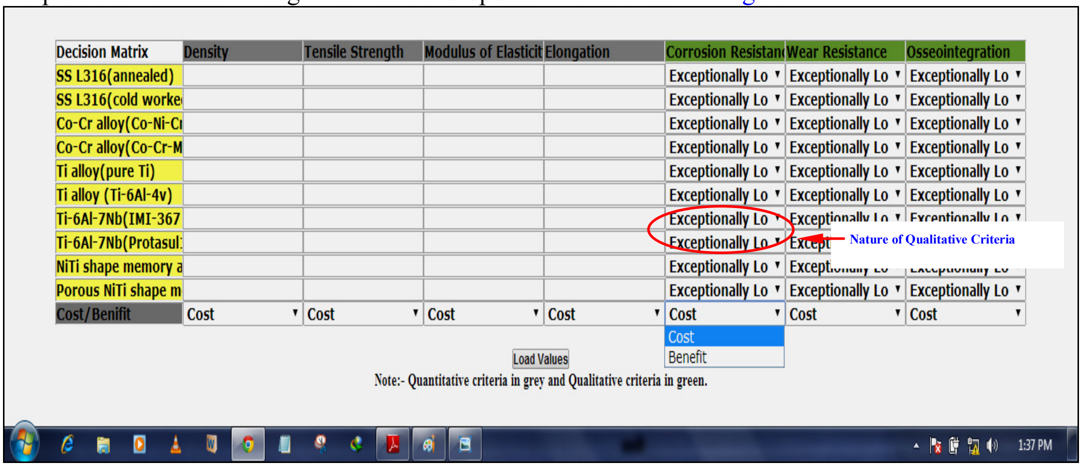


Fig.4. Provision for incorporation of nature of qualitative criteria.

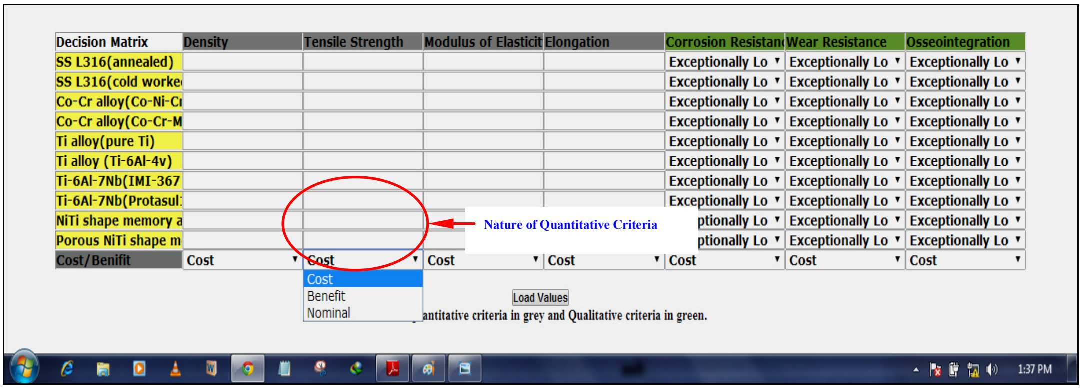


Fig. 5. Provision for incorporation of nature of quantitative criteria.

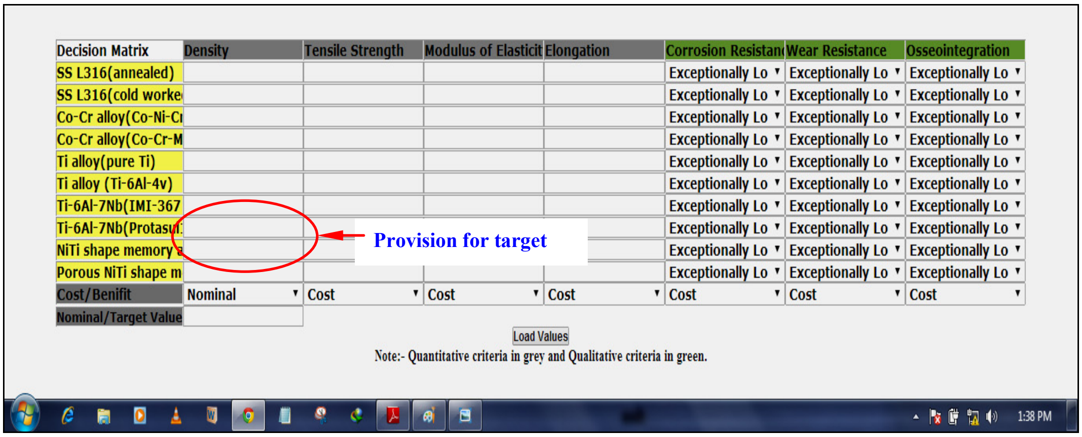


Fig. 6. Provision for incorporation of target/nominal value.

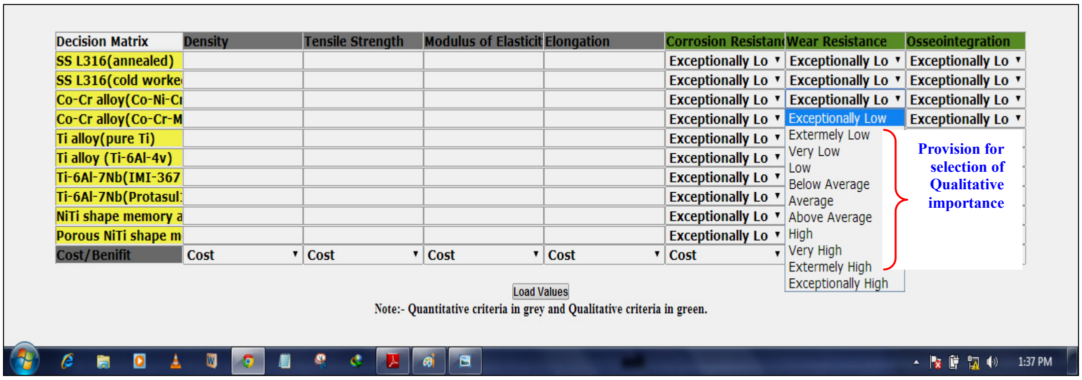


Fig. 7. Provision for incorporation of qualitative elements.

As the qualitative values chosen, in the hidden layer the expert system stores the corresponding crisp values according to Table 1. The next course of action is inclusion of crisp values for all quantitative criteria to accomplish the decision matrix as shown in Fig.8. For the present investigation all the qualitative and quantitative data were taken from Jahan and Edward [32].

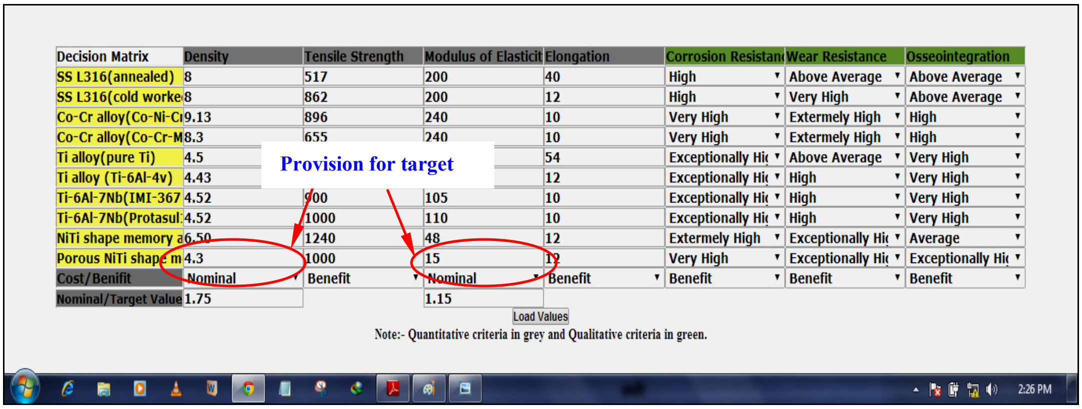
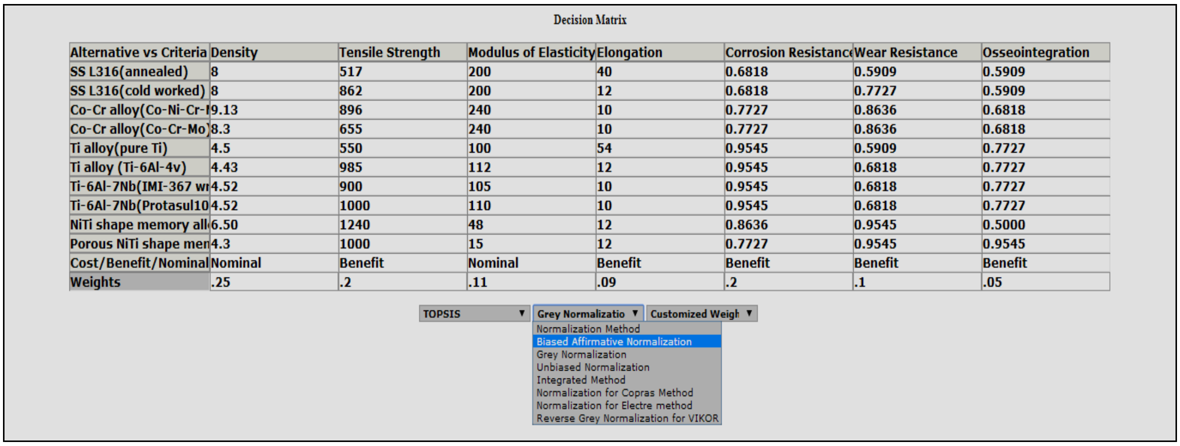


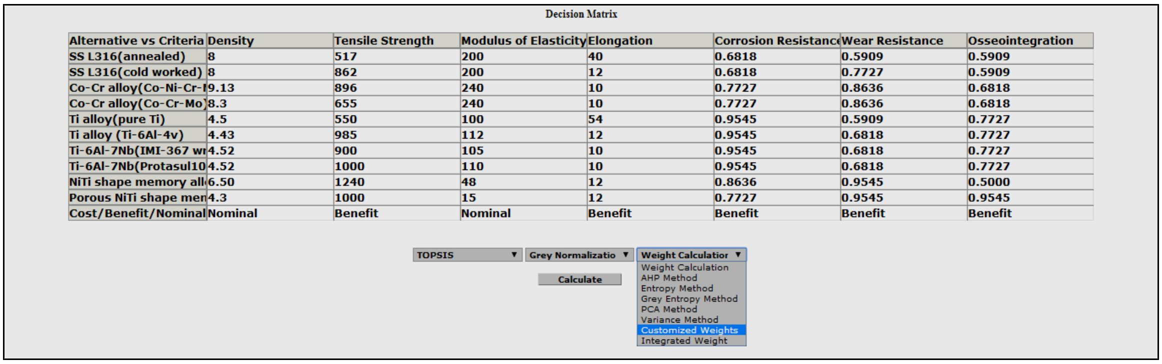
Fig.8. The decision matrix as per Jahan and Edward [32] including all entries.

Fig. 9. Provision for MCDM techniques selection.


Decision Matrix

Alternative vs Criteria	Density	Tensile Strength	Modulus of Elasticity	Elongation	Corrosion Resistanc	Wear Resistance	Osseointegration
SS L316(annealed)	8	517	200	40	0.6818	0.5909	0.5909
SS L316(cold worked)	8	862	200	12	0.6818	0.7727	0.5909
Co-Cr alloy(Co-Ni-Cr-	9.13	896	240	10	0.7727	0.8636	0.6818
Co-Cr alloy(Co-Cr-Mo	8.3	655	240	10	0.7727	0.8636	0.6818
Ti alloy(pure Ti)	4.5	550	100	54	0.9545	0.5909	0.7727
Ti alloy (Ti-6Al-4v)	4.43	985	112	12	0.9545	0.6818	0.7727
Ti-6Al-7Nb(IMI-367 w	4.52	900	105	10	0.9545	0.6818	0.7727
Ti-6Al-7Nb(Protasul10	4.52	1000	110	10	0.9545	0.6818	0.7727
NiTi shape memory all	6.50	1240	48	12	0.8636	0.9545	0.5000
Porous NiTi shape mer	4.3	1000	15	12	0.7727	0.9545	0.9545
Cost/Benefit/Nominal	Nominal	Benefit	Nominal	Benefit	Benefit	Benefit	Benefit
Weights	.25	.2	.11	.09	.2	.1	.05

Fig. 10. Provision for normalization method selection.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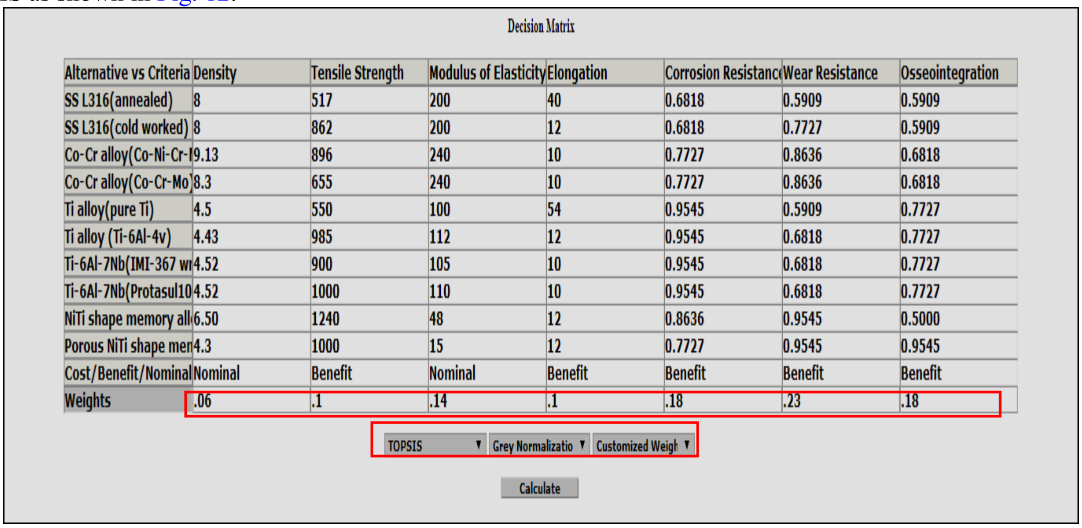
Cost/Benefit/Nominal	Nominal	Benefit	Nominal	Benefit	Benefit	Benefit	Benefit

Fig. 11. Provision for weighting techniques selection.

For the present investigation, the criteria weights have been taken as per Jahan and Edward [32] and incorporated in the expert system shown in Fig. 12. The decision making technique opted in solving this particular problem was TOPSIS as shown in Fig. 12.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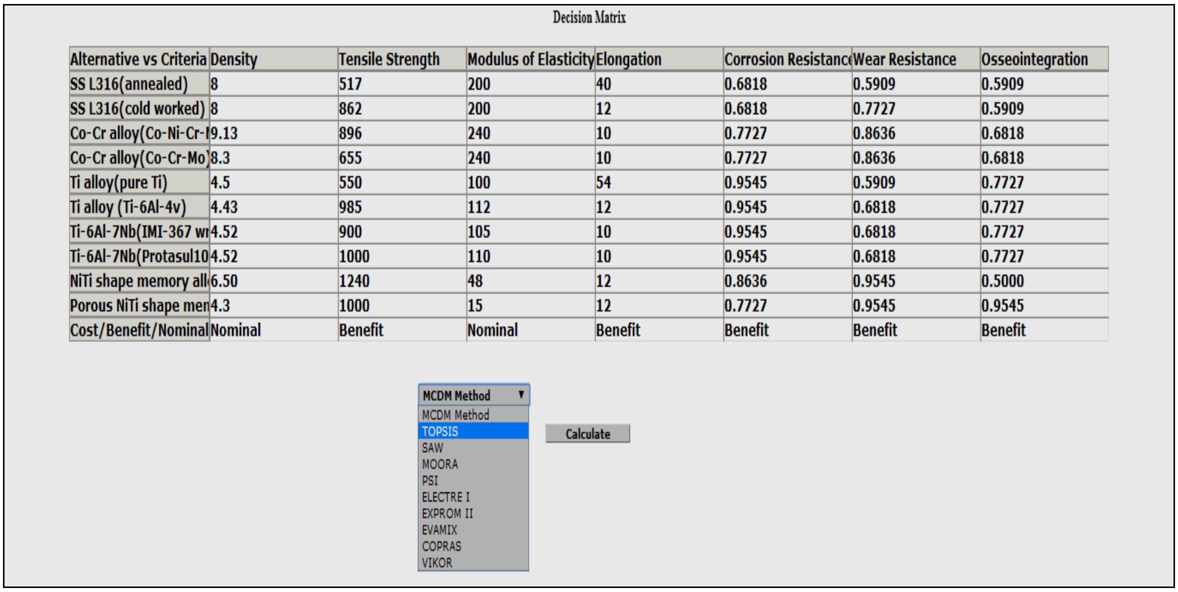
Cost/Benefit/Nominal	Nominal	Benefit	Nominal	Benefit	Benefit	Benefit	Benefit
Weights	.06	.1	.14	.1	.18	.23	.18

Fig. 12. Provision for customized weight incorporation.

Jahan and Edward [32] choose thetarget criteria values for density and modulus of elasticity tantamount to that of human bone. The nominal value for the density has been taken as 1.75 gm/cc and modulus of elasticity for subchondral bone as 1.15 GPa.To move forward the user has to select decision making method selection followed by selection of normalization method and obviously to choose one of the weighting which has been provided in the expert system in three different uni-select dropdown menu bars as shown in Fig. 9, Fig. 10and Fig. 11 respectively.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Cost/Benefit/Nominal	Nominal	Benefit	Nominal	Benefit	Benefit	Benefit	Benefit

Now on activating the "Calculate" button [Fig. 12] the expert system generates the score and rank as shown in Fig. 13. The rank through the expert system was 10>9>7>8>6>3>5>4>2>1 vis-à-vis the ranking by Jahan and Edward [32]was10>9>7>8>6>4>5>3>2>1which shows a rank correlation index of 98.79% and hence this expert system proves itself as a tool for solving multi criteria decision making problems.

Alternatives	Closeness Coefficient	Ranking
SS L316(annealed)	0.183813	10
SS L316(cold worked)	0.304711	9
Co-Cr alloy(Co-Ni-Cr-Mo)	0.452245	7
Co-Cr alloy(Co-Cr-Mo)	0.437537	8
Ti alloy(pure Ti)	0.485886	6
Ti alloy (Ti-6Al-4v)	0.523702	3
Ti-6Al-7Nb(IMI-367 wrought)	0.518360	5
Ti-6Al-7Nb(Protasul100 hot forged)	0.522920	4
NiTi shape memory alloy	0.584228	2
Porous NiTi shape memory alloy	0.681141	1

Fig. 13. Ranking by TOPSIS through the expert System.

4. Aggregated/ groupdecision making

One of the most interesting features of the expert system is that, while opting for particular MCDM techniques; simultaneously the same problem can be solved by other methods too. If a specific problem is solved by more than one method and if it is found that all the methods are giving the same result (means rank correlation ≥80%); it indirectly proves the suitability of those particular method.The expert system is poised with a provision to make group decision, where more than one method can participate in making a decision at the lower tier. The group decision maker then authenticates the consistency of one method with others by evaluating the rank correlation. Then group decision maker eliminates the upshot of the method/s which has/have less than 80% rank correlation.

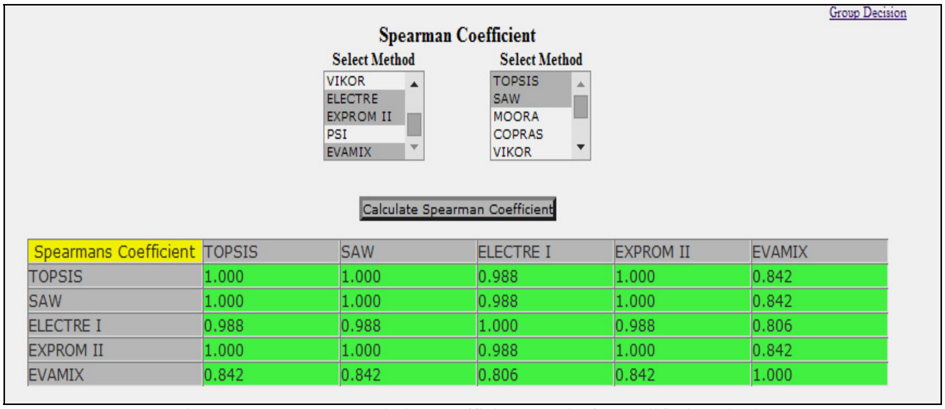
Then by eradicating the scores of defeated method/s and by aggregating the scores of the succeeding method/s the group decision is established by the group decision maker who is in the higher level. The expert system is endowed with provision to check the consistency of results through different methods by selecting multiple MCDM methods through multi select scroll boxes and can opt for the consistency check among selected methods as shown in Fig. 14. Once the intended methods are selected by clicking on the submit button entitled **"Calculate Spearman Coefficient"** one can determine the rank correlation for the selected methods as shown in Fig.15. In the matrix, combinations which are having a correlation value less than 80% have been represented with red colour whereas, the qualified elements are represented by green colour.For the present investigation except AHP all the methods were selected.

Fig.14. Provision for Consistency Check from Scroll Boxes.

Spearmans Coefficient	TOPSIS	SAW	MOORA	COPRAS	VIKOR	ELECTRE I	EXPROM II	PSI	EVAMIX
TOPSIS	1.000	1.000	0.806	0.782	0.455	0.988	1.000	0.079	0.842
SAW	1.000	1.000	0.806	0.782	0.455	0.988	1.000	0.079	0.842
MOORA	0.806	0.806	1.000	0.988	0.176	0.794	0.806	0.297	0.915
COPRAS	0.782	0.782	0.988	1.000	0.091	0.770	0.782	0.224	0.939
VIKOR	0.455	0.455	0.176	0.091	1.000	0.467	0.455	0.103	0.091
ELECTRE I	0.988	0.988	0.794	0.770	0.467	1.000	0.988	0.018	0.806
EXPROM II	1.000	1.000	0.806	0.782	0.455	0.988	1.000	0.079	0.842
PSI	0.079	0.079	0.297	0.224	0.103	0.018	0.079	1.000	0.067
EVAMIX	0.842	0.842	0.915	0.939	0.091	0.806	0.842	0.067	1.000

Fig.15Spearman's consistency correlation coefficient matrix.

Methods having rank correlation less than 80% are then eliminated through deselecting in scroll box to generate the correlation matrix for the qualified set as illustrated in Fig. 16. It is clear in the Fig.16 that the qualified methods are TOPSIS, SAW, ELECTRE I, EXPROM II and EVAMIX.These methods are then adopted by the group decision maker who himself is a MCDM technique [Considered as TOPSIS] to obtain the final decision as shown in Fig.17. To enter to the group decision platform one must click on the **"Group Decision"** link. Once clicking to it a multi-select scroll-box [Fig.17] will appears to choose the decision methods which have qualified the consistency check. Now group decision making can be accomplished by selecting one of the ten methods in the dropdown menu bar [Fig.17].



Spearmans Coefficient	TOPSIS	SAW	ELECTRE I	EXPROM II	EVAMIX
TOPSIS	1.000	1.000	0.988	1.000	0.842
SAW	1.000	1.000	0.988	1.000	0.842
ELECTRE I	0.988	0.988	1.000	0.988	0.806
EXPROM II	1.000	1.000	0.988	1.000	0.842
EVAMIX	0.842	0.842	0.806	0.842	1.000

Fig. 16.Spearman's correlation coefficient matrix for qualified methods.

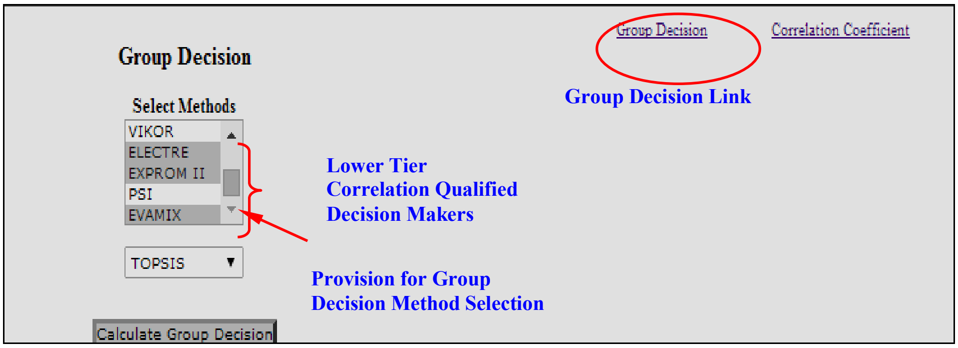
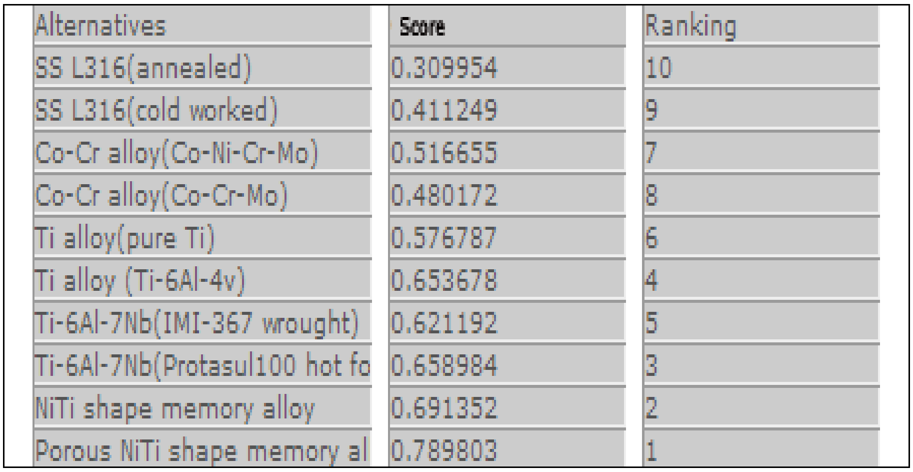


Fig. 17. The group decision platform.

Then by clicking the submit button entitled **"Calculate Group Decision"**the group decision rank of the alternatives can be achieved as shown in Fig.18. In group decision it is very evident that the decision matrix comprises of the score of every individual lower tier methods. Therefore, group decision maker has got an authority to provide different weight to different methods and this phenomenon has been included in the expert system as shown in Fig. 18.The rank achieved after making group decision is perfectly matches with the rank by Jahan and Edward [32] through TOPSIS, shows a consistency level of 100%. Hence it can be said that the expert system can be utilized for making a decision and to verify whether the decision is firm or not one may opt for group decision if necessary.



Alternatives	Score	Ranking
SS L316(annealed)	0.309954	10
SS L316(cold worked)	0.411249	9
Co-Cr alloy(Co-Ni-Cr-Mo)	0.516655	7
Co-Cr alloy(Co-Cr-Mo)	0.480172	8
Ti alloy(pure Ti)	0.576787	6
Ti alloy (Ti-6Al-4v)	0.653678	4
Ti-6Al-7Nb(IMI-367 wrought)	0.621192	5
Ti-6Al-7Nb(Protasul100 hot fo	0.658984	3
NiTi shape memory alloy	0.691352	2
Porous NiTi shape memory al	0.789803	1

Fig. 18. The group decision upshots.

5. Conclusion

In compliance with the design, development and implementation of a robust expert system**[branDEC-V:1R:1]** to eradicate unnecessary delay in computational time in line with MCDM problems, standard MCDM methodologies have been implemented through PHP keeping in view of web applications. Provision for different methods for normalization of discrete data as well as different weighting techniques, have been implemented. So far the authors have been able to implement methods like, AHP, TOPSIS, VIKOR, SAW, MOORA, ELECTRE I, EXPROM II, PSI, COPRAS, and EVAMIX. Provision has been made to use these techniques in stand-alone mode as well as aggregated group decision making mode. The authors validated the results of this expert system with the problems already revealed in literature survey and found a suitably high correlation which indicates the viability of the expert system.

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