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SELECTION OF RAPID PROTOTYPING TECHNOLOGY

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Abstract:
The competition in world market has intensified tremendously. Time to market a product is reduced considerably. Therefore, substantial reduction in time, methodology and material resources for development & production is required. Rapid Prototyping is a promising Time Compression technique. There are a large number of R.P. Technologies available in the market.

Appropriate technology selection is a difficult, multitasking and complex process for technology seekers. The selection of RP system is difficult due to lack of bench mark standards and industry experiences with most of these systems. Earlier attempts were made to compare different RP system on basis of benchmarking studies conducted by either user companies or independent researchers.

There is a general shortage of benchmark standards and industry experience with machines. Some past benchmarking studies have confirmed that accuracy and surface finish quoted in sales brochures can only achieved under ideal laboratory conditions. Bench marking studies can be time consuming and quite expensive. Moreover RP vendors do not agree on a common benchmark part.

This work presents a systematic approach for selection of appropriate R.P. Technology. Analytic Hierarchy process technique developed by Saaty & Kearn (1985) is used to help decision maker to select appropriate technology. A structured Hierarchical model is designed incorporating objective of Rapid Prototyping Technology selection, issues and sub issues involved in Rapid Prototyping Technology selection problem.

Pair wise comparison is performed among issues, and further among sub issues using the scale of relative importance as given by Saaty. Eigen values and consistency ratio (Weight) of issues and sub issues are used for computation of grand rating point of different process. Process having highest Grand Rating point is obviously appropriate technology.

Methodology is illustrated by assuming a fictitious decision maker to select appropriate Rapid Prototyping Technology. Data have drawn from experience of end users of R.P. system and some data is taken arbitrarily by fictitious decision maker. The methodology is an effective tool for selecting appropriate Rapid Prototyping Technology that best fits end user's needs.

The novel contribution of this work is to develop AHP model based systematic approach to enable the potential academic and industrial users both to select the appropriate Rapid Prototyping Technology for their use. In the future work, we will include decision making uncertainties & risk involving in R.P. technology selection.

Key Words: Rapid Prototyping, Technology Selection, AHP

1. 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 and mythology is required to compress time to market of products. Rapid Prototyping is a promising time compression technique. There are a large number of R.P. Technologies available in the market. Lokesh Kumar & Jain P K presented a review paper titled" RAPID PROTOTYPING: A REVIEW, ISSUES AND PROBLEMS" [1].

Selection of any technology is a complex process to select appropriate technology [1,2] Decision maker must consider various quantitative and qualitative criteria. Important criteria are cost, flexibility, complexity, user friendliness, environmentally green as well as technical capabilities. The main problems with new technology selection are:

1- Multiple alternatives available,
2- Long term performance,
3- Quantitative criteria.

2. RAPID PROTOTYPING

Rapid prototyping is new technologies to cut time to market of a product. Rapid prototyping technology has the ability to cut the design-to market time by 75%, or more in some cases [3].

It has many applications in design of manufacturing of a product.

Main areas include concept presentation, design verification, prototype development and rapid tooling. [4], [5], [6] Rapid prototyping directly converts CAD model into real solid physical model.

Various steps in Rapid of prototyping are as follows:

1- Creation of CAD model of Design,
2- Conversion of CAD model to STL Format,
3- Cutting the STL File into thin cross-sectional layers or slice,
4- Construction of physical model by making one layer over another of material,
5- Clean and finish the physical model.

Various Rapid prototyping technologies are Steriolithography (SLA), Selective Layer Sintering (SLS), fused deposition modeling (FDM), 3 Dimensional printing (3DP), Solid Ground Curing (SGC), laminated object manufacturing (LOM), etc.

3. SELECTION OF RAPID PROTOTYPING TECHNOLOGY

The selection of Advanced Manufacturing Technologies (AMTs) is a hard and complex task because of the various attributes involved. Selection of an appropriate technology is becoming an increasing difficult task for organizations intending to adopt the technology to serve their specific needs.

There are a large number of RP systems available in market and number is increasing with time. Different users will require different things from an RP machine. Machines vary in terms of cost, size, range of build material, accuracy of the part, build envelope, time of build, surface finish and application etc. Manufacturers of RP systems are biased toward their own product. Conventions and exhibitions are a good way to make comparisons. But this does not identify usability of machine [7].

There are large expensive machines that can produce parts using a variety of materials with relativity high accuracy and for specific needs. In contrast, there are cheaper systems, which are designed to produce parts of acceptable quality in predictable and reliable manner. Therefore, to select best machine to suit one's need, no standard for trading off between costs and benefits, are not available [7].

In 2000, there were more than 6500 RP machine in use and producing over 2.3 million parts per year. RP market is growing at constant rate of 20 percent per annum. There are approximately 20 system manufacturers offering around 40 different models of RP machine. Therefore, it is very difficult to select appropriate technology for one's specific needs [8].

Selection of a RP system depend on several factors such as price accuracy, build envelope, build material, build speed, surface finish and type of application. Each RP system has its own strengths, limitations and application. The selection of RP system is also difficult due to lack of bench mark standards and industry experiences with most of these systems.

Earlier attempts were made to compare different RP system on basis of bench marking studies conducted by either user companies or independent researchers. In benchmarking studies, a bench mark part is created on different RP system to test the capability of RP system. But benchmarking studies are often hard to justify. The problem to be addressed will be, treated as material process chain selection. As for a given CAD model and prototyping requirement, choose a suitable prototyping material and then, choose sequence of process for that part to meet all of prototyping requirements in best way [9].

There is a general shortage of benchmark standards and industry experience with machines. Some past benchmarking studies have confirmed that accuracy and surface finish quoted in sales brochures can only achieved under ideal laboratory conditions. Bench marking studies can be time consuming and quite expensive. Moreover RP vendors do not agree on a common bench mark part [9].

4. ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchic Process (AHP) provides a framework to cope with multiple criteria situations involving intuitive, rational, qualitative and quantitative aspects. It first structures the problem in the form of a hierarchy to capture the basic elements of a problem and then derives ratio scales to integrate the perceptions and purposes into a synthesis.

AHP is developed by Saaty and Kearn (1985). [10], [11], [12]. It is a systematic procedure to break down problem into its smaller constituent parts. Then, it guides decision makers through as a series of pair wise comparison, judgment to express the relative strength or intensity of impact of elements in the hierarchy. Now, these judgments are translated to numbers step-by-step AHP can be described as follows:

Step 1:- Define the problem and objective

Step 2:- Structure the hierarchy from top (the objectives) through the intermediate level (criteria on which subsequent level depends) to lowest level (list of alternatives).

Step 3:- Make pair wise comparison of matrix for lower level elements. Make the comparison of elements in lower level based on their effects on the governing elements. This gives a square matrix of judgments. The pair wise comparisons are done element's dominance on other element.

Step 4:- There are n(n-1)/2 judgment decision needed to develop each matrix.

Step 5:- Now, consistency is determined using Eigen value. Then, consistency ratios are calculated.

Step 6:- Step 3, 4, 5, are followed for all levels in hierarchy.

Step 7:- Now, this synthesis is employed to weight the Eigen vectors by weights of criteria. Sum is taken over all weighted Eigen vector entries corresponding to those in next lower level of the hierarchy.

Step 8:- Now, consistency of entire hierarchy is obtained by multiplying each consistency index by priority of the corresponding criterion and adding them together. The result is then divided by the same type of expression using the random consistency index, corresponding to the dimension of each matrix, weighted by priorities as before.

The scale of relative importance as given by Saaty [12] is given in Table I.

Table I: Scale for pair wise comparison.

Intensity of relative importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over other	Experience and judgment slightly favor on activity over another
5	Essential or strong importance	Experience or judgment strongly favor on activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Extreme importance	The evidence favors on activity over another is of highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgment	When compromise as needed

AHP formulated can be solved by using commercial software such as expert choice. But, for simplicity, geometrical means or arithmetic mean can be used over Eigen vector which is difficult to compute manually

4.1 Development of the AHP structure

A graphical summary or tree diagram of AHP model constructed and Hierarchical structure representing objective and criteria is shown in Figure 1.

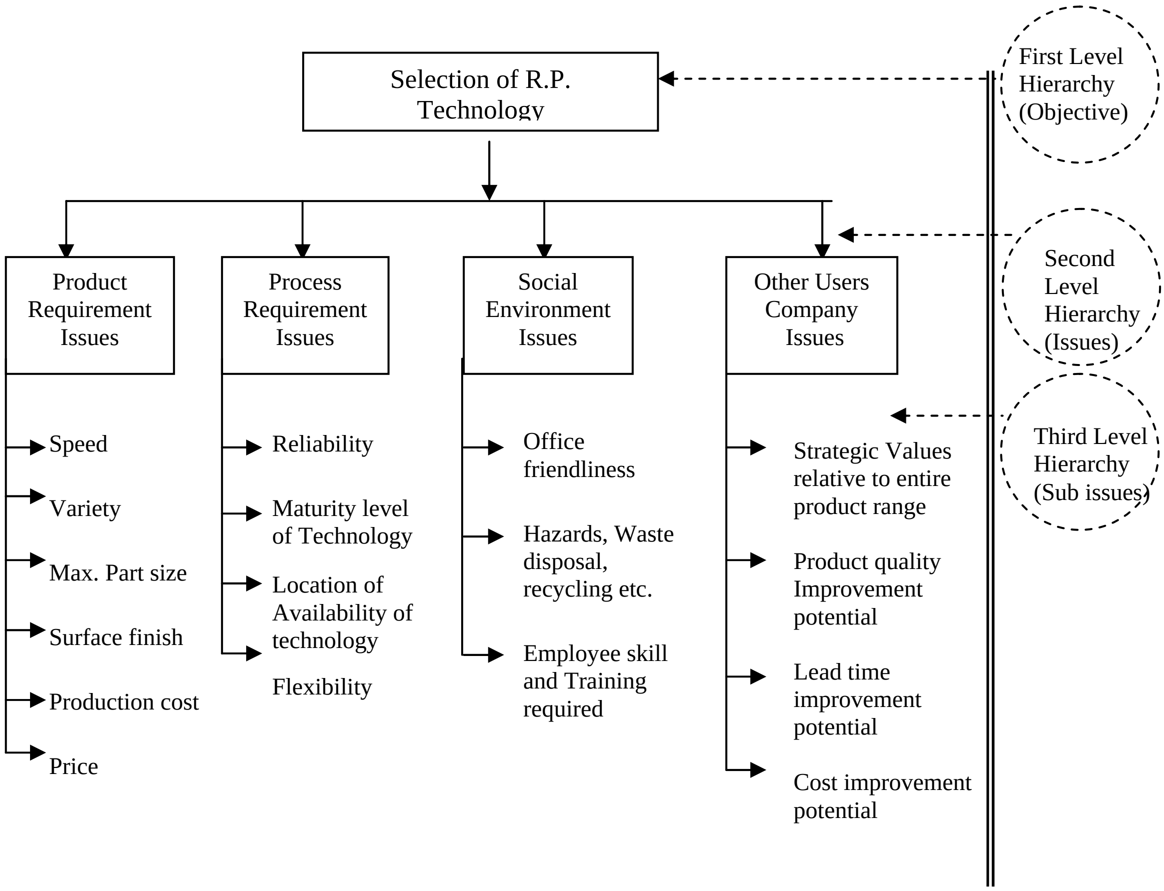

Figure 1: Tree diagram of model constructed.

4.2 Implementation of the AHP framework

For selection of appropriate R.P. process, a lot of information is required. It can be obtained from Journals, periodical, Internet, R.P. process company literature, interaction with expert in industry.

Table II shows assessment criteria and questionnaire to gain necessary perspective and information. Table III shows Rapid Prototyping Process at a glance. Table IV shows Pair wise comparison for Eigen values, consistency ratio (Priority values or weights) for various issues. Table V shows pair wise comparison for Eigen values, consistency ratio (Priority values or weights) for product requirement. Table VI shows pair wise comparison for Eigen values, consistency ratio (Priority values or weights) for Social and Environment issues. Table VII shows pair wise comparison for Eigen values, consistency ratio (Priority values or weights) for process requirement. Table VIII shows pair wise comparison for Eigen values, consistency ratio (Priority values or weights) for other issues of company. Table IX shows rating of different R.P. process.

Table II: Assessment criteria and questionnaire.

Issues ↓	Criteria	Assessment question	Rating point
Product requirement issues	Speed	What is the speed of system?	10- highest 5- moderate 7- high 3- low
	Variety	Can variety of material used?	10- highest 5- moderate 7- high 3- low
	Surface finish	Which surface finish can be obtained?	10- highest 5- moderate 7- high 3- low
	Production cost	What is the cost production?	10- low 5- high 7- moderate 3- highest
	Price	What is price of system?	10- low 5- high 7- moderate 3- highest
	Max part size	What is the maximum part size?	10- highest 3- moderate 7- high 0- low
Process requirement issues	Reliability	How reliable is process to give expected result?	10- highest 3- moderate 7- high 0- low
	Location of availability of technology	Distance of place of availability of technology,	7-10 Within country 2-5 several nearby countries 0-1 Just one country
	Maturity level of Technology	Availability of technology in market.	7-10 State of the Art 3-7 Emerging Tech. 0-2 Still in R & D Phase
	Flexibility	Ability to adjust to variety of product	7-10 Without difficulties 3-7 With Freedom 0-2 Nil, The Whole Process Restart
Social & Environmental issues	Office friendliness	Ease of use, accident free use	10- highest 3- moderate 7- high 0- low
	Hazardous recycling	Hazard to people, environment, recycling	0- highest 7- moderate 3- high 10- low
	Employee skill, training required	What skill and training needed	10- low 3-high 7- moderate 0- low
Other company issues	Strategic value relative to entire product range	What is the importance production manufactured products by process relative entire product range?	10: Important in short (today) and long term 7: Unimportant in short (today) and long term 3: Important in short (today) and long term 0: Unimportant in short (today) and long term
	Product quality improvement potential	Degree of quality of manufactured product by process that can be further improved?	10: High Potential 6: Medium Potential 2: Less potential 0: Zero
	Lead time improvement potential	Degree by which lead time of manufactured product by process that can be further improved?	10: High Potential 6: Medium Potential 3: Less potential 0: Zero
	Cost improvement potential	Degree by which cost of manufactured product by process that can be further improvement	10: High Potential 6: Medium Potential 3: Less potential 0: Zero

Table III: Rapid prototyping process at a glance.

R.P. System →		SLA	SLS	FDM	LOM	3DP	SGC
Issues↓	Criteria↓						
Product requirement issues	Speed (m/sec.)	254	125-250	175	380-610	860-1960	210
	Variety	Moderate	High	High	Less	Very low	Highest
	Max. part size	20x40x24	15x13x18	24x20x24	33x22x20	20x24x16	20x14x20
	Surface finish (μm)	2.25	7.5-10	6.5-12	30-40	60-70	5.8
	Prod. Cost $	33-50	25-42	52-68	4-8	0.1-0.3	32-92
	Price $	75-80k	300k	30-300k	120-24k	30-70k	35k
Social & Environment issues	Office friendly	Moderate	Less	Ok	Less	Ok	Less
	Hazard and waste disposal, recycling	Hazardous	Less Hazardous	Less Hazardous	Material compliant but in process smoke & fuzzy	Less Hazardous	Wax can not recycled
	Employee skill & training required	High	High	High	High	High	High
Process requirement issues	Reliability	Highest	High	High	Low	Higher	Lower
	Location of availability of technology	Less	Moderate	Moderate	Few	Highest	Lowest
	Maturity level of Technology	State of art	State of art	Emerging	Emerging	State of art	State of art
	Flexibility	Very less	Less	Moderate	High	Highest	Very less
Other company issues	Strategic value relative to entire product range	Important in short (today) and long term	Important in short (today) and long term	Important in short (today) and long term	Unimportant in short (today) and long term	Unimportant in short (today) and long term	Unimportant in short (today) and long term
	Product quality improvement potential	High potential	Medium potential	Medium potential	Medium potential	High potential	Zero potential
	Lead time improvement potential	Medium potential	Medium potential	Less potential	Medium potential	High potential	Less potential
	Cost improvement potential	Less potential	Medium potential	Less potential	Medium potential	High potential	Medium potential

Table IV: Pair wise comparison for Eigen values, consistency ratio (Priority values or weights) for various issues.

	Product .Requirem ent issues	Process Requirem ent issues	Social & Environme nt	Other issues of company	Eigen values (Geometri c mean)	Consisten cy ratio or weight
Product Requirement issues	1	3	5	5	(1x3x5x5)1/4 = 2.943	1.4953/5.4969 = 0.536
Process Requirement issues	1/3	1	5	3	1.4953	0.272
Social & Environment issues	1/5	1/5	1	1/5	0.2991	0.055
Other issues of company	1/5	1/3	5	1	0.7597	0.138
					Sum = 5.4969	

Table V: Pair wise comparison for Eigen values, consistency ratio (Priority values or weights) for product requirement.

	Speed	Variety	Surface finish	Prod. Cost	Price	Max part size	Eigen values	Consistency ratio
Speed	1	1/3	1/3	3	3	3	1.201	1.201/8.1693=0.147
Variety	3	1	2	5	5	5	3.014	0.369
Surface finish	3	½	1	5	5	5	2.392	0.293
Prod. Cost	1/3	1/5	1/5	1	5	3	0.765	0.012
Price	1/3	1/5	1/5	1/5	1	5	0.49	0.06
Max part size	1/3	1/5	1/5	1/3	1/5	1	0.31	0.04
							8.1693	

Table VI: Pair wise comparison for Eigen values, consistency ratio (Priority values or weights) for social and environment issues.

	Employee skill & training required	Office friendliness	Hazard recycling	Eigen values	Consistency ratio
Employee skill & training required	1	5	1/7	0.894	0.292
Office friendliness	1/5	1	3	0.844	0.276
Hazard recycling	7	1/3	1	1.3264	0.433
				3.0693	

Table VII: Pair wise comparison for Eigen values, consistency ratio (Priority values or weights) for process requirement.

	Reliability	Location of availability of technology	Maturity level of Technology	Flexibility	Eigen value	Consistency ratio
Reliability	1	5	3	2	$(1x5x3x2)^{1/4}$ = 2.34	0.464
Location of availability of technology	1/5	1	1/2	1/5	0.376	0.074
Maturity level of Technology	1/3	2	1	1/3	0.687	0.136
Flexibility	½	5	3	1	1.66	0.329
					5.042	

Table VIII: Pair wise comparison for Eigen values, consistency ratio (Priority values or weights) for other issues of company.

	Strategic value relative to entire product range	Product quality improvement potential	Lead time improvement potential	Costs improvement potential	Eigen value	Consistency ratio
Strategic value relative to entire product range	1	¼	¼	1/2	0.5	0.10
Product quality improvement potential	4	1	1/3	3	1.414	0.273
Lead time improvement potential	4	3	1	4	2.632	0.508
Costs improvement potential	2	1/3	¼	1	0.639	0.123
					5.185	

Table IX: Rating of different R.P. process.

Issues ↓	**Process →**	**Weight**		**SLA**		**SLS**		**FDM**		**LOM**		**3DP**		**SGC**	
	Criteria	Issues Weigtage (IW)	Criteria Weigtage	User Rating Point (U.R.)	Weighted rating (IWxCWxUR)	User rating point	Weighted rating (IWxCWxWRxUR)	User rating	Weighted rating	User rating	Weighted rating	User rating	Weighted rating	User rating	Weighted rating
Product requirement issues	Speed	0.535	0.147	7	0.35	3	0.24	3	0.24	2	0.55	9	0.71	3	0.24
	Variety	0.535	0.369	3	0.59	5	0.99	7	1.38	2	0.4	3	0.6	9	1.8
	Surface finish	0.535	0.293	8	1.25	3	0.47	7	1.1	7	0.31	1	0.16	5	0.94
	Prod. Cost	0.535	0.012	3	0.02	5	0.032	3	0.02	7	0.05	9	0.06	3	0.02
	Price	0.535	0.06	3	0.1	5	0.16	5	0.16	9	0.23	9	0.30	3	0.01
	Max. Part Size	0.535	0.04	8	0.17	6	0.13	7	0.15	4	0.2	8	0.17	7	0.15
Process Requirement Issues	Reliability	0.272	0.484	9	1.14	5	0.63	5	0.63	3	0.51	7	0.9	5	0.63
	Location of availability of technology	0.272	0.074	7	0.14	7	0.14	9	0.18	7	0.55	9	0.18	5	0.1
	Maturity level of Technology	0.272	0.136	8	0.3	9	0.33	7	0.26	8	0.26	9	0.33	1	0.04
	Flexibility	0.272	0.329	3	0.27	3	0.27	5	0.4	3	0.64	9	0.72	3	0.24
Social & Environment Issues	Employee skill &Training required	0.055	0.292	3	0.05	3	0.05	3	0.05	7	0.05	3	0.05	3	0.05
	Office friendliness	0.055	0.276	5	0.08	6	0.09	6	0.09	3	0.11	7	0.11	7	0.11
	Hazard Recycling	0.055	0.433	3	0.07	3	0.07		0.07	1	0.07	3	0.07	3	0.07
Other issues of company or organization	Strategic value relative to entire product range	0.138	0.1	9	0.12	9	0.12	9	0.12	7	0.04	7	0.1	1	0.04
	Product quality improvement potential	0.138	0.273	9	0.34	7	0.27	7	0.27	7	0.27	1	0.04	1	0.04
	Lead time improvement potential	0.138	0.508	7	0.07	7	0.49	3	0.21	7	0.49	7	0.49	3	0.21
	Costs improvement potential	0.138	0.123	5	0.09	5	0.09	5	0.09		0.12	9	0.15	7	0.12
Grand Rating point of process →				5.15		4.412		5.42		4.89		4.98		4.81	

5. CONCLUSION

This paper presents a model for selection of R.P. process. Model consider various issues such as product requirement issues, process requirement issues, social & environment issues and other issues of company which are vital consideration. Various issues and sub issues are structured in Hierarchy. Top level in hierarchy has objective i.e. selection of rapid prototyping technology. Second level consist of product requirement issues, process requirement issues, social and environment issues and other issues of company. Third level consists of sub issues in problem such as speed, variety, price, production cost, maximum part size, surface finish etc.

For modeling and solution, AHP technique is used. Various issues and sub issues are pair-wise compared. Weighted rating and grand rating of process is determined. Assessment and process rating is carried out by a fictitious decision maker as per his need. According to his assessment highest Grand rating point belong to FDM process. Therefore, for this user, FDM is found to be an appropriate technology.

This methodology can be used by decision makers to choose most appropriate R.P. technology. The novel contribution of this work is to develop AHP model based systematic approach to enable the potential academic and industrial users both to select the appropriate Rapid Prototyping Technology for their use. In the future work, we will include decision making uncertainties & risk involving in R.P. technology selection.

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