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Development of Team-compromised Instrument for Group Decision-making using Modified Nominal Group Technique

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Abstract: Team approach to Design, the norm in Concurrent Engineering, has a few hitches. The difficulty by different professionals in a team agreeing on contentious design specifications is one such problem. On critical examination, conflicts appear to emanate from the following: Strong professional-leaning of individual stakeholders; Stakeholders' lack of comprehensive information on the product/component requirements at design decision point; Adoption of "village community" style of design decision-making process; and Individual team member's mistrust of Team leaders in the design decision process. This article reviews the research on the Nominal Group Technique (NGT) and presents a modified version of the NGT in developing a team-compromised instrument for decision-making. The team members provide data of matrix used to compute consensus values for a set of weights, thereby avoiding possible team conflicts.

Keywords: Team-compromise, Decision making, design criteria, nominal group technique

1. INTRODUCTION

Teamwork is the ability to compromise and collaborate with others with the intent of achieving a common goal, striving toward agreed upon strategic goals and initiatives. Many varying definitions of team exist. The most common explanation of team is a small number of people with abilities and strengths that complement one other, striving toward a common purpose, in which there is equitable accountability and ownership. Teams are created according to need and include members that are able to accomplish the predetermined goal. These groups then serve on committees, ad hoc groups, and task forces whose purpose is to realize a certain purpose.

In any organization where individuals work closely together in a stressful environment, conflicts are bound to occur. These conflicts arising from the design team in making choices, such that each member of the team of designers may have a preference for some criteria. For instance, using the principle of design for assembly, design for manufacture, design for safety, design for cost and so forth where everybody wants its point of view. The Mechanical engineer, for instance, may prefer mechanical properties: Safety engineer, safety-related properties: Manufacturing engineer, manufacturing requirements: Cost engineer, cost requirements: even the customer is interested in one property or the other, etc.Therefore, to maintain productivity and prevent morale from deteriorating, conflict needs to be dealt with swiftly and effectively. By using the technique of compromise, conflict negotiators can achieve a "win-win" solution, where all parties involved can attain a measure of satisfaction.Compromise can help resolve disputes quickly, which is important when a protracted disagreement could potentially derail a time-sensitive project or when there is the need to keep a simmering conflict from escalating. When each side in a dispute realizes that the other is required to make a sacrifice, the parties are often more willing to reach an agreement and move forward, while avoiding the need to determine an ultimate winner and loser. In a case where a prolonged conflict can prove costly, a relatively quick compromise can minimize the potential financial losses. Though, there is no clear-cut winner or loser, compromise allows all parties involved in a dispute to save face and maintain their integrity without feeling humiliated. This is important in a work environment where teamwork is essential for success and where the parties will need to work together on future projects. Saving face can eliminate the occurrence of lingering resentments that can undermine the sense of friendship among workers and ultimately lead to the erosion of workplace morale. At times, the parties may have equally strong points of view that can make it difficult to determine which is "right," and continuing negotiating efforts may do little to end the stalemate. Finding a compromise in which each side must "give in" to a certain extent may be the only way to achieve a resolution in decision making. The key is to make each side feel that the other is giving up something of equal value. In achieving the stated goal, this paper tends to develop an instrument known as team-compromise that can be used for any group decision makingthrough the nominal group technique.

2. GROUP DECISION

Group decision making is a type of participatory process in which multiple individuals acting collectively, analyze problems or situations, consider and evaluate alternative courses of action, and select from among the alternatives a solution or solutions. The number of people involved in group decision-making varies greatly, but often ranges from two to seven. The individuals in a group may be demographically similar or quite diverse. Decision-making groups may be relatively informal in nature, or formally designated and charged with a specific goal. The process used to arrive at decisions may be unstructured or structured. The nature and composition of groups, their size, demographic makeup, structure, and purpose, all affect their functioning to some degree. The external contingencies faced by groups (time, pressure and conflicting goals) impact the development and effectiveness of decision-making groups as well. The following are a number of structured group decision approaches reported in the literature (Kreitner and Kinicki, 2010; Abdullah and Rafikul, 2011; MountHolyoke 2011; MacPhail 2013):

- Brain storming,
- Brain writing,
- Analytical Hierarchy process, (AHP);
- Delphi; and
- Nominal Group Technique, (NGT).

2.1 Brainstorming:

Brainstorming involves group members verbally suggesting ideas or alternative courses of action. The "brainstorming session" is usually relatively unstructured. The situation at hand is described in as much detail as necessary so that group members have a complete understanding of the issue or problem. The group leader or facilitator then solicits ideas from all members of the group. Usually, the group leader or facilitator will record the ideas presented on a flip chart or marker board. The "generation of alternatives" stage is clearly differentiated from the "alternative evaluation" stage, as group members are not allowed to evaluate suggestions until all ideas have been presented. Once the ideas of the group members have been exhausted, the group members then begin the process of evaluating the utility of the different suggestions presented. Brainstorming is a useful means by which to generate alternatives, but does not offer much in the way of process for the evaluation of alternatives or the selection of a proposed course of action.

One of the difficulties with brainstorming is that despite the prohibition against judging ideas until all group members have had their say, some individuals are hesitant to propose ideas because they fear the judgment or ridicule of other group members. In recent years, some decision-making groups have utilized electronic brainstorming, which allows group members to propose alternatives by means of e-mail or another electronic means, such as an online posting board or discussion room (Putman et al. 2009). Members could conceivably offer their ideas anonymously, which should increase the likelihood that individuals will offer unique and creative ideas without fear of the harsh judgment of others.

2.2 Brain-writing:

Brain-writing is an alternative method to brainstorming that tries to encourage a more uniform participation within a group. Like brainstorming, it is designed to generate lots and lots of ideas in a short amount of time (Litcanu et al., 2015). The difference is that in Brain-writing each participant thinks and records ideas individually, without any verbal interaction.The Brain-writing has a method known as 6-3-5 method (also known asMethod 635) is a group creativity technique used in marketing, advertising, design, writing and product development. The technique involves 6 participants who sit in a group being supervised by a moderator. Each participant thinks up to 3 ideas every 5 minutes. The ideas are written down on a worksheet and passed on to the next participant. The participant reads the ideas and uses them as inspiration for more ideas. Participants are encouraged to draw on others' ideas for inspiration, thus stimulating the creative process. After 6 rounds in 30 minutes the group has thought up a total of 108 ideas. Brain-writing involves silently sharing written ideas in groups. Relative to brainstorming, brain-writing, potentially, minimizes the effect of status differentials, dysfunctional interpersonal conflicts, domination by one or two group members, pressure to conform to group norms, and digressions from the focal topic.

2.3 The Analytic Hierarchy Process:

The AHP is a general measurement theory that depends on the values and judgments of individuals and groups. It is based on a well-defined mathematical structure of consistent matrices and their associated right-eigenvector's ability to generate true or approximate weights (Merkin 1979, Saaty 1990, Saaty 1980, 1994). More precisely, judgments are brought together according to a multilevel hierarchic structure that allows deriving priorities. The major advantage of the hierarchical structure is that it allows for a detailed, structured and systematic decomposition of the overall problem into its fundamental components and interdependencies, with a large degree of flexibility. The AHP has found its widest applications in multi-criteria decision making, in planning and resource allocation and in many other fields (Ngai 2003; Sarkis and Talluri, 2004). This methodology is made up of the following steps. More recently, a more general form of AHP approach, which incorporates feedbackand interdependent relationships among decision attributes and alternatives, has been proposed as a more accurate approach for modeling complex decision environments. It is a well-known technique that decomposes a problem into several levels in such a way that they form a hierarchy (Kahraman et al. 2004).

• *Structuring of the problem into a hierarchy*. In general hierarchies concern the distribution of a property (the goal) among the elements being compared, to judge which one influences or is influenced more.

• *Comparative judgment*. The aim is to measure the relative importance of the elements (attributes, indexes) to the overall goal. The question to ask when comparing two elements is "*how important is one of the two elements with respect to the goal of the problem?*".

• *Synthesis of the priorities*. The objective of this phase is to derive a total score for each alternative starting from the measured scores and the calculated priorities of each element of the hierarchy.

2.4 Dephi Technique:

The Delphi technique involves circulating questionnaires on a specific problem among group members, sharing the questionnaire results with them, and then continuing to recirculate and refine individual responses until a consensus regarding the problem is reached.
In contrast to the nominal group technique or brainstorming, the Delphi technique does not have group members meet face to face. The formal steps followed in the Delphi Technique are:

- A problem is identified.
- Group members are asked to offer solutions to the problem by providing anonymous responses to carefully designed questionnaires.
- Responses of all group members are compiled and sent out to all group members.
- Individual group members are asked to generate a new individual solution to the problem after they have studied the individual responses of all other group members.
- Step 3 and 4 are repeated until a consensus problem solution is reached.

2.5 Nominal Group Technique, or NGT

This is a *weighted ranking* method that enables a group to generate and prioritize a large number of issues within a structure that gives everyone an equal voice. The tool is called *nominal* because there is limited interaction between members of the group during the NGT process. NGT is an interview technique where participants work in the presence of each other but write ideas independently rather than stating them verbally (Macphail, 2001, Muhammed and Rafikul, 2011).The nominal group meetings allow for individual brainstorming as well as group dynamics to generate rich, qualitative information, which is then prioritized by meeting participants into earlier to analyze and understand quantitative information. More like other focus groups, and qualitative methods, the nominal group technique provides a more in-depth understanding of stakeholders' preferences and concerns regarding decision making than traditional quantitative survey methods.Past research has it that the ideas generated from a group environment lead to increased accuracy, confidence, and satisfaction over individual generation in the decision making process (Roth, 1994).Further research in group dynamics has shown that more ideas are generated by individuals working alone but in a group environment than the individuals engaged in a formal discussion. One of the reason for this is that people tends to fear they will look foolish or stupid before the group and therefore refrain themselves from taking active participationsin discussions.

Since the introduction of NGT by Delbecq et al in 1975, the technique has been applied to solve various problems where stakeholders are invited from various places and location to participate in the NG session. Though, a number of modifications of the technique have been proposed. Fox (1989) proposed to use 3x5 inch cards to provide all the ideas by one person at one time instead of round-robin recording ideas. Rafikul (2002) also proposed the use of Analytical Hierarchy Process to guide the participants to choose and rank the best ideas instead of the holistic approach. However, this paper therefore proposes an instrument for team approach to design in solving decision-making problems with material-related properties by adopting a modified nominal group technique.

Nominal group technique has been applied in so many ways. Muhammad and Rafikul (2011) applied it in generating large number of ideas to solve quality related problems especially in higher education setting. According to Jones (2004), the NGT was also applied to select the most appropriate topics for postgraduate research students' seminars.This technique has able to establish collegial discussions and networking among participants and has expanded the discussion within the Faculty about peer review of teaching (Burrows et al. 2011). Potter et al., (2004) has described NGT as a means of reviewing the applications in health care research and increasing the awareness among physiotherapists of the potential applications in NGT physiotherapy research.

However, the purpose of the NGT is to generate information in response to an issue that can then be prioritized through group discussion. Participants involved in the NGT take part in a highly structured face-to-face meeting usually lasting up to two or more hours. Task completion and immediate dissemination of results to the group promotes satisfaction with participation.There are a number of requirements for a successful application of nominal group technique. First of all, a group should be formed comprising 9 to 12 persons who are expected to be knowledgeable about the issue for which the session is convened. It is preferable if the participants are of diverse background. For instance, in an engineering organization, group members may come from various departments like structural engineers, mechanical engineers, electrical engineers, project engineers, safety engineers, chemical engineers, cost engineers, quality control, production engineers, etc. The reason for having diverse experience among these people is the fact that people can visualize the issue from different perspectives in order to provide different types of ideas on the issue. Though, bringing members together may cost money and time, but this paper proposes a modified NGT which tends to develop a mathematical model that resolve some of the limitations associated with NGT.

3 THE PROPOSED MODEL

Having taken a critical look at each of these approaches, NGT decision-making structure appears most suitable for mathematical modeling such that all the three conditions stated earlier will be simultaneously satisfied. It is therefore chosen for modeling the team-compromise instrument. By developing a mathematical model which will accept as inputs the rankings from all members or stakeholders in a design team, preference indices may be computed for the set of criteria. The discriminability of the instrument will be tested in generating the criteria preferences between individual team members, between disciplines using correlation analysis. Such a team-compromise instrument is developed in the following.

It is believed here that by structuring an instrument which allows the facilitator to send information of interest by e-mails, courier or hand delivery depending on the proximity to their respective or selected members.In thiscase, members are not allowed to meet face-to-face. The ideas can be gathered from group members who are too geographically separated or busy to meet face to face. The instrument allows individuals to:

1) Receive list of material-selection-related design criteria to be satisfied including their respective lower and upper limits;
2) Receive information on the contributions by each criterion to the product/component functions, manufacturing processes, aesthetics, etc.;
3) Receive comprehensive information on the product/component requirements and operating environment;
4) Independently study the information in items 1, 2 and above; and
5) Independently rank itemized criteria with ordinal scale of 1st, 2nd, 3rd, 4th, etc, without ties.

3.1 Theoretical Consideration

Let w_j be the value of team preference index for criterion j. In multi-criteria optimisation, a preference index, w_j, has to satisfy the following conditions (Nijkamp et al., 1990; Anderson, 2000):

1) $\sum_{j=1}^{n} w_j = 1$
2) $w_j > 0 \forall j$

For the purpose of fostering team-spirit, the following additional condition is added:

3) Input data for computing w_j have to come from every team member reasoning independently.

The desirable NGT properties which make it attractive for this purpose are:

(1) Decision team size ($Z \geq 7$) is fixed;
(2) Number of possible criteria (N) are known;
(3) Each team member is given some time to independently study and thoroughly comprehend information on the problem situation, criteria and the ranking system;
(4) Criteria ranking by an individual is done covertly and independently;
(5) Criteria ranking uses ordinal scale: 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, etc., without allowing ties between criteria by all individuals; Zero rank is not valid.
(6) The ranks in (5) are converted to scores such that the criterion with the highest rank receives highest possible score, say N; second position criterion scores N-1; third position, N-2; fourth position, N-3; etc.;
(7) Considered over all the scores by a team member in a particular ranking situation, the individual scores form the Arithmetic Series: 1, 2, 3, 4, 5,..............., N-4, N-3, N-2, N-1, N.
Which criterion receives high or low score depends on the judgment of the individual.
(8) Aggregate score for a criterion is sum of all scores by individual members on that criterion. Thus, should each member of a team of 12 rank a particular criterion lowest, then the set of scores is: {1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1} with the sum of scores being 12. On the other hand, should each member assign highest rank then: {N, N, N, N, N, N, N, N, N, N, N, N} is the set of scores with 12N as total. Tallied from all team members, any combination of scores whose values lie between 1 and N is possible depending on the independent judgment of members.
(9) The sum of all the scores (SS) by Z team members using ordinal scale to rank a set of N criteria in a NGT system whose (Min, Max) range of scores is (1, N) is given by the expression:
SS = Z(1+2+3+4+.....................+N) = ZN(N+1)/2 (3.1)

These NGT properties are now used to develop a mathematical model which will satisfy the earlier mentioned properties of w_j. Let ψ_{kj} be the relative rank assigned by team member *i* to criterion *j* and R_{kj} the associated score. Thus, if N is the maximum possible score on any criterion and 1, the minimum by an individual, then the relation between ψ_{ij} and R_{kj} is given by the following expression:

$$R_{kj} = N - \psi_{kj} + 1 \qquad (3.2)$$

Using ordinal ranking: 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, etc., expression (3.2) implies that the higher the rank, the higher the score. The ranking by individuals allows team members to exercise better independent judgment based on relativity principles. That is, "this criterion appears more relevant than the other, in view of the general requirements". By this reasoning, every team member may easily rank all N criteria.

Observe that, by using an ordinal scale (ψ_{kj} =1^{st}, 2^{nd}, 3^{rd}, etc.) without ties, it is impossible for a single member to score two or more criteria the same value. Consequently, the scores of any member conform to the following Arithmetic Series:

$$R_{kj} = \{1, 2, 3, 4, 5, ..., N-3, N-2, N-1, N\} \qquad (3.3)$$

Although, (3.3) is an ordered set, it does not in any way show which criterion receives a particular score. It only says that, regardless of the criterion that receives low or high scores, the whole set of scores from each team member contains an Arithmetic Series Let Z be the team size. Since every member has to rank every criterion using the rank indicator (ψ_{kj}) without ties, the total score of criterion j (TC_j) by all Z members of the team is given by the expression:

$$TC_j = \sum_{k=1}^{Z} R_{kj} \qquad (3.4)$$

It may also be clearly stated here that the set of scores by all members on one criterion may not necessarily be an Arithmetic Series as illustrated in NGT property 8.

Notice that expression (3.4) indicates the team ranking of criterion j. Clearly, a team preference index of criterion j, w_j, will be a function of TC_j. To bring about the desirable properties of w_j, it is defined as follows:

$$w_j = \frac{TC_j}{\sum_{k=1}^{Z}\sum_{j=1}^{n} R_{kj}} = \frac{\sum_{k=1}^{Z} R_{kj}}{\sum_{k=1}^{Z}\sum_{j=1}^{n} R_{kj}} \quad (3.5)$$

From the NGT property 9, clearly,

$$\sum_{k=1}^{Z}\sum_{j=1}^{N} R_{kj} = ZN(N+1)/2 \quad (3.6)$$

Substituting into (3.5),

$$w_j = \frac{\sum_{k=1}^{Z} R_{kj}}{ZN(N+1)/2} \quad (3.7)$$

In terms of the ranking variable (ψ_{kj}) in expression (3.2),

$$w_j = \frac{\sum_{k=1}^{Z} (N - \psi_{kj} + 1)}{ZN(N+1)/2} \quad (3.8)$$

Expressions (3.7) and (3.8) are the team preference index for criterion j; ψ_{ij} being the individual team member criterion-by-criterion ranking variable. Also, note that [ψ_{ij}] is a Z x N matrix indicating the rankings by all the team members on all the criteria. Using the data from such matrix, the values of w_j ; $j = 1, 2, 3, ..., N$ will be determined. By allowing every individual team member some time to privately study all the relevant information concerning product/component for which material will be selected, the itemized criteria may now be ranked independently without formal meeting by the design team. That is, team members provide data of the matrix, [ψ_{ij}] while the mathematical expression (3.7) or (3.8) are used to compute consensus values of the set, {w_j}, thereby avoiding possible team conflicts. Of course, team members who may want some clarifications are free to call the team leader by phone or contact by e-mail during the process of attempting to understanding the problem situation before ranking.

3.2 Team-Compromise Criteria Preference Assigning Instrument

Based on the above, the following are the steps to be accomplished to enable a design team amicably decide the set of preference indices of a set of criterion.

STEP 1: Team leader documents all relevant information on the requirements of the products/components to be designed including itemized criteria to be satisfied in the design process; tolerances; manufacturing processes. Also included is the ranking system to be adopted.

STEP 2: Send the document obtained in step 1 to all team members requesting the ranking and returning of the data set: {ψ_{kj} /j=1, 2, 3,............,N} on or before a specified closing date.

STEP 3: Compute the set: {w_j /j=1, 2, 3,.......N} for N design criteria using expression (3.8).

4 NUMERICAL EXAMPLE

In this section, some given engineering applications for material are used to demonstrate the feasibility of the proposed approach to evaluate and find the weighting parameter. An example will be used to illustrate the model: An armature shaft of a direct electric motor. The criteria relative ranks were independently assigned by individuals from a team of twenty-eight (28) professional design engineers comprising of 11– Mechanical Engineers (ME), 7- Production/Industrial Engineers, 6- Electrical Engineers, and 4- Agricultural Engineers participated in the modified nominal group technique exercise with the component. Information relating to the component such as the functionality, operational condition and manufacturability were equally stated to enable each of the team member rank the properties/criteria wisely.

In this example, the criteria ranking for the armature shaft is considered using the procedure described in section 3. First and foremost, all necessary performance criteria were identified based on service requirements of the armature shaft of a d.c motor as well as the manufacturability and cost requirements. A total of ten criteria were listed out of which seven were beneficial while three are non-beneficial. The selected properties/criteria considered for the armature shaft are: ultimate tensile strength (UT), yield strength (YS), elastic modulus (EM), ductility (DU), hardness (H), density (D), thermal conductivity (TC), thermal diffusivity (TD), thermal expansion (TE), and cost of the base material (C). The criteria ranking using ordinal scale 1st, 2nd, 3rd, etc. was independently assigned by twenty eight (28) professionalsare presented in Table 1. These scores were converted to associated score using equation(3.3) with their respective weightscomputed as presented in Table 2.

NAME OF COMPONENT: Armature shaft
Function: The shaft provides a mechanical support and it also transfer torque to the rotor and rotates the armature to the direction of motion.
Operation Environment: Frictional heat will be generated; humidity may be high at some times and low at other times; must be able to withstand the armature load, bearing loading, and shaft stress.
Manufacturing processes with surface finish requirements: Machining, and case hardening
Diagram of Component:

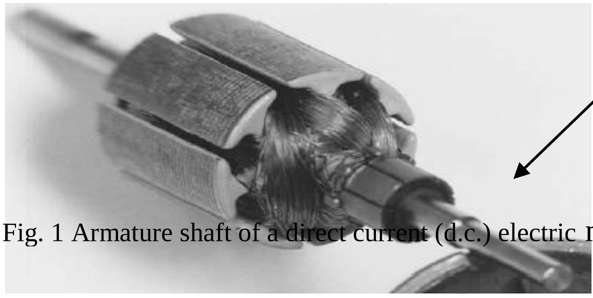

Fig. 1 Armature shaft of a direct current (d.c.) electric motor

Table 1: The Relative Ranks (Raw Input Data) Assigned by Individual team member for the Armature Shaft of a D.C. Motor

Participants	UT	YS	EM	DU	H	D	TC	TD	TE	C
	Relative rank assigned by team members									
N1	10	1	7	9	2	8	4	6	5	3
N2	3	4	5	6	7	8	1	2	9	10
N3	1	2	5	10	4	9	6	7	8	3
N4	1	6	8	9	10	7	4	5	2	3
N5	2	1	3	8	7	10	4	5	6	9
N6	1	4	3	10	2	8	5	9	6	7
N7	8	1	9	5	3	10	6	7	2	4
N8	3	1	2	9	4	10	6	8	7	5
N9	5	3	6	4	1	7	10	9	8	2
N10	2	1	6	7	8	9	3	10	4	5
N11	3	1	2	4	6	5	9	8	7	10
N12	1	3	5	4	2	8	7	9	6	10
N13	3	1	2	8	7	6	10	5	4	9
N14	2	1	3	5	4	6	8	10	9	7
N15	1	2	3	8	4	9	10	7	6	5

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N16	7	8	9	10	4	6	1	2	3	5
N17	6	7	1	3	8	9	4	10	2	5
N18	1	2	3	4	5	6	7	8	9	10
N19	1	9	10	4	2	8	6	5	7	3
N20	1	7	9	6	5	8	3	10	4	2
N21	1	4	6	3	2	7	9	10	8	5
N22	3	4	5	1	2	6	9	8	7	10
N23	1	2	3	9	4	10	5	6	8	7
N24	2	1	3	5	4	6	8	10	9	7
N25	7	1	4	6	8	3	5	10	9	2
N26	8	6	7	10	9	5	2	1	3	4
N27	1	2	4	5	3	9	6	7	10	8
N28	2	1	6	7	3	9	8	10	4	5

Table 2: The Associated Score Assigned by Individual team member with Criteria weights

Participants	UT	YS	EM	DU	H	D	TC	TD	TE	C
	Associated Score with criteria weights									
N1	1	10	4	2	9	3	7	5	6	8
N2	8	7	6	5	4	3	10	9	2	1
N3	10	9	6	1	7	2	5	4	3	8
N4	10	5	3	2	1	4	7	6	9	8
N5	9	10	8	3	4	1	7	6	5	2
N6	10	7	8	1	9	3	6	2	5	4
N7	3	10	2	6	8	1	5	4	9	7
N8	8	10	9	2	7	1	5	3	4	6
N9	6	8	5	7	10	4	1	2	3	9
N10	9	10	5	4	3	2	8	1	7	6
N11	8	10	9	7	5	6	2	3	4	1
N12	10	8	6	7	9	3	4	2	5	1
N13	8	10	9	3	4	5	1	6	7	2
N14	9	10	8	6	7	5	3	1	2	4
N15	10	9	8	3	7	2	1	4	5	6
N16	4	3	2	1	7	5	10	9	8	6
N17	5	4	10	8	3	2	7	1	9	6
N18	10	9	8	7	6	5	4	3	2	1
N19	10	2	1	7	9	3	5	6	4	8
N20	10	4	2	5	6	3	8	1	7	9
N21	10	7	5	8	9	4	2	1	3	6
N22	8	7	6	10	9	5	2	3	4	1
N23	10	9	8	2	7	1	6	5	3	4
N24	9	10	8	6	7	5	3	1	2	4

N25	4	10	7	5	3	8	6	1	2	9
N26	3	5	4	1	2	6	9	10	8	7
N27	10	9	7	6	8	2	5	4	1	3
N28	9	10	5	4	8	2	3	1	7	6
Total Score of Criterion	**221**	**222**	**169**	**129**	**178**	**96**	**142**	**104**	**136**	**143**
% Weights	**14.35**	**14.42**	**10.97**	**8.38**	**11.56**	**6.23**	**9.22**	**6.75**	**8.83**	**9.29**

In ranking criteria for the armature shaft, ultimate tensile strength and yield strength were ranked second-highest and highest by about 57 percent of team members (see Table 2). This also appears justified scientifically since toughness, portrayed by tensile and yield strengths, is highly desirable property for a shaft.

In prioritizing the design criteria using the team-compromise instrument (TCI), the opinions of Engineers within the Mechanical Engineering, Production/Industrial Engineering, Electrical Engineering and Agricultural Engineering disciplines were investigated as shown in Table 3. The hypothesis testing within the engineering disciplines indices are shown below:

H_0: The pair of data set (within the Engineering disciplines preference indices) has no relationship.
H_1: The pair of data set (within the Engineering disciplines preference indices) has relationship.

From the above stated hypothesis, the result shows that p-value is greater than the level of significance $(p > 0.05)$, this implies that correlation within engineering disciplines is not statistically significant, and the individual opinions within the disciplines (Mechanical Engineering, Production/Industrial Engineering, Electrical Engineering and Agricultural Engineering) differ considerably as indicated by the significantly low correlation coefficients of 0.12, 0.38, 0.20 and 0.06 respectively. The low correlation (0.12) of criteria ranking by the different members within the Mechanical Engineering (ME) discipline depicts serious differences in opinion in assigning ranks to the respective criteria. This may be due to differences in the design experience of the team members. It may be recalled that the participants were a mix of Professors, Senior lecturers and lecturers. This behaviour is replicated in the Production/Industrial Engineering (PIE), Electrical Engineering (EE) and Agricultural Engineering (AE) disciplines.

In addition, a statistical analysis for comparing the degree of correlation between different engineering disciplines preference indices is summarized in Table 5. The hypothesis testing between the engineering disciplines indices are shown below:

H_0: The pair of data set (between the engineering disciplines preference indices) has no relationship.
H_1: The pair of data set (between the engineering disciplines preference indices) has relationship.
The analysis from Table 4 shows the relationship between the four disciplines- Mechanical Engineers (ME), Production/Industrial Engineers (PIE), Electrical Engineers (EE) and Agricultural Engineers (AE). Between the pair ME and AE; ME and PIE; PIE and AE; ME and EE; PIE and EE; and EE and AE has a Pearson coefficient of 0.71, 0.69, 0.67, 0.66, 0.62 and 0.32 respectively at $p < 0.05$. From the above hypothesis, the p-value of zero indicates that the correlation between the pair of discipline is significant.

The high correlation between the four engineering disciplines shows that there is a consensus in their final decision; this is as a result of the team compromise instrument which has brought individual reasoning, feelings and within-discipline opinion differences in assigning ranks to each of the criteria. Also, the high correlation values indicate that the design team has able to harmonized individual ideas by eliminating conflicts that may arise among them.However, the high correlation may be due to the opinion differences within the disciplines as earlier explained. Hence, the relatively high correlation between disciplines may be accounted for by the near identical within-discipline opinion differences which appear to be replicated in all the disciplines.

Table 3: Analysis of the paired correlation between individual team members within the disciplines

Within the disciplines	Sum of the individual-to-individual paired correlation	Total number of pairs	Correlation
Mechanical Engineers (ME)	25.24	217	0.12
Production/ Industrial Engineers (PIE)	31.54	84	0.38
Electrical Engineers (EE)	11.71	60	0.20
Agricultural Engineers (AE)	1.367	24	0.06

Table 4. Associated score (weight) of the relevant disciplines for Armature Shaft of a D.C. Motor

	Disciplines of Design team of Engineers			
Criteria	ME (%)	PIE (%)	EE (%)	AE (%)
Ultimate tensile strength	7.00	8.71	9.33	6.75
Yield strength	8.18	8.57	6.67	8.00
Elastic modulus	6.55	5.71	4.83	7.00
Ductility	5.00	2.86	6.50	3.75
Density	6.18	6.29	8.00	4.50
Hardness	4.09	2.14	3.33	4.00
Thermal conductivity	5.00	4.86	4.50	6.50
Thermal diffusivity	3.09	3.86	3.00	6.25
Thermal expansion	4.82	6.14	3.67	4.50
Cost	5.09	5.86	5.17	3.75

Table 5. Statistical analysis for comparing the degree of correlation between different engineering disciplines preference indices.

Pair of Discipline	Correlation in proportion	Correlation in percentage
(ME & PIE)	0.687	68.7%
(ME & EE)	0.662	66.2%
(ME & AE)	0.708	7.08%
(PIE & EE)	0.623	62.3%
(PIE & AE)	0.666	66.6%
(EE & AE)	0.323	32.3%

5. CONCLUSION

A team-compromise instrument for data gathering of product design input data from multiple stakeholders has been established. Also, a mathematical optimisation model which allows all product design stakeholders involvement that simultaneously satisfy all design criteria has been establishedusing the modified NGT which has been shown to be a suitable tool for making group decision that are crucial to design and particularly the weighting system. The model ranked material properties/criteria from best to worst assigned by the team without conflicts. Results of example problems demonstrate the consensus and sensitivity of the approach to every design situation in assigning a weight for a particular criterion.

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