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RAPID PROTOTYPING TECHNOLOGY RANKING USING AN ANP APPROACH AND ITS SENSITIVITY ANALYSIS

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ABSTRACT

There are many rapid prototyping machine available in the market and all of them have their own advantages and limitations. When the time come to purchase a new machine it is a crucial decision to select best alternate available in the market. Here in this paper analytical network process approach is applied to this problem. This approach help in selecting best machine among the available options. A Frame work was developed in previous paper[1] for Selection of RP Technology based on some qualitative and quantitative attributes. In this paper Multi criteria based decision making Analytical Network Process Approach (ANP) is used for ranking and its sensitivity analysis done for robustness of framework.

KEYWORDS: Rapid prototyping; Analytical Network process; Machine Selection; Sensitivity Analysis.

INTRODUCTION

The rapid prototyping technology is growing day by day. The use of fully automatic additive manufacturing system provides many advantages to the industries in terms of time, money, profit, resources etc. The process of manufacturing the product without human interaction or with limited human interaction with the help of computer system. There are numerous machine available in the market which can do this task and the process of selecting best machine[2] from them is a laborious work as every machine have their own advantages and limitations. The selection process is done with the help on analytical network process (ANP) approach[3]. For the use of ANP[4] we have to select the parameter on which we will categories the machine selection process and also the framework is needed to be made which shows relationships between machine and selection criteria[5] and interrelationship between different criteria. The ANP approach[6] and the framework[7] was described in previous paper and here the ranking and sensitivity analysis is being described. Table number 1 below shows the nomenclature[8] of different attributes used in the ANP for ranking different attributes and figure number 1 below shows the frame work used for the process which have already been discussed in earlier paper[1].

Table 1. Nomenclature of different attributes used

Nomenclature			
CP	Customer Perspectives	IPPT	Initial Pre Processing Time
FP	Financial Perspectives	BUT	Build up Time
MC	Market Competitiveness	PPT	Post Processing Time
EP	Environmental Perspectives	GE	Gas Emission
TC	Total cost	NV	Noise & Vibration
PQ	Product Quality	WD&R	Waste disposal & Recycling
PCT	Product Cycle time	ALT1	FDM (Fused Deposition Machine)

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PC	Pollution Control	ALT2	SLS (Selective Laser Sintering)
MC'	Machine cost	ALT3	3DP(Three Dimensional Printing)
RM&PC'	Raw material & production cost		
EC	Energy consumption		
MS	Material Strength		
ACCU	Accuracy		
SF&CT	Surface finish & Close tolerance		

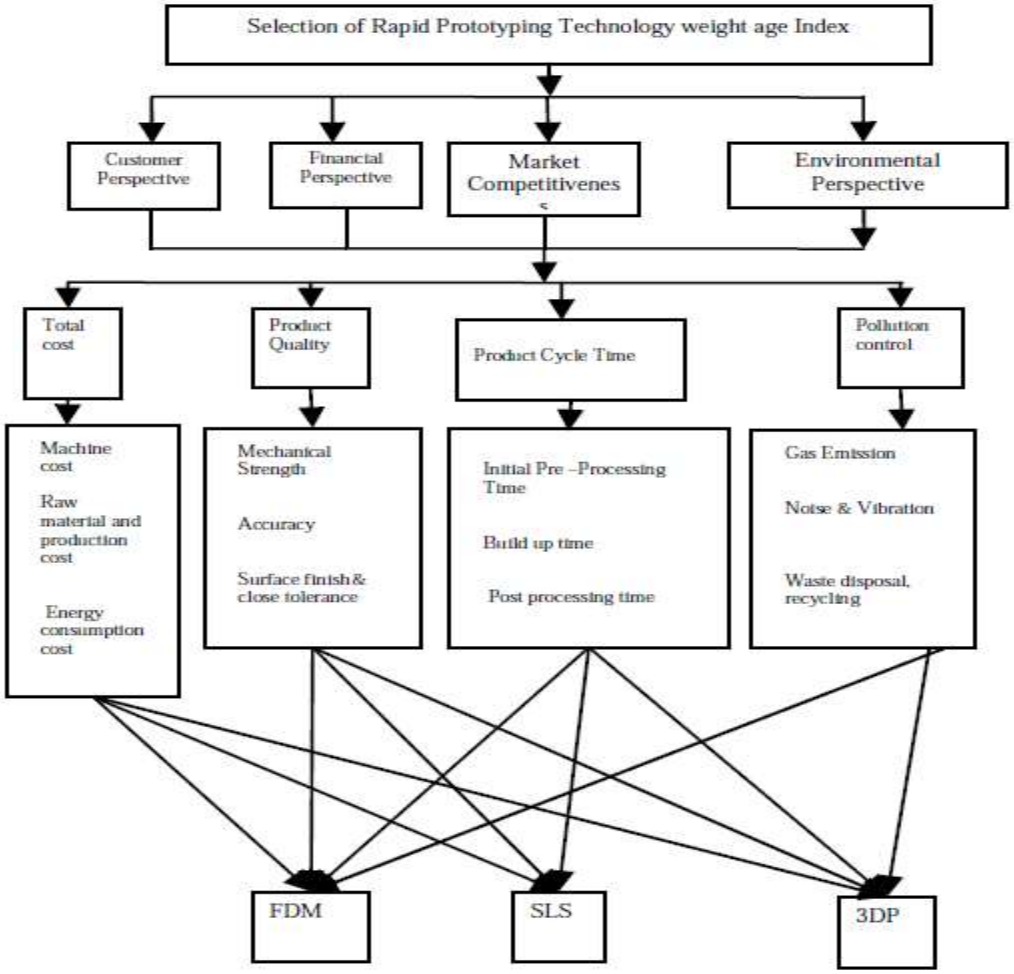

Figure 1: Decision Making Frame work

RANKING DIFFERENT TECHNOLOGIES

As there are numerous technologies available in the market but as we have discussed in our earlier paper we have selected three of them for our study i.e. fused deposition modeling, selective laser sintering and 3 dimensional printing. Now for selecting different attributes and for a robust comparison between these three technologies we have prepared a comparison between them which is shown below in table number 2.

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Table 2. Comparison between the Technologies[8,9,10,11,12,13,14,15,16]

Sr. No.	Components	FDM	SLS	3DP
1	Model Materials	ABS, Wax, Teflon Filament	Powder	Gypsum powder, conventional starch
2	Processing Speed	Low	Medium	High
3	Maximum Part Size (mm)	610x508x610	381x330x457	508x609x406
4	Accuracy (mm)	0.1-0.3 mm	0.1 to 0.2 mm	0.2 to 0.3 mm
5	Fabrication Technique	Fused deposition of Molten polymer	Selective laser tracing of polymer	Adhesive/glue Bonding of powder by inkjet
6	Preprocessing Time	5-10 min.	2Hrs	10-20 min.
7	Post Processing Time	1 to 2 Hrs.	5 to 10 Hrs.	1 to 2 Hrs.
8	Energy Consumed	Heat	High Power Laser Beam	Piezoelectric nozzle, heat
9	Laser Used	No	Yes	No
10	Solid Residues	Materials chips, removed supports	Materials chips	Removed Supports, materials chips
11	Gas Emission	CO2, CO, SOx, PM, NOx	CO_2	NIL
12	Strength	Axial compressive strength is 42 MPa	Axial -20 MPa	Axial -5 MPa Diagonal- 8 MPa Transverse-7 MPa
13	Speed (m/s)	175 m/s	125-250 m/s	860-1960 m/s
14	Variety	High	High	Very low
15	Surface Finish (µm)	6.5-12	7.5-10	60-70
16	Office friendly	OK	Less	OK
17	Employee skill & Training required	High	High	High
18	Reliability	High	High	Higher
19	Flexibility	Moderate	Less	Highest
20	Product Quality Improvement Potential	Medium Potential	Medium Potential	High Potential
21	Lead Time Improvement Potential	Less Potential	Medium Potential	High Potential
22	Cost Improvement Potential	Less Potential	Medium Potential	High Potential
23	Complex design	Limitation to extrude successively	Ease to form complex design	Ease to form complex design
24	Tensile Strength (Horizontal)	Approx. 35 MPa	Approx. 40 MPa	9 MPa
25	Tensile Strength (Vertical)	Approx. 20 MPa	Approx. 30 MPa	10 MPa

26	Minimum layer thickness (mm)	0.254 mm	0.1 mm	0.089 mm

Table number 3 below shows the relative importance among the Customer Perspective, Financial Perspective, Market Competitiveness and Environmental Perspective. The e-vectors calculated to find out the overall weighted index.

Table 3. Comparison of determinants

	CP	**FP**	**MC**	**EP**	**e-vector**	CR=CI/RI<0.1
CP	**1**	**3**	**0.2**	**3**	0.189815	0.038993444
FP	**0.333333333**	**1**	**0.166666667**	**2**	0.0936564	
MC	**5**	**6**	**1**	**9**	0.657545	
EP	**0.333333333**	**0.5**	**0.111111111**	**1**	0.0589835	

Table number 4 below shows super matrix M detailing the results of the relative measures for each of the attribute enablers for the customer perspectives determinant. Since there are 12 pair-wise comparison matrices, one for each of the interdependent enablers in Customer Perspective, there are 12 non-zero columns in the super matrix each of the non-zero values in the column of super matrix is the relative importance or weight associated with interdependently pair wise comparison matrices. In this model there are four super matrices, one such super matrix is shown in table 4.

Table 4. Super matrix for Cost before convergence

CP	MC'	RM & PC'	EC	MS	ACCU	SF & CT	IPPT	BUT	PPT	GE	NV	WD &R
MC'	0	0.125	0.166667	0	0	0	0	0	0	0	0	0
RM &PC'	0.75	0	0.833333	0	0	0	0	0	0	0	0	0
EC	0.25	0.875	0	0	0	0	0	0	0	0	0	0
MS	0	0	0	0	0.75	0.25	0	0	0	0	0	0
ACCU	0	0	0	0.333333	0	0.75	0	0	0	0	0	0
SF &CT	0	0	0	0.666667	0.25	0	0	0	0	0	0	0
IPPT	0	0	0	0	0	0	0	0.666667	0.2	0	0	0
BUT	0	0	0	0	0	0	0.75	0	0.8	0	0	0
PPT	0	0	0	0	0	0	0.25	0.333333	0	0	0	0
GE	0	0	0	0	0	0	0	0	0	0	0.666667	0.25
NV	0	0	0	0	0	0	0	0	0	0.25	0	0.75
WD &R	0	0	0	0	0	0	0	0	0	0.75	0.333333	0

The super matrix is converged for getting a long term stable set of weights. For this power of super matrix is raised to an arbitrarily large number. Convergence for customer Perspective is reached 61 power the table number 5 illustrates the value after convergence.

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Table 5. Super matrix 61 power

CP	MC'	RM & PC'	EC	MS	ACCU	SF&CT	IPPT	BUT	PPT	GE	NV	WD&R
MC'	0.1268	0.1268	0.1268	0	0	0	0	0	0	0	0	0
RM&PC'	0.4488	0.4488	0.4488	0	0	0	0	0	0	0	0	0
EC	0.4244	0.4244	0.4244	0	0	0	0	0	0	0	0	0
MS	0	0	0	0.3391	0.3391	0.3391	0	0	0	0	0	0
ACCU	0	0	0	0.3478	0.3478	0.3478	0	0	0	0	0	0
SF&CT	0	0	0	0.313	0.313	0.313	0	0	0	0	0	0
IPPT	0	0	0	0	0	0	0.3359	0.33359	0.3359	0	0	0
BUT	0	0	0	0	0	0	0.4351	0.43351	0.4351	0	0	0
PPT	0	0	0	0	0	0	0.229	0.229	0.229	0	0	0
GE	0	0	0	0	0	0	0	0	0	0.313	0.313	0.313
NV	0	0	0	0	0	0	0	0	0	0.3391	0.3391	0.3391
WD&R	0	0	0	0	0	0	0	0	0	0.3478	0.3478	0.3478

The second column in table number 6 is obtained by comparing the relative impact of each of the dimensions on the Customer Perspective determinant. The pair-wise comparison matrix for the relative impact of the enablers on the dimensions is presented in the fourth column. The values in fifth column are the stable interdependent weights of enablers obtained through super matrix convergence. The relative weights of the three alternatives for each dimension are given in sixth, seventh and eight columns of table 6. These weights are obtained by comparing three alternatives for every dimensions. The final three columns represents the desirability index of each alternative for enablers. For each of the alternatives under customer Perspective determinant, the summation of these results appears in the final row of table number 6.

Table 6. Desirability index Matrix for Customer Perspective

CP	Relative weightage of Dimensions P_{ja}	Enablers	Relative weightage of enablers A^D_{kja}	Stabilized Super Matrix values A^I_{kja}	Relative weights of three alternatives S_{ikja}			Alternatives		
								ALT1	ALT2	ALT3
TC	0.201488	MC'	0.0691729	0.1825	0.166593	0.093813	0.093813	0.000424	0.000239	0.000239

	0.201488	RM&PC'	0.687086	0.3802	0.080961	0.188394	0.730645	0.004261	0.009916	0.038457
	0.201488	EC	0.243741	0.4373	0.166593	0.093813	0.739594	0.003578	0.002015	0.015884
PQ	0.42862	MS	0.1958	0.3391	0.308996	0.581552	0.109452	0.008794	0.01655	0.003115
	0.42862	ACCU	0.493386	0.3478	0.310814	0.493386	0.1958	0.022861	0.036289	0.014401
	0.42862	SF&CT	0.310814	0.313	0.559065	0.352189	0.088746	0.023312	0.014686	0.003701
PCT	0.328707	IPPT	0.124306	0.3359	0.258285	0.104729	0.636986	0.003545	0.001437	0.008743
	0.328707	BUT	0.35856	0.4351	0.080961	0.188394	0.730645	0.004152	0.009661	0.037468
	0.328707	PPT	0.517134	0.229	0.182955	0.075201	0.741845	0.007122	0.002927	0.028878
PC	0.0411848	GE	0.576905	0.313	0.292219	0.092528	0.615253	0.002173	0.000688	0.004576
	0.0411848	NV	0.341998	0.3391	0.310814	0.493386	0.1958	0.001485	0.002357	0.000935
	0.0411848	WD&R	0.0810968	0.3478	0.539615	0.163424	0.296961	0.000627	0.00019	0.000345
Desirability Index Dia								**0.082332**	**0.096955**	**0.156741**

The final results shown in table number 7 indicates rank that the three dimensional printing followed by selective laser sintering and fused deposition modelling.

Table 7. Overall weighted Index for alternatives in Frameworks

	CP	FP	MC	EP	OWI	Normalized	
Ca Vector for Determinants	0.189815	0.0936564	0.657545	0.0589835			
ALT1	0.082332306	0.061549732	0.073749268	0.081410652	0.074687781	**0.209770444**	**Rank 3 (FDM)**
ALT2	0.096954582	0.071694125	0.085617265	0.126793838	0.088893996	**0.249670467**	**Rank 2 (SLS)**
ALT3	0.156740615	0.245658327	0.199654348	0.142796046	0.192463523	**0.540559089**	**Rank 1 (3DP)**
					0.3560453	1	

SENSITIVITY ANALYSIS

Sensitivity analysis is an important concept for the effective use of any quantitative decision model. In the present work sensitivity analysis is done to find out the changes in the OWI for Fused Deposition Modeling, Selective Laser Sintering, three dimensional Printing with variation in the expert opinion towards Customer Perspective with respect to Financial Perspective[17], Market Competitiveness[5], Environment Perspective[15] and Financial Perspective[18].

Overall objective of sensitivity analysis[19],[20] is to see the robustness of proposed framework due to variation in experts' opinion in assigning the weights during comparison. Table number 7 weighted index (OWI) for proposed framework

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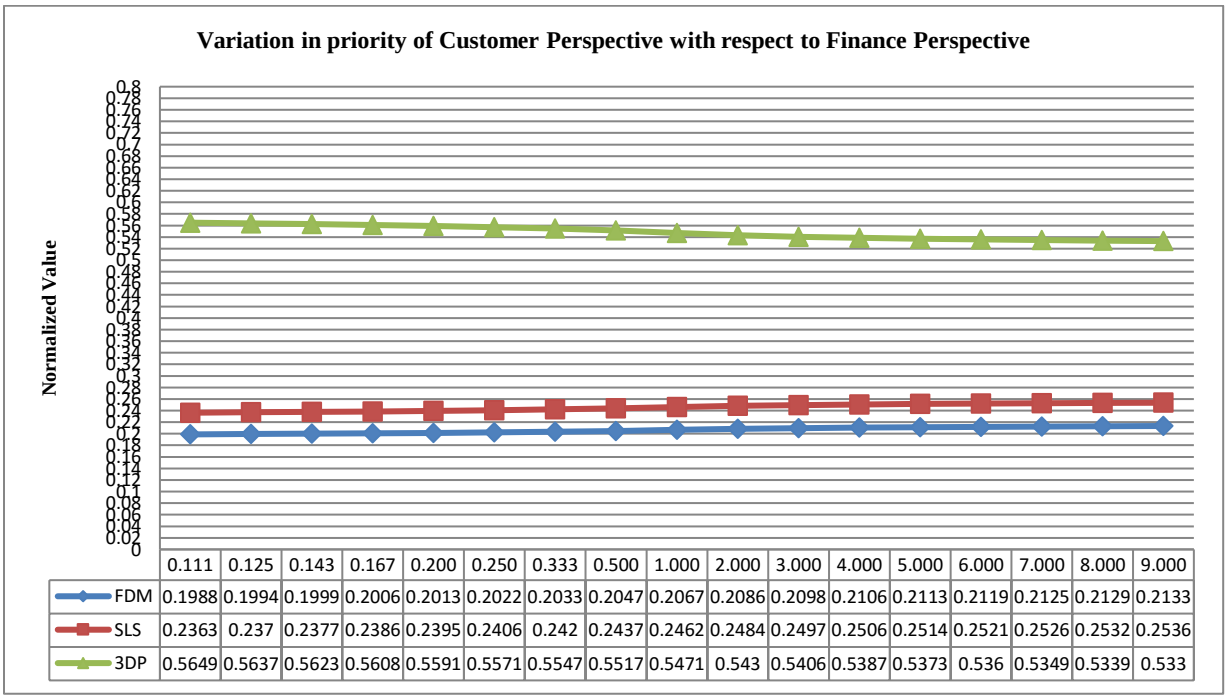
of three alternatives varies with changing priority of Customer Perspective, Financial Perspective, Market Competitiveness and Environmental Perspective[15].

In figure 2, X-axis represents the relative weight of Customer perspective as compare to Financial perspective weights are in the scale of 1/9-9 (Saaty Scale[21]). Y-axis represents the normalized value of Selection of Rapid Prototyping Technology weight-age index (OWI). These weights are obtained using ANP framework, which captures the interdependence among Rapid Prototyping Technology Variables[17]. This frame work consists of 117 pair wise comparison matrices. The purpose is to analyze the effect of variation in relative weight assigned to selection of Rapid prototyping technology determinants on the priority level of alternative.

In present ANP framework, experts have assigned relative weight 0.189815 to Customer Perspective in compare with Financial Perspective. With this relative weight, OWI for Three dimensional Printing is the highest followed by Selective Laser Sintering and FDM. This priority level does not change if XCP/FP Changed from 0.111 to 9.



	0.111	0.125	0.143	0.167	0.200	0.250	0.333	0.500	1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000
FDM	0.1988	0.1994	0.1999	0.2006	0.2013	0.2022	0.2033	0.2047	0.2067	0.2086	0.2098	0.2106	0.2113	0.2119	0.2125	0.2129	0.2133
SLS	0.2363	0.237	0.2377	0.2386	0.2395	0.2406	0.242	0.2437	0.2462	0.2484	0.2497	0.2506	0.2514	0.2521	0.2526	0.2532	0.2536
3DP	0.5649	0.5637	0.5623	0.5608	0.5591	0.5571	0.5547	0.5517	0.5471	0.543	0.5406	0.5387	0.5373	0.536	0.5349	0.5339	0.533

Figure 2. Variation in priority of Customer Perspective with respect to Finance Perspective

In figure 2 graph results showed that as we increase the weightage of financial perspective with respect to customer perspective with constant market competitiveness and environmental Perspective the normalized over all weight age of 3DP slightly decreases and the normalized overall weight age of SLS and FDM slightly increases .In this graph the above trends represents that overall financial perspective (Machine cost, processing cost, material cost, processing cost, energy consumption cost and other costs including Fixed and variables cost and product cost produced by machines and overall revenue considered in it) weightage increases with respect to customer perspectives like (product strength, surface finish[22] & close tolerances[23] etc.) Considered then SLS and FDP technology gives better results than 3DP with constant market competitiveness (Factors like lead time, processing and post processing time etc. and product cost etc.) and environmental perspective like (gas emission ,noise& vibration and waste deposal & recycling etc.)

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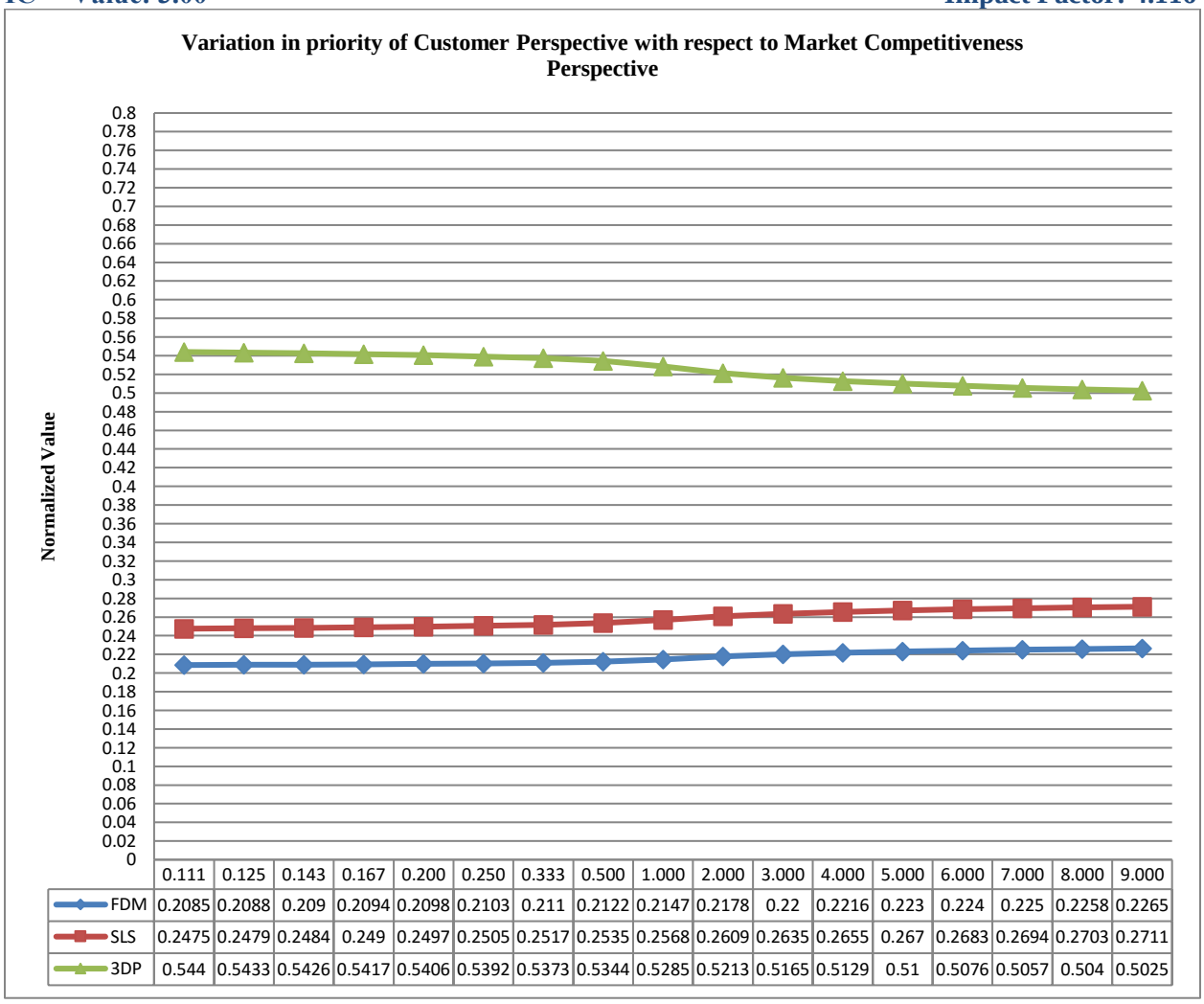

	0.111	0.125	0.143	0.167	0.200	0.250	0.333	0.500	1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000
FDM	0.2085	0.2088	0.209	0.2094	0.2098	0.2103	0.211	0.2122	0.2147	0.2178	0.22	0.2216	0.223	0.224	0.225	0.2258	0.2265
SLS	0.2475	0.2479	0.2484	0.249	0.2497	0.2505	0.2517	0.2535	0.2568	0.2609	0.2635	0.2655	0.267	0.2683	0.2694	0.2703	0.2711
3DP	0.544	0.5433	0.5426	0.5417	0.5406	0.5392	0.5373	0.5344	0.5285	0.5213	0.5165	0.5129	0.51	0.5076	0.5057	0.504	0.5025

Figure 3. Variation in priority of Customer Perspective with respect to Market Competitiveness Perspective

The figure 3 graph represents that as the expert opinioned weightage increases for customer perspectives (Product Mechanical strength compressive and tensile strength, surface finish & close tolerances etc. with respective to Market competitiveness product with different technology with constant Financial perspective (Machine cost, processing cost, material cost, processing cost, energy consumption cost and other costs including Fixed and variables cost and product cost produced by machines and overall revenue considered in it) weightage and Environmental Perspective like Gas Emission, Noise &Vibration and waste disposal & Recycling . The trends showed that 3DP weightage decreases slightly, SLS and FDM Trends increases with increasing Customer Perspective weightage with market competitiveness.

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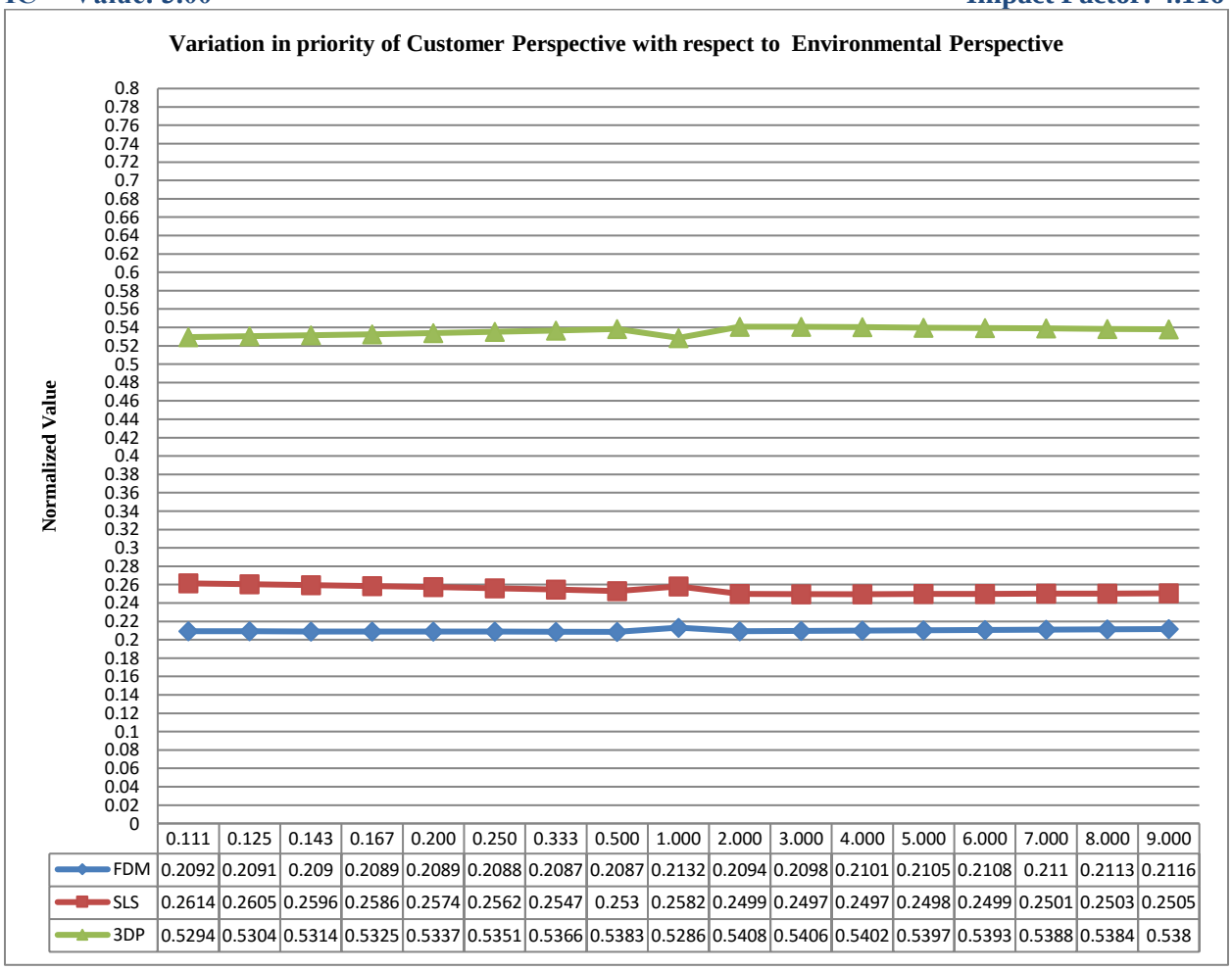

	0.111	0.125	0.143	0.167	0.200	0.250	0.333	0.500	1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000
FDM	0.2092	0.2091	0.209	0.2089	0.2089	0.2088	0.2087	0.2087	0.2132	0.2094	0.2098	0.2101	0.2105	0.2108	0.211	0.2113	0.2116
SLS	0.2614	0.2605	0.2596	0.2586	0.2574	0.2562	0.2547	0.253	0.2582	0.2499	0.2497	0.2497	0.2498	0.2499	0.2501	0.2503	0.2505
3DP	0.5294	0.5304	0.5314	0.5325	0.5337	0.5351	0.5366	0.5383	0.5286	0.5408	0.5406	0.5402	0.5397	0.5393	0.5388	0.5384	0.538

Figure 4. Variation in priority of Customer Perspective with respect to Environmental Perspective

The figure 4 graphs represents that as we have same financial as well as market competitiveness and varies weightage with respect to Environmental perspective form 1/9 to 9 according to T.L Saaty[21]. The results are in favor of 3DP due to more gas emission for SLS like CO_2, CO, SO_X, PM, NO_X and for FDM CO_2 emission.

CONCLUSION

In the previous paper[1] a framework was developed by considering three rapid prototyping technologies. Then an ANP methodology was adopted for decision making through ranking. In this paper the result of that study are discussed. In the ANP methodology pair wise comparison matrices are developed for determinants, dimensions, enablers, alternatives. This methodology integrates various determinants, dimensions, enablers and alternatives and also gives their relationships and interdependencies along hierarchies by considering quantitative as well as qualitative characteristics. This methodology gives finally normalized over all weight age indexes for FDM, SLS and 3DP are 0.209770444, 0.249670467 and 0.540559089 respectively. This results shows that NOWI (Normalized over all weight age Index) for 3DP is higher than SLS and FDM Technology weight age. For its robustness a Sensitivity analysis is also done by consider expert opinion variation form 1/9 to 9 weightage in T.L Saaty Scale[21]. This study demonstrates potential benefits of using ANP Approach for selection of rapid prototyping technology by considering some limited determinants, dimensions, enablers, and alternatives. In future this methodology can be implemented for other criteria which are not considered in it for decision making.

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