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Decision Support System for Rapid Prototyping Process Selection

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Abstract- This paper presents a methodology for decision support system for rapid prototyping process selection. Experimentation recommends the methodology for RP process selection which is divided into three stages. First stage is to identify part requirements in terms of quality, cost and time. Second stage is generating feasible alternative processes and attributes data collection based on benchmarking. Attributes considered for evaluation are the most significant those will affect the selection of RP process. Third stage is to evaluate the data by decision making Method such as Graph Theory and Matrix Approach and TOPSIS method.

Index Terms- RP Process Selection, Graph Theory and Matrix Approach, AHP, TOPSIS, Decision Methods

I. Introduction

The competition in world market is rising tremendously day-by-day. Now, it is crucial for products to reach market as early as possible before competitors. New technology is required - compress time to market the products. Rapid Prototyping is a promising time compression technique. Rapid Prototyping technologies are energy efficient, less material wastage and can process complex shapes without tooling.

Rapid prototyping is widely used in the automotive, aerospace, medical, and consumer products industries. Rapid prototyping and manufacturing prototypes are increasingly used in the development of new products, spanning conceptual design, functional prototypes, and tooling.

There are a large number of R.P. Technologies available in the market and continuously new advancement in technologies as well as their materials are making selection problem more complex. However, it is really difficult for users with RP experience to select a suitable process because there are so many RP systems worldwide, and the best selection depends on many attributes. Furthermore, each system has its own strengths, defects, applications, utilities and limitations. It is a complex problem that cannot be solved readily using conventional statistical techniques alone. Selection of an appropriate process requires a sound understanding of the interactions between the part quality, part properties, part cost, build envelope, build time (speed) and other concerns. [3]

Since the selection of the appropriate technology addresses different process and cost attributes, it is a decision problem with many objectives implying many quantitative and qualitative factors that can be studied. So main problem with technology selection are:

i. Multiple alternatives are available.
ii. Wide application areas of RP parts.
iii. Various quantitative and qualitative attributes data.
iv. Expert judgment.

II. Methodology

II. 1 *Previous Work Study*

Marcello Bragalia, Alberto Petroni [1], proposes a methodology that is based on Analytic Hierarchy Process. Data have been drawn from a survey of twenty-one end-users (consisting of both firms and service bureaus) of twenty different types of RP Machines. The methodology has proved to be an effective tactical tool for selecting the technology that best fits the end-user's needs.

P.C. Smith, A. E. W. Rennie [2], studied all the processes, machine specifications, materials available in particular region and database for selector tool was developed. Relationship database was constructed detailing the types of machines available from various producers, the different types of technologies each machine used, available materials for each machine and based on this database selector tool was developed.

Rao and Padmanabhan [3], by using Diagraph method and Matrix approach, ‘rapid prototyping process selection index’ is proposed to evaluate and rank the RP processes for producing a given part. It defines desirable attributes of a rapid prototyping system as process selection criteria. The interrelations between the selection criteria in terms of their relative importance are modeled in diagraph and matrix style and evaluated with permanent function.

Nagahanumaiah, K. Subburaj, B. Ravi [4], presents a computer aided rapid tooling process selection and manufacturability evaluation methodology. Analyze customer tooling requirement and pair wise comparison of attributes by AHP. Then selection of Rapid tooling process based on process capability mapping in quality function deployment (QFD) against a set of tooling requirements. Then the effect of each process variable of the selected RP process is mapped and prioritized to identify critical process parameters.

D.T.Pham, R.S.Gault [5], presented an overview of the RP technologies and further process strengths and weaknesses are detailed. Flowcharting logical technique is used for selection of RP process based on requirement of part.

Market needs a decision support system which is simple but able to manage complexity and technique should be scientific. To increase use of RP process and for proper process selection, a decision support system needs to be developed keeping in view the end use of part.

2.2 Methodology:

Step 1: Part requirements are divided into basic three categories:

a) Quality attributes – Accuracy, Surface Finish, Strength, Heat Resistance and Percentage Elongation.
b) Cost – RP Part Cost
c) Time requirement – Build Time

Step 2: Data collection of RP processes for attributes relevant to part requirements data –

a) Benchmark part fabrication through selected RP processes – SLA, SLS, 3DP and FDM.
b) Measurements of part against parameter - quality, cost and build time.

Step 3: Apply decision making methods - Graph Theory and Matrix Approach, TOPSIS, for analyzing the data and for selection of RP process.

III. RAPID PROTOTYPING PROCESS SELECTION

1. Prototype part requirements identification

Proto part for design verification purpose, requirements were identified from three users. One is Prototype part service bureau which produces parts based on order received (A), Actual User of the part (B), and third one is RP process Machine manufacturer (C). Based on part requirement user rating obtained on scale of 1 to 10 and data is tabulated in table 1.

TABLE I
RP DESIGN VERIFICATION PROTO PART REQUIREMENTS

User	Accuracy (A)	Surface Finish (R)	Tensile Strength (S)	Elongation (E)	Part Cost (C)	Build Time (T)	Heat Deflection Temperature (HR)
A	7	7	6	6	5	5	4
B	7	7	7	6	5	5	3
C	8	7	6	6	6	5	4

2. RP Process attributes data collection

The fabrication of the geometric benchmark part done on four widely used RP processes, which are the liquid-based Steriolithography (SLA), Fused Deposition Modeling (FDM) and powder-based Selective Laser Sintering (SLS) and 3 Dimensional Printing Machine. The RP process was set to achieve required geometric accuracy as part to be used for design verification.

Fabricated part from each process measured on CMM for geometrical accuracy and for surface roughness by Roughness Tester Taylor Hobson Talysurf Model 120. Other mechanical properties such as tensile strength, Percentage Elongation, heat resistance are taken from standard Material data sheet available from material manufacturer. Build Time measured during part production and part cost are taken as per estimation. Results are tabulated in Table 2.

TABLE 2
RP PROCESS BENCHMARK PART ATTRIBUTE VALUES

RP Process	Machine details	Material	Accuracy (A)	Surface Finish (R)	Tensile Strength (S)	Elongation (E)	Heat Deflection Temperature (HR)	Part Cost (C)	Build Time (T)
Unit of Measurement			mm	μm	MPa	(%)	°C	Rs.	min
SLA	VIPER SI2	ACCURA 110	0.129	4	62	5	56	5500	240
SLS	Sinterstation HiQ	Duraform	0.205	12	43	8	177	5800	240
3DP	Z510	Zp150	0.319	28	14	0.2	70	2000	180
FDM	FDM 900mc	ABS P400	0.289	18	22	10	90	3200	300

3. Decision Making methods

Decision makers frequently face the problem of assessing a wide range of alternative options and selecting one based on a set of conflicting criteria. In decision making environment, need is for simple, systematic, logical and scientific method to guide decision makers in considering a number of selection criteria and their interrelations.

Graph Theory and Matrix Approach

Graph Theory and Matrix Approach, Multiple Attribute Decision Making (MADM) method require both intra- and inter-attribute comparisons and involve explicit tradeoffs that are appropriate for the problem considered.

Table 2 data values normalized for non-beneficiary attribute Value $A_i = V_j / V_i$ where in V_j - Lowest Value of Measure, V_i– Measured value of ith alternative and for beneficiary attribute $A_i = V_i / V_j$ where in V_i- Measured value of ith alternative, V_j – Highest value of jth alternative.

TABLE 3
RP PROCESS BENCHMARK PART ATTRIBUTE VALUES

RP Process	(A)	(R)	(S)	(E)	(C)	(T)	(HR)
SLA	1.000	1.000	1.000	0.500	0.273	0.510	0.316
SLS	0.627	0.333	0.694	0.800	0.259	0.510	1.000
3DP	0.403	0.143	0.226	0.020	1.000	1.000	0.395
FDM	0.444	0.222	0.355	1.000	0.500	0.432	0.508

Secondly attributes are compared pair wise for their importance and relative importance decision matrix prepared.

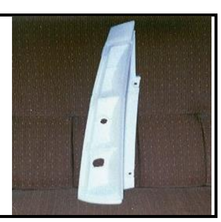
D =

Attributes	(A)	(R)	(S)	(E)	(C)	(T)	(HR)
(A)		0.500	0.600	0.600	0.700	0.700	0.800
(R)	0.500		0.600	0.600	0.700	0.700	0.800
(S)	0.400	0.400		0.500	0.600	0.600	0.700
(E)	0.400	0.400	0.500		0.600	0.600	0.700
(R)	0.300	0.300	0.400	0.400		0.500	0.600
(T)	0.300	0.300	0.400	0.400	0.500		0.600
(HR)	0.200	0.200	0.300	0.300	0.400	0.400	

RP Process selection attribute function which is Permanent of attribute matrix evaluated with MATLAB and RPSI for each process obtained and arranged in descending order of RP process selection index. The RP process having the highest value of RP process selection index is the best suitable process.

TABLE 4
RPSI FOR DESIGN VERIFICATION PROTO PART (CAR TAIL LAMP HOUSING)

RP Process	RPSI
SLA	42.3577
SLS	38.5798
3DP	24.6768
FDM	29.8983



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TOPSIS Method

This method is based on the concept that the chosen alternative should have the shortest Euclidean distance from the ideal solution, and the farthest from the negative ideal solution.

Step1: In this method Table 2 values are normalized by R_{ij} and the normalized decision matrix obtained as mentioned in Table 5.

$$Rij = \frac{m_{ij}}{\left[\sum_{j=1}^{M} m^2 ij\right]^{\frac{1}{2}}}$$

TABLE 5
NORMALISED RP PROCESS ATTRIBUTES R_{ij}

RP Process	(A)	(R)	(S)	(E)	(C)	(T)	(HR)
SLA	0.260	0.112	0.777	0.364	0.634	0.523	0.257
SLS	0.415	0.337	0.539	0.582	0.669	0.523	0.812
3DP	0.646	0.786	0.175	0.015	0.173	0.267	0.321
FDM	0.586	0.505	0.276	0.727	0.346	0.617	0.413

Step 2: decide the relative importance (i.e. weights) of different attributes with respect to the objective. A set of weights W_j (for j=1, 2… M) such that $\sum W_j = 1$. These weights are obtained by Analytic Hierarchy Process (AHP) method and are as mentioned below.

TABLE 6
Weights W_j by AHP Method

RP Process	(A)	(R)	(S)	(E)	(C)	(T)	(HR)
W_j	0.2570	0.1990	0.1701	0.1395	0.1099	0.0586	0.0658

Step 3: Obtain the weighted normalized matrixV_{ij}. This is done by the multiplication of each element of the column of the matrix R_{ij} with its associated weightW_j. Hence, the elements of the weighted normalized matrix V_{ij} are expressed as:

$$V_{ij} = W_j \,.\, R_{ij}$$

Step 4: Obtain the ideal (best) and negative ideal (worst) solutions in this step. The ideal (best) and negative ideal (worst) solutions can be expressed as:

$$V^+ = \{(\sum_i^{max} V_{ij} / j\epsilon J), (\sum_i^{min} V_{ij} / j\epsilon J')/i = 1,2, \dots, N\}$$
$$= \{V_1^+, V_2^+, V_3^+, \dots V_M^+\}$$
$$V^- = \{(\sum_i^{max} V_{ij} / j\epsilon J), (\sum_i^{min} V_{ij} / j\epsilon J')/i = 1,2, \dots, N\}$$
$$= \{V_1^-, V_2^-, V_3^-, \dots V_M^-\}$$

Where J = (j = 1,2,…,M) / j is associated with beneficial attributes, and

J' = (j = 1,2,…,M) / j is associated with non-beneficial attributes.

V_j^+ indicates the ideal (best) value of the considered attribute among the values of the attributes for different alternatives. In case of beneficial attributes it indicates the higher value of the attribute. In case of non-beneficial attributes it indicates the lower value of the attribute and vice versa for V_j^-.

TABLE 6
V_{ij} MATRIX

RP Process	(A)	(R)	(S)	(E)	(C)	(T)	(HR)
SLA	0.0669	0.0224	0.1321	0.0507	0.0697	0.0307	0.0169
SLS	0.1066	0.0671	0.0916	0.0812	0.0735	0.0307	0.0535
3DP	0.1660	0.1565	0.0298	0.0020	0.0190	0.0156	0.0212
FDM	0.1506	0.1006	0.0469	0.1015	0.0380	0.0362	0.0272
V_j^+	0.0669	0.0224	0.1321	0.1015	0.0190	0.0156	0.0535
V_j^-	0.1660	0.1565	0.0298	0.0020	0.0735	0.0362	0.0169

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Step5: The separation of each alternative from the ideal one is given by the Euclidean distance in the following equations.

$$S_i^+ = \sqrt{\{\sum_{j=1}^{M}(V_{ij} - V_j^+)^\wedge 2\}} \ , \quad S_i^- = \sqrt{\{\sum_{j=1}^{M}(V_{ij} - V_j^-)^\wedge 2\}} \ , \quad i=1,2,\ldots,N$$

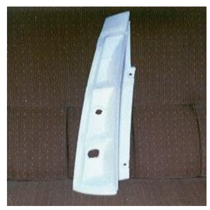
Step6: The relative closeness of a particular alternative to the ideal solution, P_i, can be expressed as below-

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

A set of alternatives are arranged in descending order , according to the value of Pi indicating the most preferred and least preferred feasible solutions. Pi may also be called the overall or composite performance score of alternative Ai.

TABLE 7
CPSI FOR DESIGN VERIFICATION PROTO PART (CAR TAIL LAMP HOUSING)

RP Process	S_i^+	S_i^-	P_i
SLA	0.0819	0.2017	0.7112
SLS	0.0939	0.1516	0.6173
3DP	0.2218	0.0584	0.2084
FDM	0.1479	0.1221	0.4523

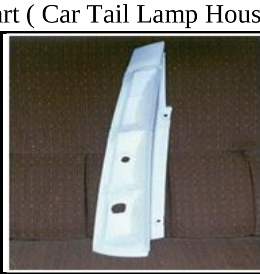


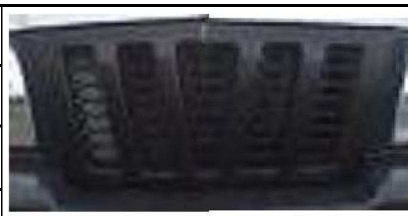
3.3 *Comparison of Results:*

As mentioned in below table RP Process Selection Index by Graph Theory and Matrix Approach and Composite Performance Selection Index by TOPSIS method, process ranking achieved is same. Same Calculations repeated for other applications like functional proto, Direct End use proto part and results are tabulated as below.

TABLE 8
RESULTS COMPARISION

Design Verification Proto Part (Car Tail Lamp Housing)		
RP Process	RPSI (GTMA)	CPSI (TOPSIS)
SLA	**42.3577**	**0.7112**
SLS	38.5798	0.6173
3DP	24.6768	0.2084
FDM	29.8983	0.4523
Functional Proto Part (Car Front Grill)		
SLA	24.5713	0.5289
SLS	**25.9885**	**0.7198**
3DP	17.0396	0.1544
FDM	18.7041	0.3791
Direct End Use Proto Part (Car Fuel Cap Assembly Gauge)		
SLA	**40.0232**	**0.6721**
SLS	36.0913	0.6709
3DP	23.5863	0.1336
FDM	28.4627	0.4889





IV. CONCLUSION

i. Decision making methods helps in systematic and analytical manner to address every element of selection - complexity due to interrelation of attributes, wide range of RP alternatives available, variety of RP prototype application areas, expertise requirement in process selection.
ii. Qualitative and subjective judgments by different peoples can be included in the priority setting.
iii. Proposed approach forms a basis for database creation for network RP processes, database creation based on variety of alternatives and evaluating part requirements for best suitable RP process.
iv. This study demonstrates potential benefits of using structured approach to the selection of alternative rapid prototyping processes. The methodology described in this study can provide guidance not only for RP process selection but also for other areas of Decision making in manufacturing areas.

APPENDIX

Nil

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