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Selection of 3D Printers for Educational Institutions using ANP- Similarity based Approach

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***Abstract*: 3D Printing is a promising technology that has been implemented in many spheres of industry, particularly in the area of new product development due to its unique characteristics of fabricating functional prototypes timely and efficiently along with minimised cost. With the diminishing cost of the various commercial 3D printers available in the market and their increasing need, 3D printers are now being increasingly adopted in the various educational institutions for rendering hands-on experience to the students. It is therefore necessary to examine to what extent the technological capabilities of open source 3D printing could serve as a means of learning and communication. The learning theory of constructionism is used as a theoretical framework in creating an experimental, educational scenario focused on 3D design and printing. Because of the capability, service quality, and cost of the printers vary widely, how to select a suitable 3D printer is very critical to the institutions willing to engage in new product developments and other research work. However, selection of an optimal 3D printer is a tedious work due to involvement of various criteria or objectives in the decision making process and it is often necessary to compromise among possibly conflicting factors. Thus, the multiple criteria decision making (MCDM) becomes a useful approach to solve this kind of problem. This study focuses on a hybrid multiple-criteria decision making (HMCDM) tool for selecting an appropriate 3D printer based on the Deng's Similarity based approach.**

Keywords: 3D Printing, MCDM, ANP, Similarity method, Supermatrix.

I. INTRODUCTION

Three-dimensional (3D) printing actually a subset of additive manufacturing is, in short, the process of joining material, layer-by-layer, to make objects from 3D model data (usually created by a computer-aided design software or a scan of an existing object), in contrast to subtractive manufacturing technologies. This technological capability has been around for more than three decades and has been known as the ‘‘rapid prototyping machine’’ [1]. It was called ‘‘rapid’’ because one-offs could be made more easily and quickly than by the conventional numerically-controlled machines and it was called ‘‘prototyping’’ because it was too slow and expensive to be used for production [2].The three-dimensional (3D) printing emerged recently as one of the most promising technologies aiming at more flexible manufacturing at a lower cost while at the same time maintaining the desired qualities. 3D printing implies possible reconfiguration of firms' strategies and operations along supply and manufacturing, as well as retailing chains. Therefore, the Economist heralds 3DP as “the manufacturing technology that will change the world.” In 3D printing, additive processes are used, in which successive layers of material are laid down under computer control. These objects can be of almost any shape or geometry, and are produced from a 3D model or other electronic data source. A 3D printer is a type of industrial robot. 3D printing in the term's original sense refers to processes that sequentially deposit material onto a powder bed with inkjet printer heads. More recently the meaning of the term has expanded to encompass a wider variety of techniques such as extrusion and sintering based processes by enabling a machine to produce objects of any shape, on the spot and as needed, the 3DP really is ushering in a new era. The market for 3D printers and services is small but growing fast. Hutchings and Martin summarized that the numbers of the overall market size are small compared to the global market in 2009 for 2D inkjet technologies, of the order of US$50 billion (including hardware, media, and chemistry). McKinsey Global Institute estimated that 3DP could generate economic impact of $230 billion to $550 billion per year by 2025, based on reduced cost and the value of customization; the largest source of potential impact would be from consumer uses, followed by direct manufacturing and the use of 3DP to create tools and moulds.

As discussed by [3], the main reasons why an educational institution can choose 3D printing may be-What role could 3D printing and design, along with the modern ICT, play in developing and implementing new educational ideas based on the principles of constructionism? Therefore, from the aforementioned question a few sub-questions emerge: What kind of educational environments could be created fused with the values of collaboration and meaningful communication which are pillars of the Commons-oriented, open source movement? Could these scenarios and environments be considered as ‘‘objects-to-think-with’’ [4], which would contribute to the social process of constructing the education of the future. Therefore the adoption of 3D printers in educational institutions is gaining momentum and with the increasing number of alternatives in the market, it has become essential that there be a proper guide towards the selection of the 3D printers. Educational institutions are increasingly getting inclined towards the 3D printing process due to its increasing applicability and demand in various fields such as automobile, aerospace, new product development etc. In this paper, a multi criteria decision making tool is being used in order to provide a guideline for the selection of the commercially available 3Dprinters based on the important criteria related to the process of 3D printing. ANP (Analytic Network Process) along with Deng's Similarity Based Approach method is being used to generate a rank of the various alternatives in the market with respect to the desirable criteria. The rank provided by the specified method can act as a guideline for the educational institutions that are willing to procure a 3D printer from those available in the market at the present point of time.

II. LITERATURE REVIEW

Researchers have used ANP for selection of full service advertising agency where ANP has provided a more systematic analysis of allotment of weights by capturing interdependence between criteria [5].ANP has been used for allotting weights to the criteria for section of contractor – a more complicated construction management issue [6]. The limitation of AHP that it can be used only for the problems having a hierarchal structure was addressed by using ANP. It has been shown that ANP will be preferred to AHP when it is to be used to solve problems having interrelated selection criteria. Similarity based approach has been used for purchasing fleet jet fighters and a ranking order quite different from that obtained by using TOPSIS emerged out [7]. This approach was however established as one with strong theoretical background. Limitation of TOPSIS related to sole dependence on distance between alternative and ideal solution has been addressed here by considering this Similarity based approach. ANP has also been used for supplier selection with the help of supermatrix, limit supermatrix and cluster matrix for weighing the correlated criteria [8]. It has been shown that ANP leads to selection of a more suitable supplier than that was obtained by AHP. Some work has been done on the use of 3D printing as a means of learning in classrooms, to investigate the potential of open-source (OS) 3D printing technologies in an educational setting, given the combination of economic constraints affecting all educational environments and the ability of OS design to profoundly decrease the cost of technological tools and technological innovation. But selection of these 3D printers for educational institutions using MCDM methods have not been utilised given the number of criteria they entail. Therefore this paper intends to fill in that gap by giving a detailed ranking of the alternative 3D printers available in the market so that they are increasingly adopted according to the purposes of the institutions.

III. OBJECT AND SCOPE OF PRESENT STUDY

3-D printing technologies have the potential to improve Science, Technology, Engineering, and Mathematics (STEM) education and Career and Technical Education (CTE), as well as integrating these two educational emphases and providing opportunities for cross-curriculum engagement. This paper focuses on the implementation of a hybrid multi-criteria decision making tool known as ANP-Similarity Based method to generate a ranking of the commercially available 3D printers in the market with respect to the desired criteria for their procurement by educational institutions, keeping in mind the potential of open-source (OS) technologies in an educational setting.

IV. METHODS

A. Analytic network process

ANP is a method proposed by Saaty [9]. In ANP, the decision problem is structured network to deal with decision without making assumptions about the independence of higher level elements from lower level elements [9]. In the literature, ANP has been applied in many complicated decision making problems. The ANP has its own advantages and has produced ideal results in various fields.

Modeling with ANP

Many decision problems cannot be structured hierarchically because they involve the interaction and dependence of higher-level elements on lower-level elements. Not only does the importance of the criteria determine the importance of the alternatives as in a hierarchy, but also the importance of the alternatives themselves determines the importance of the criteria [9]. A matrix manipulation approach, developed is applied to solve a network, which is very similar to a hierarchy but has dependence among criteria and dependence among alternatives with respect to each criterion [10]. The Analytic Network Process (ANP) is a new theory that extends Analytical Hierarchy Process (AHP), the theory that depends on the values and judgments of individuals and groups, to cases of dependence and feedback and generalizes on the supermatrix approach [9]. The ANP approach replaces hierarchies with networks. The ANP is the first mathematical theory that makes it possible for us to deal systematically with all kinds of dependence and feedback. The reason for its success is the way it elicits judgments and uses measurement to derive ratio scales. The feedback structure does not have the linear top-to-bottom form of a hierarchy but looks more like a network, with cycles connecting its components of elements, which we can no longer call levels, and with loops that connect a component to itself. It also has sources and sinks (Figure 1). A source node is an origin of paths of influence (importance) and never a destination of such paths. A sink node is a destination of paths of influence and never an origin of such paths.

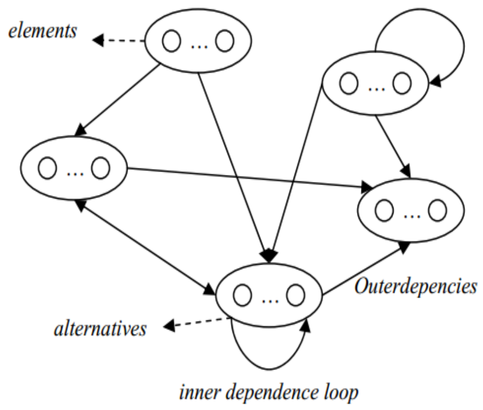

Fig. 1 ANP Network

The ANP provides a general framework to deal with decisions without making assumptions about the independence of higher level elements from lower level elements and about the independence of the elements within a level. In fact the ANP uses a network without the need to specify levels as in a hierarchy. Influence is a central concept in the ANP. The ANP is a useful tool for prediction and for representing a variety of competitors with their surmised interactions and their relative strengths to wield influence in making a decision.

The ANP is a coupling of two parts. The first consists of a control hierarchy or network of criteria and subcriteria that control the interactions. The second is a network of influences among the elements and clusters. The network varies from criterion to criterion and a different supermatrix of limiting influence is computed for each control criterion. Finally, each of these supermatrices is weighted by the priority of its control criterion and the results are synthesized through addition for all the control criteria.

With the ANP a problem is often studied through a control hierarchy or control system of benefits, a second for costs, a third for opportunities, and a fourth for risks each represented in the controlling system. The synthesized results of the four control systems are combined by taking the quotient of the benefits times the opportunities to the costs times the risks for each alternative, then normalizing the results over all the alternatives to determine the best outcome. A rough outline of the steps of the ANP, as stated by Saaty, is as follows:

a. Determine the control hierarchies including their criteria for comparing the components of the system and their subcriteria for comparing the elements of the system- one hierarchy for benefits, a second for costs, a third for opportunities, and a fourth for risks. If in some cases, a hierarchy does not apply because its criteria are all unimportant, leave out that hierarchy. For benefits and opportunities, ask what gives the most benefits or presents the greatest opportunity to influence fulfillment of that control criterion. For costs and risks, ask what incurs the most cost or faces the greatest risk. Sometimes, the comparisons are made simply in terms of benefits, opportunities, costs, and risks in the aggregate without using criteria and subcriteria.

b. For each control criterion or subcriterion, determine the clusters of the system with their elements.

c. To better organize the development of the model, as well as you can and roughly, for each control criterion, number and arrange the clusters and their elements in a convenient way (perhaps in a column). Use the identical label to represent the same cluster and the same elements for all the control criteria.

d. Determine the approach you want to follow in the analysis of each cluster or element, being influenced by other clusters and elements, or influencing other clusters and elements with respect to a criterion. The sense (being influenced or influencing) must apply to all the criteria for the four control hierarchies.

e. For each control criterion, construct a three-column table placing each cluster label in the middle column. List in the left column on a line all the clusters that influence the cluster, and in the column on the right those clusters which it influences.

f. Following each entry in the table above, perform paired comparisons on the clusters as they influence each cluster and on those that it influences, with respect to that criterion. The derived weights are used later to weight the elements of the corresponding column clusters of the supermatrix corresponding to the control criterion. Assign a zero when there is no influence.

*g***.** Perform paired comparisons on the elements within the clusters themselves according to their influence on each element in another cluster they are connected to (or elements in their own cluster). The comparisons are made with respect to a criterion or subcriterion of the control hierarchy.

h. For each control criterion, construct the supermatrix by laying out the clusters in the order they are numbered and all the elements in each cluster both vertically on the left and horizontally at the top. Enter in the appropriate position the priorities derived from the paired comparisons as parts (subcolumns) of the corresponding column of the supermatrix.

i. Compute the limiting priorities of each supermatrix according to whether it is irreducible (primitive or imprimitive [cyclic]) or it is reducible with one being a simple or a multiple root and whether the system is cyclic or not.

j. Synthesize the limiting priorities by weighting each limiting supermatrix by the weight of its control criterion and adding the resulting supermatrices.

k. Repeat the synthesis for each of the four control hierarchies: one for benefits, one for costs, a third for opportunities, and a fourth for risks.

l. Synthesize the results from the four control hierarchies by multiplying the benefits by the opportunities and dividing by the costs multiplied by the risks. Then, read off the highest priority alternative or the desired mix of alternatives.

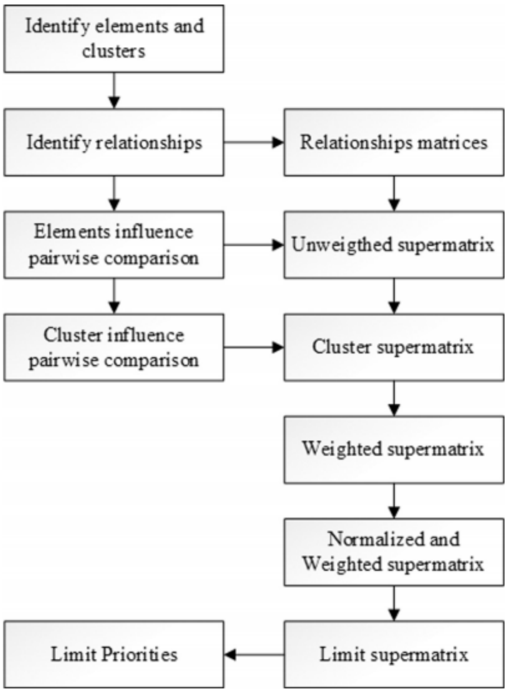

Fig.2 ANP Steps

B. Similarity based Approach

It is a method for rating multi criteria first discovered and implemented by Deng (2007).Here the conflict index equals to one characterized by variables is for solving interrupted multi criteria problems and effectively uses the concept of ideal solution and in a way in which strongly preferred variable must have highest similarity degree in positive ideal solution and the lowest similarity in negative similarity solution.

The required steps for this technique are as follows-

a. Determining the decision matrix:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & x_{ij} & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \ldots.(1)$$

A general multiple criteria analysis problem is represented as a decision matrix which consists of a set of alternatives Ai (i=1,2,…,n) to be evaluated against a set of criteria C_j (j=1,2, …,m). In order to facilitate the development of the multiple criteria decision making approach, all of the criteria C_j are assumed to be benefit criteria. It means that the larger the value of the performance of each alternative with respect to each criterion, the more preferable the alternative. If a criterion is a cost one, the transformation processes such as a reversing original criterion value, could be necessary to maintain the consistency of the decision matrix.

b. Determining the weighting vector:

$W=(w_1,w_2,\ldots,w_j,\ldots,w_m)$ ….(2)

In which the relative importance of criterion C_j with respect to the overall objective of the problem is represented as w_j.

c. Normalizing the decision matrix through Euclidean normalization

$$X_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{n} x_{ik}^2}} \ldots.(3)$$

As a result, a normalized decision matrix can be determined as

$$X' = \begin{bmatrix} x'_{11} & x'_{12} & \cdots & x'_{1m} \\ x'_{21} & x'_{22} & \cdots & x'_{2m} \\ \cdots & \cdots & x'_{ij} & \cdots \\ x'_{n1} & x'_{n2} & \cdots & x'_{nm} \end{bmatrix} \ldots(4)$$

d. Calculating the performance matrix:

The weighted performance matrix which reflects the performance of each alternative with respect to each criterion is determined by multiplying the normalized decision matrix (4) by the weight vector (2).

$$Y = \begin{bmatrix} w_1 x'_{11} & w_2 x'_{12} & \cdots & w_m x'_{1m} \\ w_1 x'_{12} & w_2 x'_{22} & \cdots & w_m x'_{2m} \\ \cdots & \cdots & w_j x'_{ij} & \cdots \\ w_1 x'_{1n} & w_2 x'_{n2} & \cdots & w_m x'_{nm} \end{bmatrix}$$

$$= \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1m} \\ y_{21} & y_{22} & \cdots & y_{2m} \\ \cdots & \cdots & y_{ij} & \cdots \\ y_{n1} & y_{2n} & \cdots & y_{nm} \end{bmatrix} \ldots.(5)$$

e. Determining the PIS and the NIS:

The positive and negative ideal solution consists of the best and worst criteria values attainable from all the alternatives, respectively. In mathematical form they can be stated as-

$I_j^+ = \max y_{ij}$, i = 1,2,...,n

$I_j^- = \min y_{ij}$, i=1,2,...,n …..(6)

f. Calculating the conflict index between the alternatives and the PIS and the NIS:

In the Figure, assume that A_i is a vector which represents an alternative and I_j^+ and I_j^-– are two vectors of positive and negative ideal solution in a given multiple criteria analysis problem. These vectors can be considered in the m-dimensional real space. The angle between A_i and $I_j^+(I_j^-)$ in the m-dimensional real space, which is shown by$\theta_i^+(\theta_i^-)$, is a good measure of conflict between the vectors. The above vectors and the degree of conflict between them are shown in Figure 3. The situation of conflict occurs when $\theta_i \neq 0$, that is, when the gradients of Ai and $I_j^+(I_j^-)$ are not coincident. Thus the conflict index is equal to one as the corresponding gradient vectors lie in the same direction, and the conflict index is zero when $\theta_i = n/2$

which indicates that their gradient vectors have the perpendicular relationship with each other.

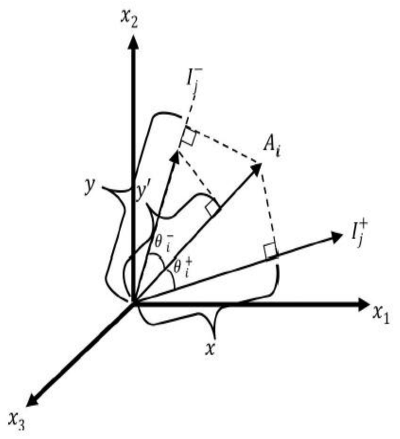

Figure.3 The degree of conflicts between the alternatives and $I_j^+(I_j^-)$

The degree of conflict between alternative (A_i) and $I_j^+(I_j^-)$ is determined by

$$\cos\theta_i^+ = \frac{\sum_{j=1}^{m} y_{ij} * I_j^+}{\sqrt{\sum_{j=1}^{m} y_{ij}^2 \sum_{j=1}^{m}\left(I_j^+\right)^2}} \quad i=1,2,\ldots,n$$

…(7)

$$\cos\theta_i^- = \frac{\sum_{j=1}^{m} y_{ij} * I_j^-}{\sqrt{\sum_{j=1}^{m} y_{ij}^2 \sum_{j=1}^{m}\left(I_j^-\right)^2}} \quad i= 1,2,\ldots,n$$

g. Calculating the degree of similarity of the alternatives between each alternative and the PIS and the NIS: Based on the degree of the conflict between the alternatives and the PIS and the NIS, the degree of similarity between the alternatives and $I_j^+(I_j^-)$can be calculated. The degree ofsimilarity denoted as S_i^+, measures the relative similarity of the alternative A_i toI_j^+, and the degree of similarity denoted as S_i^- measures the relative similarity of the alternative A_i to I_j^-

$$|C_i| = \frac{\sum_{j=1}^{m} y_{ij} * I_j^+}{\sqrt{\sum_{j=1}^{m} y_{ij}^2 \sum_{j=1}^{m}\left(I_j^+\right)^2}} * \sqrt{\sum_{j=1}^{m} y_{ij}^2}$$

… (14)

$$S_i^{\mp} = \frac{|C_i|}{|A_i^{\mp}|} = \cos\theta_i^{\mp} * \frac{\sqrt{\sum_{j=1}^{m} y_{ij}^2}}{\sqrt{\sum_{j=1}^{m} y_{ij}^{\mp 2}}}$$

i= 1,2,…,n

i= 1,2,…,n

h. Calculating the overall performance index for each alternative across all criteria:
This index can be calculated based on the concept of the degree of similarity of alternative A_i relative to the ideal solutions.

$$P_i^+ = \frac{S_i^+}{S_i^+ + S_i^-} \quad \ldots(10)$$

i= 1,2,…,n

i. Ranking the alternatives in the descending order of the performance index value

V. RESULTS

PARAMETERS / 3D PRINTERS	C1. PRINT VOLUME (cu. Inch.)	C2. MAXIMUM PRINT SPEED (mm/sec)	C3. MINIMUM. LAYER THICKNESS (µm)	C4. NUMBER OF EXTRUDERS	C5. PRICE PER UNIT (Rs.)	C6. MANUFACTURER FILAMENT PRICE (PLA) DOLLARS/KG
A1. MAKERBOT REPLICATOR MINI	3.9×3.9×4.9	80	200	1	146400	48
A2. PRINTRBOT SIMPLE	6×6×6	80	100	1	73100	30
A3. ULTIMAKER 2	9×8.85×8	300	20	1	255500	42
A4. XYZ DA VINCI 1.0	7.8×7.8×7.8	150	100	1	77400	46.65
A5. MAKERBOT REPLICATOR 5.0	9.9×7.8×5.9	100	100	1	289800	48
A6. ALFINIA H	5×5×5	30	150	1	127600	31.99
A7. UP PLUS 2	5.5×5.5×5.3	30	150	1	167100	56.4
A8. DITTO PRO	8.7×6.5×8.7	120	50	1	192800	44.99
A9. AIRWOLF AW3D HD	12×8×12	150	60	1	301600	48
A10. FELIX 3.0	10×8×9	200	50	1	203100	32.6
A11. CUBIFY CUBEPRO	11.2×10.6×9.06	15	70	1	283500	99
A12. MBOT GRID	10×9.0×7.8	120	100	2	146700	29.16

In the above table, different types of available 3D printers alongwith their corresponding values of parameters have been shown.

- Criteria C1, C2 and C4 are of maximisation type whereas C3, C5 and C6 are of minimisation type.
- *Printer max level of resolution* describes minimum attainable layer thickness in micrometres (µm).
- *Extruder***:** A group of parts which handles feeding and extruding of the build material. It consists of two assemblies: a cold end to pull and feed the thermoplastic from the spool, and a hot end that melts and extrudes the thermoplastic.
- *Filament***:** Plastic material made into (often 3mm) string to be used as raw material in 3Dprinters.
- *PLA (Polylactic acid)*: A biodegradable thermoplastic polymer used as a 3D printer material.

A. *Determination of relative weights of criteria using ANP :*

The relative weights of criteria, judging the selection of suitable 3D printer for educational institutions, can be determined using an ANP Network of Nodes and Clusters.The ANP Model illustrated below has been framed using *Super Decisions Software.*The clusters include goal, criteria and alternatives. The alternatives' cluster is composed of different 3D printers among which the best one has to be chosen. The network for the ANP model shown in Figure 3 well describes the links between the clusters.

- *Unweighted Supermatrix***:** The unweighted supermatrix is constructed from the priorities derived from the different pairwise comparisons. The supermatrix for the network in Figure 3 is shown in Table 1.
- *Cluster Matrix*: The cluster themselves must be compared to establish their relative importance and use it to weight the corresponding blocks of the supermatrix to make it column stochastic. A cluster impacts another cluster when it is linked from it, that is, when at least one node in the source cluster is linked to nodes in the target cluster. The cluster matrix is shown in Table 2.
- *Weighted Supermatrix:* The weighted supermatrix shown in Table 3 is obtained by multiplying each entry in a block of the component at the top of the supermatrix by the priority of influence of the component on the left from the cluster matrix in Table 2.
- *Limit Supermatrix:* The limit supermatrix shown in Table 4 is obtained from the Weighted Supermatrix.
- *Priorities List:* Finally by utilising Limit Supermatrix, as shown in Table 4, the priorities list has been laid out in Table 5 and the Bar graph in Figure 4 shows the corresponding weights for every criterion.

In this paper we use a Similarity based approach introduced by Deng [7], to rank 3D printers according to parameters relevant for their selection in educational institutions.
Tables 6-9 represent the results that were obtained by using this technique.

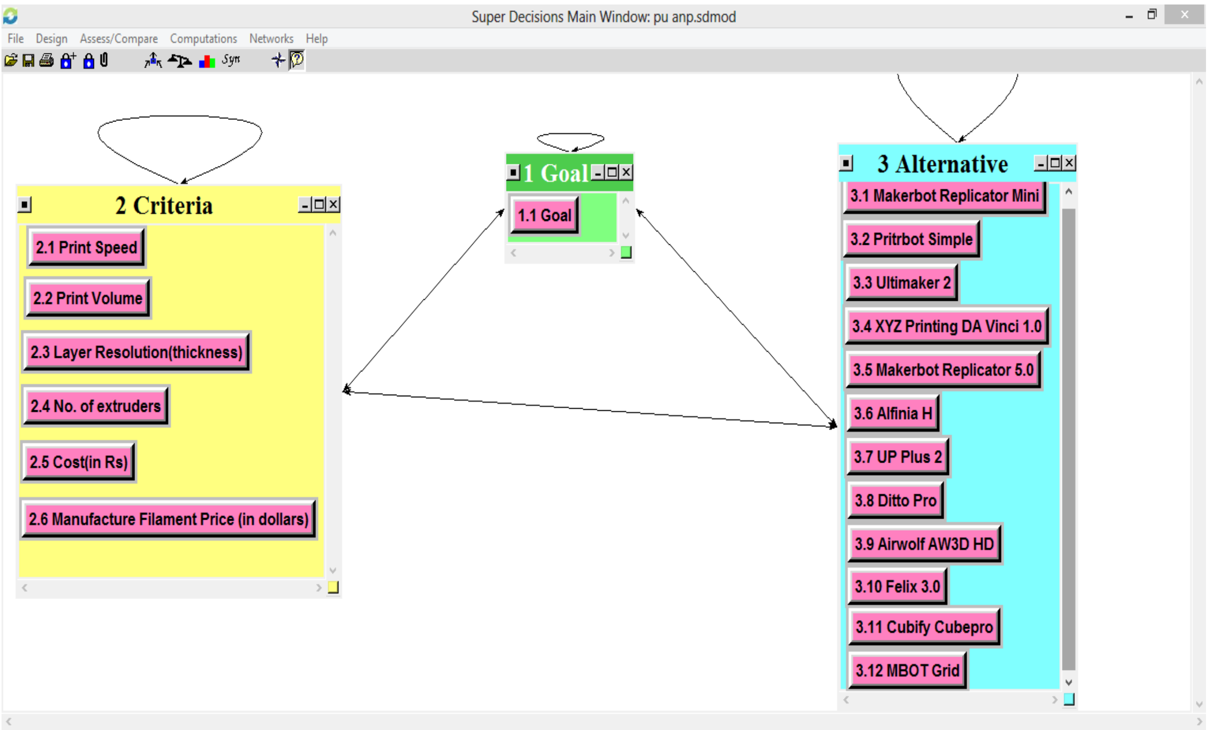

Figure 4: The Clusters and Nodes of a Model to determine the relative weights of criteria

Table 1. UNWEIGHTED SUPER MATRIX

	GOAL	C1	C2	C3	C4	C5	C6	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
GOAL	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
C1	0.10489	0.00000	0.00000	0.12601	0.19469	0.24102	0.25000	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667
C2	0.14936	0.28717	0.00000	0.00000	0.08808	0.05084	0.00000	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667
C3	0.08025	0.29867	0.00000	0.00000	0.00000	0.16904	0.75000	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667
C4	0.05568	0.41417	0.16667	0.00000	0.00000	0.09903	0.00000	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667
C5	0.39386	0.00000	0.83333	0.45793	0.71723	0.00000	0.00000	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667
C6	0.21596	0.00000	0.00000	0.41606	0.00000	0.44006	0.00000	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667
A1	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
A2	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
A3	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
A4	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
A5	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
A6	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
A7	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000
A8	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000
A9	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000
A10	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000
A11	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000
A12	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000

Table 2 CLUSTER MATRIX

	1. GOAL	2. CRITERIA	3. ALTERNATIVE
1.GOAL	0.636986	0.636986	0.636986
2.CRITERIA	0.258285	0.258285	0.258285
3.ALTERNATIVE	0.104729	0.104729	0.104729

Table 3. WEIGHTED SUPER MATRIX

	GOAL	C1	C2	C3	C4	C5	C6	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
GOAL	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699
C1	0.02709	0.00000	0.00000	0.03254	0.05029	0.06225	0.06457	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305
C2	0.03858	0.07417	0.00000	0.00000	0.02275	0.01313	0.00000	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305
C3	0.02073	0.07714	0.00000	0.00000	0.00000	0.04366	0.19371	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305
C4	0.01438	0.10697	0.04305	0.00000	0.00000	0.02558	0.00000	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305
C5	0.10173	0.00000	0.21524	0.11828	0.18525	0.00000	0.00000	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305
C6	0.05578	0.00000	0.00000	0.10746	0.00000	0.11366	0.00000	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305	0.04305
A1	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.10473	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
A2	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00000	0.10473	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
A3	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00000	0.00000	0.10473	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
A4	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00000	0.00000	0.00000	0.10473	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
A5	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00000	0.00000	0.00000	0.00000	0.10473	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
A6	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00000	0.00000	0.00000	0.00000	0.00000	0.10473	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
A7	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.10473	0.00000	0.00000	0.00000	0.00000	0.00000
A8	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.10473	0.00000	0.00000	0.00000	0.00000
A9	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.10473	0.00000	0.00000	0.00000
A10	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.10473	0.00000	0.00000
A11	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.10473	0.00000
A12	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.10473

Table 4. LIMIT MATRIX

	GOAL	C1	C2	C3	C4	C5	C6	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
GOAL	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699	0.63699
C1	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261	0.03261
C2	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308	0.03308
C3	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423	0.03423
C4	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074	0.02074
C5	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432	0.08432
C6	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330	0.05330
A1	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873
A2	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873
A3	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873
A4	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873
A5	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873
A6	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873
A7	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873
A8	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873
A9	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873
A10	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873
A11	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873
A12	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873	0.00873

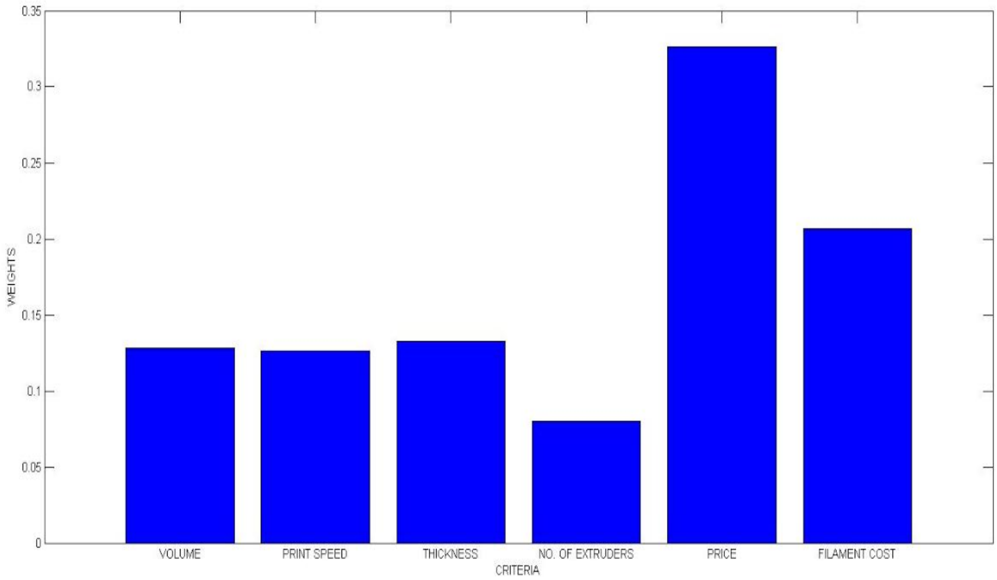

Figure 5: Graph illustrating Relative Weights of Different Criterion

TABLE 6: DECISION MATRIX

3D PRINTER	C1(+)	C2(+)	C3(-)	C4(+)	C5(-)	C6(-)
A1	74.529	80	200	1	146400	48.00
A2	216.000	80	100	1	73100	30.00
A3	637.200	300	20	1	255500	42.00
A4	474.552	150	100	1	77400	46.65
A5	455.598	100	100	1	289800	48.00
A6	125.000	30	150	1	127600	31.99
A7	160.325	30	150	1	167100	56.40
A8	491.985	120	50	1	192800	44.99
A9	1152.000	150	60	1	301600	48.00
A10	720.000	200	50	1	203100	32.60
A11	1075.600	15	70	1	283500	99.00
A12	702.000	120	100	2	146700	29.16
WEIGHTS	0.12808	0.12627	0.13254	0.08029	0.32645	0.20637

TABLE 7: NORMALISED DECISION MATRIX

3D PRINTER	C1(+)	C2(+)	C3(-)	C4(+)	C5(-)	C6(-)
A1	0.0344	0.1673	0.5366	0.2582	0.2075	0.2785
A2	0.0999	0.1673	0.2683	0.2582	0.1036	0.174
A3	0.2948	0.6274	0.0536	0.2582	0.3622	0.2437
A4	0.2196	0.3137	0.2683	0.2582	0.1097	0.2707
A5	0.2108	0.2091	0.2683	0.2582	0.4108	0.2785
A6	0.0578	0.0627	0.4024	0.2582	0.1809	0.1856
A7	0.0741	0.0627	0.4024	0.2582	0.2369	0.3272
A8	0.2276	0.2509	0.1341	0.2582	0.2733	0.2611
A9	0.5331	0.3137	0.1609	0.2582	0.4275	0.2785
A10	0.3331	0.4182	0.1341	0.2582	0.2879	0.1891
A11	0.4977	0.0313	0.1878	0.2582	0.4019	0.5745
A12	0.3248	0.2509	0.2683	0.5165	0.2079	0.1692
WEIGHTS	0.12808	0.12627	0.13254	0.08029	0.32645	0.20637

TABLE 8. PERFORMANCE MATRIX

3D PRINTER	C1	C2	C3	C4	C5	C6	COS θ+	COS θ-	Si+	Si-
A1	0.004	0.021	0.071	0.021	0.068	0.057	0.53	0.94	0.51	0.56
A2	0.013	0.021	0.036	0.021	0.034	0.036	0.72	0.89	0.40	0.31
A3	0.038	0.079	0.007	0.021	0.118	0.050	0.81	0.77	1.03	0.61
A4	0.028	0.040	0.036	0.021	0.036	0.056	0.83	0.82	0.62	0.38
A5	0.027	0.026	0.036	0.021	0.134	0.057	0.6	0.93	0.77	0.74
A6	0.007	0.008	0.053	0.021	0.059	0.038	0.51	0.95	0.38	0.44
A7	0.009	0.008	0.053	0.021	0.077	0.068	0.52	0.99	0.50	0.59
A8	0.029	0.032	0.018	0.021	0.089	0.054	0.73	0.91	0.69	0.53
A9	0.068	0.040	0.021	0.021	0.140	0.057	0.73	0.84	1.03	0.73
A10	0.043	0.053	0.018	0.021	0.094	0.039	0.83	0.8	0.84	0.51
A11	0.064	0.004	0.025	0.021	0.131	0.119	0.61	0.93	0.95	0.89
A12	0.042	0.032	0.036	0.041	0.068	0.035	0.83	0.82	0.72	0.44

Ranking the alternatives in the descending order of the performance index value by Deng's Similarity Method**:**

TABLE 9.

3D PRINTER	Pi	RANKS
A3	0.628	1
A10	0.623	2
A4	0.619	3
A12	0.618	4
A9	0.584	5
A2	0.565	6
A8	0.564	7
A11	0.515	8
A5	0.511	9
A1	0.475	10
A6	0.464	11
A7	0.457	12

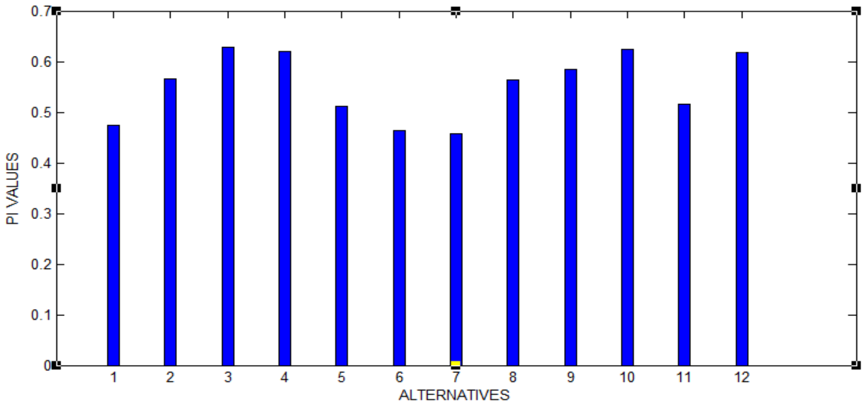

Figure 6: Performance Index for different 3D Printers

VI. ANALYSIS OF RESULTS

In this method the overall performance index of each alternative across all criteria has been determined based on the combination of the degree of similarity to PIS and NIS using alternative gradient and magnitude. On the basis of the ranks obtained, Ultimaker 2(A3) emerges out to be the best solution while on the contrary UP PLUS 2(A7) proves to be the worst one. The feasibility of Ultimaker 2 to be regarded as the best solution, can be clearly illustrated using graph accounted below, wherein Ultimaker 2 has taken a gargantuan lead relative to each criteria, the only exception being the fifth non-beneficial criteria where it suffers a major setback.

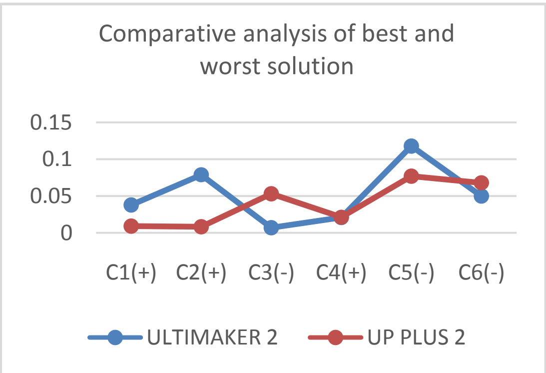

Figure 7

VII. CONCLUSION

Most decision making processes concern themselves with judging alternatives by what goes into them. But considering consequences may be more important than ensuring that every attribute has been included. Linear hierarchic methods of decision making can only project forward. It is necessary as well as beneficial to look into what comes out of the alternatives as consequences or effects and choose the best alternative after such consideration. The consequences must also need to be considered in the frameworks of different benefits, costs, opportunities and risks involved. The traditional linear structures of decision making process derive priorities or utilities for alternatives in terms of attributes and criteria. For considering consequences, it becomes complex to deal with them in our present linear structures. But it can be done easily and far more correctly in a network structure such as ANP (Analytic Network Process) by simply including a cluster of consequences. This cluster would enable to create a feedback cycle with the alternatives that would modify their priorities as determined by the influence of other clusters in that network.

The Similarity based method presents a new methodology using the concept of alternative gradient and magnitude for solving the general multicriteria analysis problem effectively. The concept of the degree of similarity between the alternatives and the ideal solution is combined to derive an overall performance. The advantages of this method are named as the logic that represents the rationale of human choice and a scalar value that accounts for both the best and the alternatives simultaneously.

In this paper both ANP and Similarity based method have been used to rank the alternatives according to the desired criteria. While ANP gives the proper weightage of the criteria taking into consideration the consequences and priorities, the Similarity based method ranks them accordingly considering the human choice as well. However further improvement is possible in ranking these alternatives involving more criteria pertaining to educational institutions and other decision making tools.

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