ECONOMIC AND PRODUCTIVITY ANALYSIS OF RAPID PROTOTYPING TECHNIQUES WITH TRADITIONAL MODEL MAKING

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ABSTRACT: *Different techniques are being used to make the models for the manufacturing industry. The traditional model-making techniques consist of the production processes such as machining, fabrication and hand crafting, usually referred as manual prototyping. Another model making technique is the analysis and simulation carried out on a complex developed computer model. This is called virtual prototyping (VP), also referred to as computer-aided engineering (CAE). The latest is rapid prototyping technique (RP) which is used to convert the virtual models into three dimensional models. The core purpose of such modeling is to have better understanding of the physical parts. The main purpose of this research is to compare all these prototyping techniques. The research will focus on the emergence of the Rapid prototyping and to make the local manufacturers aware of its importance in terms of time, cost and productivity.The data is collected by carrying out the survey in different manufacturing industries. The survey consists of direct visits. It consists of two parts. In first part, general data regarding the model making techniques is collected for the parameters of time, cost, quality, flexibility and productivity for different models, produced. The second part consists of the data which is collected for particularly prototype of V-block which is made by rapid prototyping techniques, i.e. 3D printing, fused deposition modeling and manual prototyping techniques, i.e. machine and foundry shop. In all traditional and Rapid Prototyping techniques, 3D printing (powdered technique) is one of the most economical and less time consuming to create solid objects. More flexible, durable prototypes can be made within short period of time.*

Final result and discussions reveal that the local manufacturing industry is unaware of the usefulness of Rapid Prototyping. Main reason of this fact is the gap between the academia and the industry. The findings of this research may be useful to elaborate the importance of this emerging technique to the industry. This will save both, the time and cost, contributing to the national prosperity

INTRODUCTION

Statement of the Problem

Now a day, different techniques are being used to make the models for the manufacturing industry. The traditional model-making techniques consist of the production processes such as machining, fabrication and hand crafting. These can be used individually or in a combination. The areas of application include the existing model modification and solid model appearance. Moreover low featured complexity models can be targeted. Another advantage is the variety of materials that can be used such as plastics, glass sheet, ferrous and non-ferrous metals etc.

Another model making technique is the analysis and simulation carried out on a complex developed computer model. This is called virtual prototyping (VP), also referred to as computer-aided engineering (CAE) or engineering analysis simulation [1].

Rapid prototyping [2-3] is a technique which is used to convert the virtual models into three dimensional models. The core purpose of such modeling is to have better understanding of the physical parts. The physical model can be made without the use of any jigs/fixtures and numerically controlled programming. There are several names assigned to this technology such as

- Layer manufacturing
- Material deposit manufacturing
- Material addition manufacturing
- Solid freeform manufacturing
- Three-dimensional printing

The main purpose of this research is to compare both the traditional model making techniques and the prototyping. The research will focus on the emergence of the new model making technique i.e. Rapid prototyping.

Research Question

The research question is, “How we can compare the design models of V-Block by rapid prototyping (RP) and conventional model making techniques. What are the parameters on which the comparison of both techniques takes place, i.e. time, cost, quality, flexibility and productivity”.

LITERATURE REVIEW

Prototype

A prototype can be defined as “The first or original example of something that has been or will be copied or developed. It can be also called as a model or preliminary version” [4] . It can be also defined as “An approximation of a product, system or its parts which has a definite purpose in its implementation” [5] .It may be also called a compass which can tell the direction of the production while manufacturing.

This generic form of the definition contains three aspects.

- The form of the prototype
- Implementing the prototype
- The degree of approximation of prototype

Before the final product is made, a specimen is fabricated which has all the characteristics of final product. A prototype can be used to

- Communicate the information
- Synthesize the product concept
- Demonstrating the ideas &
- Helps in scheduling of the product through proper planning.

Types of Prototyping

There are three types of prototyping.

- Manual Prototyping
- Virtual Prototyping
- Rapid Prototyping

Manual Prototyping

The art of prototyping started with the invention of the tools which were used to help the human beings in the daily life. The modern prototyping has evolved in different phases starting from the simple or manual prototyping. In manual prototyping, the models manufactured are non-sophisticated taking three to four weeks depending upon the complexity of the parts and material used. These are made through the hand crafted techniques requiring more time and intensive labor.

Virtual Prototyping:

The second phase of the prototyping is known as soft or virtual prototyping which emerged in the early 1980's. The main advantage of this prototyping is that the models can be stressed, tested and analyzed like the real scenario. This became possible with the advent of CAD, CAM and CAE. By using this technique, the complexity increased to two times as compared to the manual prototyping [6].

Rapid Prototyping:

The third phase is rapid prototyping which has great time saving for the complex parts. The manufacturing industry is competing to launch their products as soon as possible to the market. Now the competition is in terms of agility [7]. In order to bring the products in market quickly, all the processes have been squeezed. New tools and techniques are required for this purpose. That's why Rapid prototyping has evolved as an emerging technique in the last few decades.

Rapid Prototyping

In rapid prototyping, models are generated with the help of the layer deposition. The layers to be deposited are kept thin in order to approximate the intended original design. The commonly used thickness for the layer is 0.1 mm. whereas in some applications, layer thickness is reduced to the 0.02 mm (e.g. medical applications). RP is actually opposite to the classical techniques such as turning, milling etc. in which an object is formed by the material removal whereas in RP, material is normally added layer by layer. Rapid prototyping can also be linked with other terms which describe this technology.

- It is a technique which is geometrically independent i.e. the product complexity does not make its manufacturing difficult.
- It can be linked with the numerical control machines, resulting in higher productivity, less intervention of the humans, more throughputs. Moreover there is no need of skilled labor as it is required in the traditional model making techniques.It simplifies the process of three dimensional manufacturing with the help of two dimensional layer depositions. In this way the complex models can be made with ease [8].

Since 1988, more than 22 rapid prototyping techniques have been introduced. These can be also used for the limited testing. There are some other techniques which are under development in the laboratories. It basically relies on the CAD modeling. Furthermore, depending upon the size of production, 50 – 90% time and cost could be saved [9].

Main Characteristics of Rapid Prototyping

The main characteristics of the rapid prototyping are

- Manufacturing of the models takes place with the help of three dimensional CAD files.
- The time taken for manufacturing can be reduced to the great extent. It may take three to seventy two hours to make a prototype. It seems a prolonged process but it is time saving as compared to the traditional model making processes which may take weeks or even months to build a prototype [10].
- The customized products can be made without the help of the tooling.

Historical Development of Rapid Prototyping

The historical development of Rapid Retyping and its related technologies can be seen in table 1:

Table 1: Historical Development of Rapid Prototyping and its Related Technologies [11]

Inception Year	Technologies
1770	Mechanization
1946	First computer
1952	First Numerical Control (NC) machine tool
1960	First commercial laser
1961	First commercial Robot
1963	First interactive graphics system
1988	First commercial Rapid Prototyping system

A company known as 3D Systems, Inc. first time introduced the rapid prototyping process in November 1987 at AUTOFACT show in the city of Detroit, USA. The parts produced were less accurate and there was limitation in the selection of the materials [12].

Rapid prototyping as an Additive Process:

Rapid prototyping can be defined as an additive process example of which are

- Stereo lithography
- Selective Laser Sintering
- Fused Deposition Modeling

Each of the above processes have their own pros and cons which are briefly discussed here.

SL has the characteristics of better finish, tolerance and can make small detailed parts. FDM makes the prototypes layer by layer using ABS and polycarbonates. It also gives surface finish and larger work envelopes. It is very cost effective for building of the larger functional parts. As far as SLS is concerned, it is faster than FDM. It also provides testing of the multifunctional parts on the platform. Moreover, accurate dimensional tolerances can be achieved.

The other techniques are subtractive processes which use high speed spindles on machine aluminum alloys. It can provide better turnarounds for functional parts as well as for tooling. For the above mentioned reasons, it is sometimes considered as an alternative to the additive processes [13].

The Main Process

There are a number of RP techniques but they use the same basic process which consists of five steps. These five steps

Model Creation Using Cad

First step involves the creation of object modeling using the CAD software

Creation of STL Format

CAD use different algorithms by which the solid objects are represented. STL (Standard Triangulation Language) format is used as standard for the Rapid Prototyping techniques. This step involves the conversion of the CAD model into the STL format. In this format, 3D surface is represented by planer triangles. This STL format is universally accepted [14].

Slicing the STL File

In this step, the STL model is converted into a number of layers. The thickness of the layers is kept between 0.01 mm to 0.7 mm. The thickness of the layer depends upon the method of building of the layers. This is accomplished with the help of a pre-processing software which is supplied by the machine manufacturer [14].

Actulal Construction

In this step, the prototype is actually built layer by layer. Only one layer is laid at time. Different materials used for the layer building are paper, polymers or powder metals [14].

Finishing

This is the final step in which the prototype is removed from the machine and cleaned if necessary. If a photosensitive material is used, it needs to be cured before its use. In order to make the prototype durable, it should be painted, sealed [15].

Areas of Application of Rapid Prototyping:

Some of the applications of Rapid Prototyping are in the field of electronics, , jewelry, kitchenware, automotive and aerospace, toy making etc. Moreover it can be used for the processes such as rapid manufacturing, rapid tooling, injection molding, sand molding and industrial design[16-17].

There are mainly four processes which are being used for Rapid Prototyping.

1. Stereo lithography (SL)
2. Fused Deposition Modeling (FDM)
3. Selective Laser Sintering (SLS)
4. Laminated Object Manufacturing (LOM) [19]
5. Processes of Rapid Prototyping
6. The Rapid Prototyping processes can be classified on the basis of material being used. These materials are thermoplastic, photopolymer, adhesive. Each of the material constitutes its own system which is shown in Figure.1.

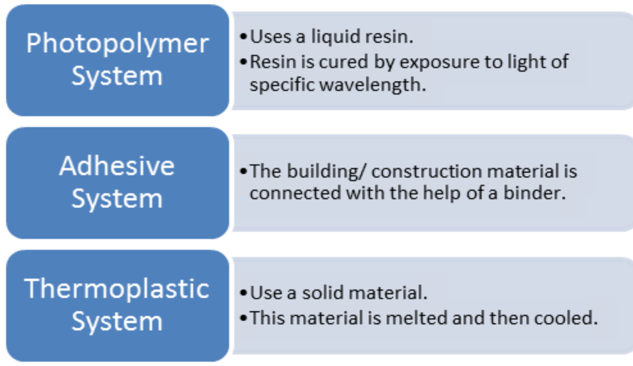

Figure 1: Different Material Systems used for Rapid Prototyping [18]

In addition to the above mentioned techniques, there are some other techniques which are being used. Some of the techniques are in research phase. These are listed below.

- Solid Ground Curing (SGC)
- Ink Jet Printing
- Multi jet Modeling (MJM)
- Paper Lamination Technology (PLT)
- Laser Engineered Net Shaping (LENS)
- Photopolymer Phase Change Inkjets
- Electro set Technology
- Photochemical Machining
- Design-Controlled Automated Fabrication (DESCAF)
- Liquid Metal Jet Printing (LMJP)
- Sparx- Hot Plot [20].

RESEARCH METHODOLOGY

The data is collected by carrying out the survey in different manufacturing industries. The survey consists of General data collection from survey questionnaire and Physical model of v-block prepared by all techniques. The type of flexible/CNC system they are using, effectiveness of machines and processes, layout system, utilization of system, degree of complexity to make prototype or model, equipment and workforce utilization and overall equipment effectiveness has been discussed against the parameter of productivity. Average number of operations to make prototype, technique's flexibility, and design changes at later stages, design modification using previous data, maintenance of machine quality,and level of technique's skill and durability of prototype has been discussed against the parameters of flexibility and quality. Cost is the next major factor in which Survey questionnaire is surrounded to get the fraction of cost associated with labor, tool, gauges and fixtures and the material. Similarly parameter of time is discussed that how much fraction of time is associated with the material handling, setup and waiting in queuing by the result of survey.

The second part consists of the data (case study) which is collected for particularly prototype of V-block. The preparation of prototype of v-block is carried out in three main phases, which are further subdivided in different techniques, details are given below.

1. Manual Prototyping
   i) In machine shop
   ii) In foundry shop
2. Virtual Prototyping
3. Rapid Prototyping
   i) 3D printing
   ii) Fused Deposition Modeling

The Prototype of V-Block was manufactured using traditional model making techniques (i.e. in Machine shop and Foundry) and Rapid Prototyping (i.e. 3D printing and fused deposition modeling). Cost, time, labor, electricity and KWH will be compared.

There are different techniques to make model or prototype like manual, virtual and rapid prototyping. Which type of technique is being used by industries to make prototype? The most of the industries are using traditional model making techniques for the production of prototypes. Some of them used only computerized presentation in both 2D and 3D, but not make physical model, i.e. virtual prototyping. There is need to use the latest prototyping technique i.e. Rapid Prototyping, as illustrate in Figure. 2

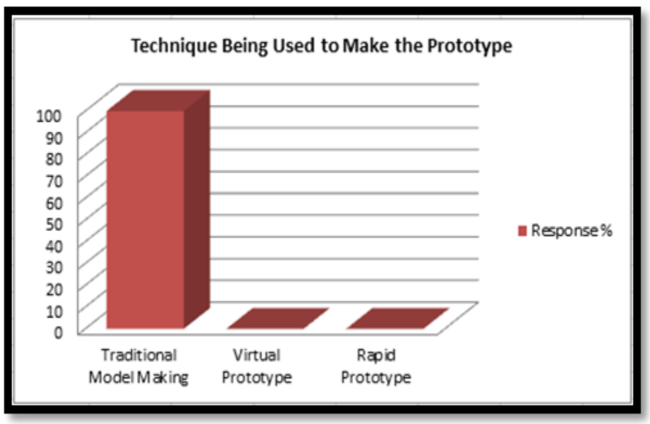

Figure 2: Technique being Used to Make the Prototype

There are different major manufacturing/assembly methods being used during prototype processing like manual, automatic and CNC flexible system. The most of the industries are using flexible systems/CNC. But in our industry, we have found less courage of rapid prototyping technology which can be used for better quality of design. Secondly they can adapt Rapid Prototyping with ease as they are already using flexible systems. Results illustrate in Figure 3.

In order to compare all techniques with consideration of each aspect as described, research has been carried out in two phases i.e. General and case study servey.

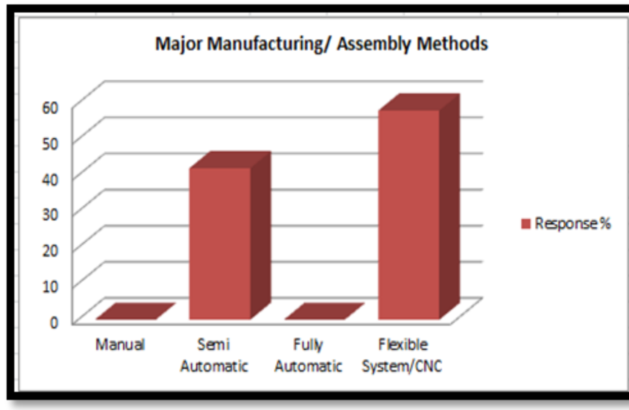

Figure 3: Major Manufacturing/Assembly Methods being used

GENERAL SURVEY

While making survey in industry, question has been asked about effectiveness of processes, effectiveness of machine, degree of system utilization, degree of complexity to make prototype, layout for prototype manufacturing, degree of equipment utilization, the average workforce utilization, Overall Equipment Effectiveness, that average number of operations to make prototype, Technique's Flexibility, Design Changes at Later Stages, Use of CAD/ CAM or other Design Techniques, Design Modification using Previous Data, Maintenance of Machine Quality, Level of Technique's Skill, Durability of Prototype, Fraction of Cost Associated with Use of Tools, Gauges & Fixtures, Fraction of Cost Associated with material, Fraction of Cost Associated with Labor, Fraction of Time Associated with the Setup, Fraction of Time Associated with material handling, Fraction of Time Associated with queuing, quality, flexibility and productivity for different models produced.

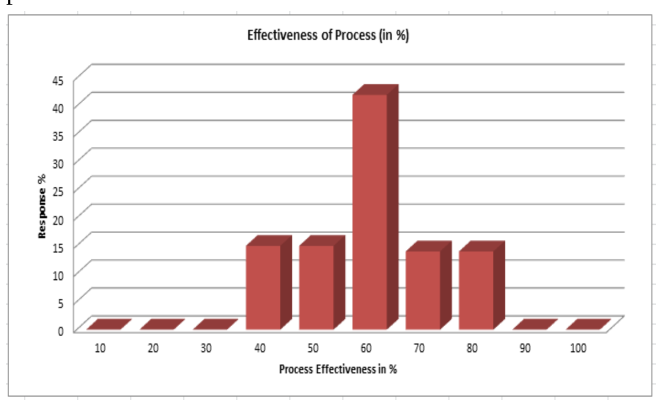

Figure 4: Effectiveness of Process (in %)

The most of the respondent industry have the opinion that the effectiveness of the process used for making prototype is 60 %.

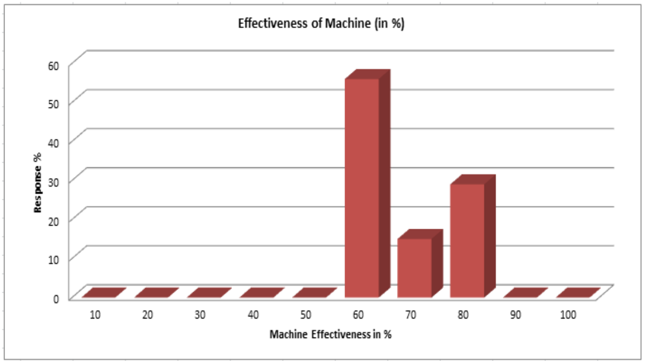

Figure 5: Effectiveness of Machine (in %)

The most of the respondent industry have the opinion that the effectiveness of the machines used for making prototype is 60 %.

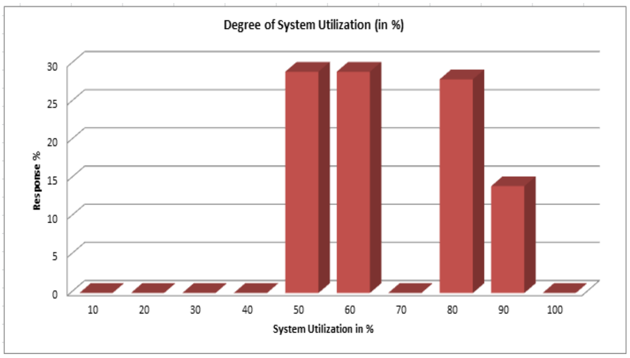

Figure 6: Degree of System Utilization (in %)

The most of the respondent industry have the opinion that the degree of system utilization is 50-60 %.

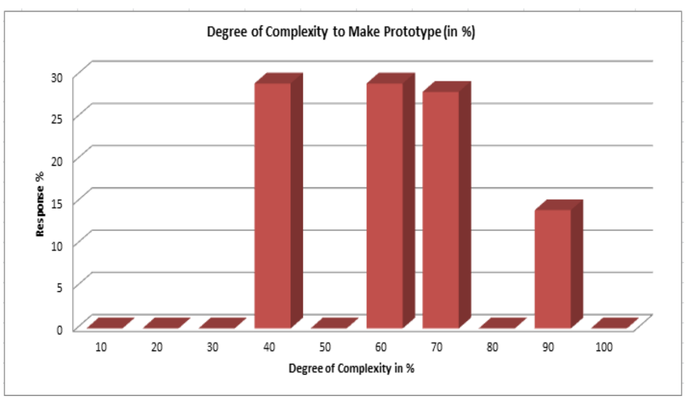

Figure 7: Degree of Complexity to Make Prototype

The most of the respondent industry have the opinion that degree of complexity to make prototype is 40-60 %.

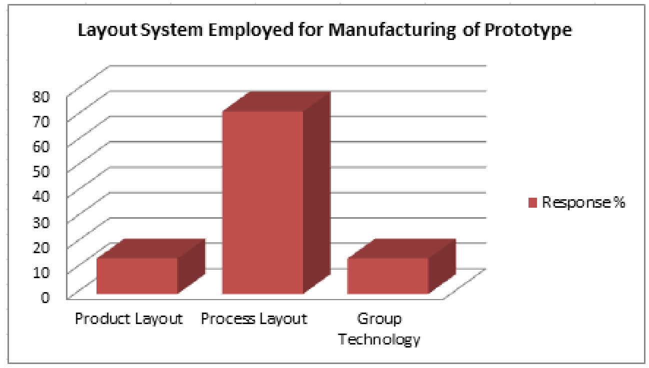

Figure 8: Layout System Employed for Manufacturing of Prototype

The most of the respondent industry use process layout for prototype manufacturing.

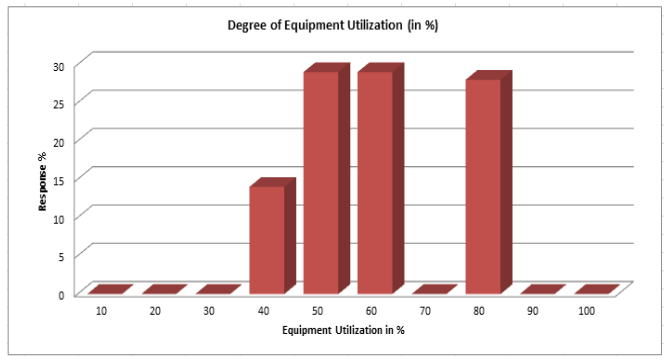

Figure 9: Degree of Equipment Utilization (in %)

The most of the respondent industry have the opinion that the degree of equipment utilization is 50-60 %.

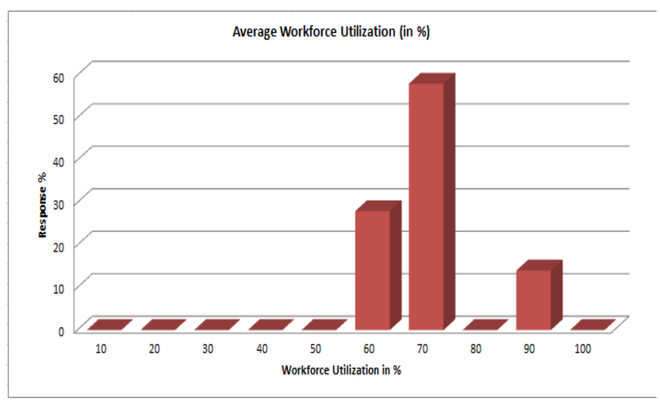

Figure 10: Average Workforce Utilization (in %)

The most of the respondent industry have the opinion that the average workforce utilization is 70 %.

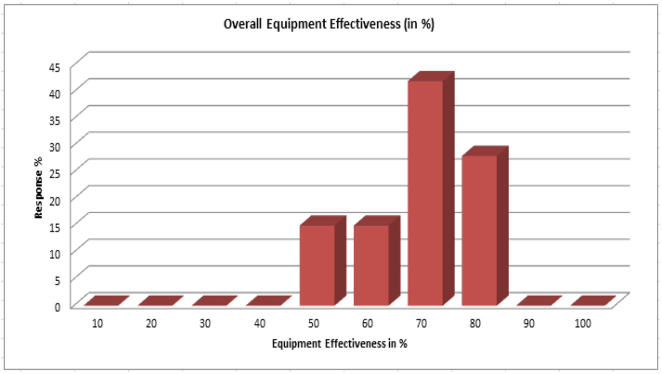

Figure 11: Overall Equipment Effectiveness (in %)

The most of the respondent industry have the opinion that the overall equipment effectiveness 70 %.

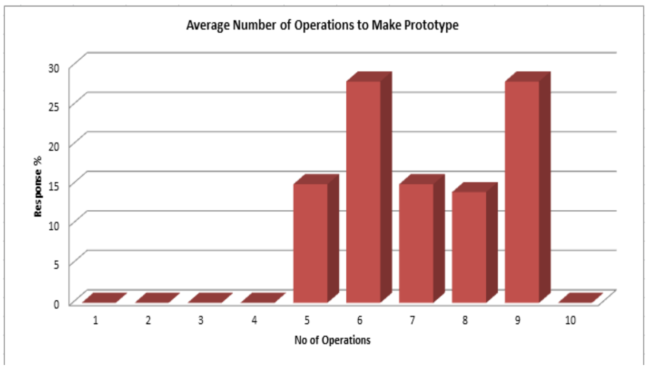

Figure 12: Average Number of Operations to Make Prototype

The most of the respondent industry have the opinion that average number of operations to make prototype is 6-9.

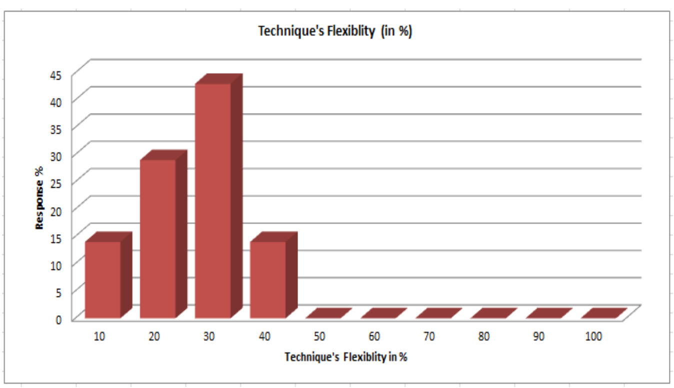

Figure 13: Technique's Flexibility (in %)

The most of the respondent industry have the opinion that prototype making technique has flexibility up to 30 %.

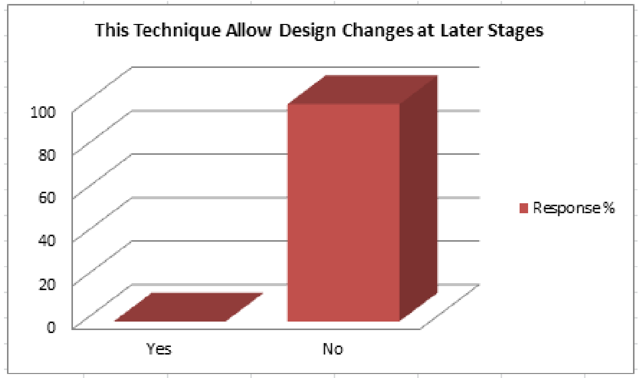

Figure 14: Design Changes at Later Stages

The most of the respondent industry have the opinion that traditional model making technique does not allow design changes at the later stages.

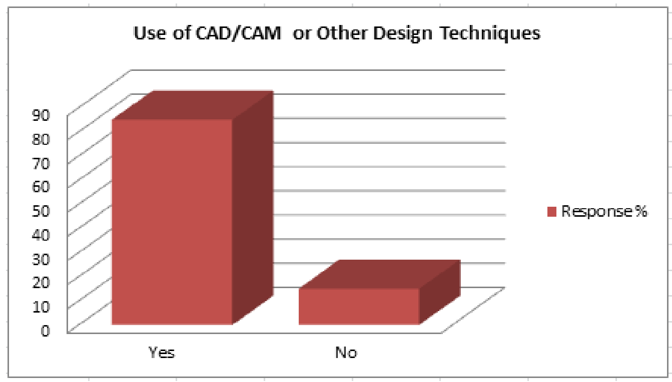

Figure 15: Use of CAD/ CAM or other Design Techniques

The most of the respondent industry use CAD/ CAM and other design techniques.

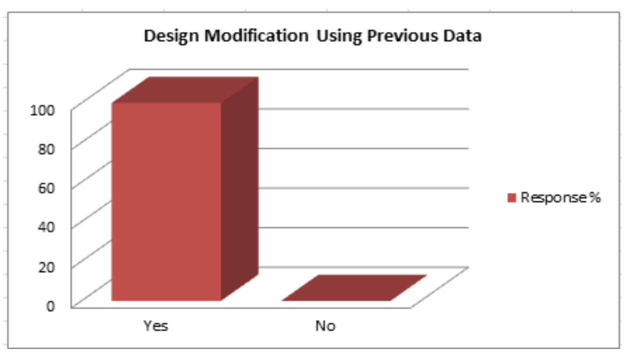

Figure 16: Design Modification using Previous Data

The most of the respondent industry have the opinion that they use the previous data, modify it and make the new prototype.

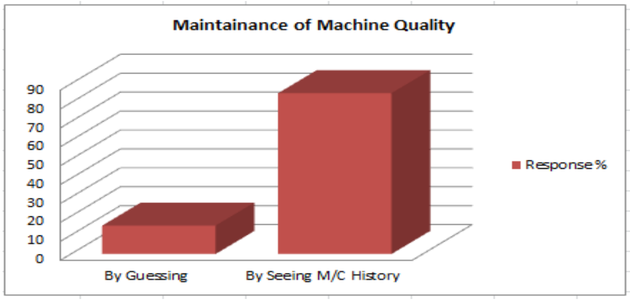

Figure 17: Maintenance of Machine Quality

The most of the respondent industry have the opinion that they maintain the machine quality by seeing machine history.

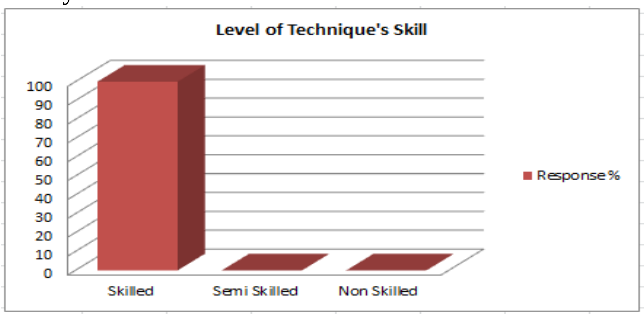

Figure 18: Level of Technique's Skill

The most of the respondent industry have the opinion that the level of technique's skill is skilled which can be upgraded to highly skilled level.

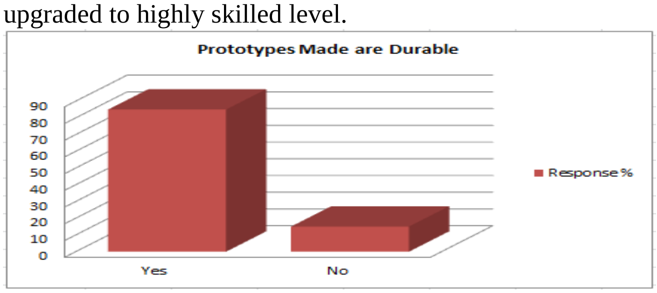

Figure 19: Durability of Prototype

The most of the respondent industry have the opinion that the prototypes made by traditional techniques are durable.

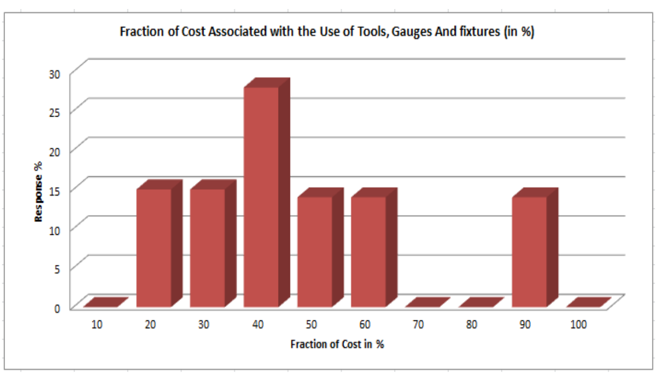

Figure 20: Fraction of Cost Associated with Use of Tools, Gauges & Fixtures (in %)

The most of the respondent industry have the opinion that 40 % of total cost is associated with the use of Tools, Gauges and Fixtures.

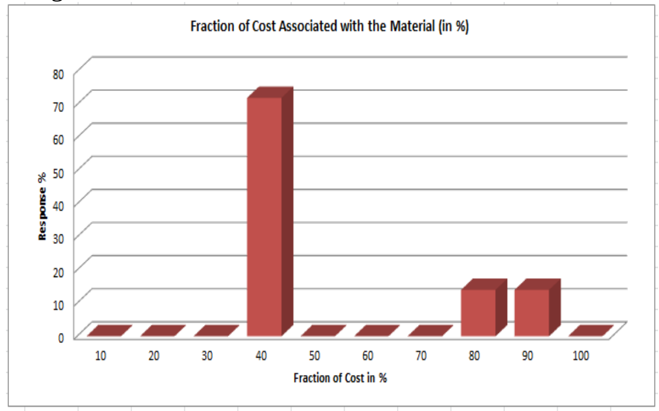

Figure 21: Fraction of Cost Associated with Material (%)

The most of the respondent industry have the opinion that 40 % of total cost is associated with the Material.

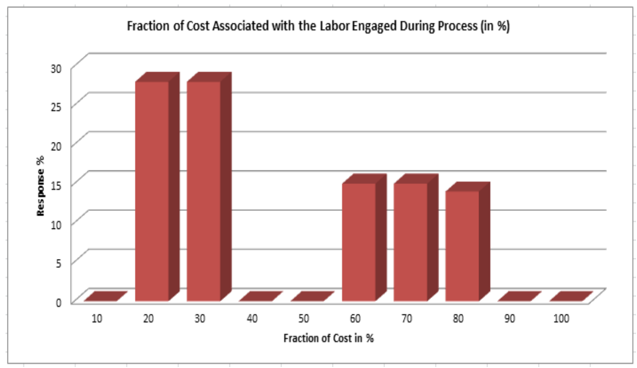

Figure 22: Fraction of Cost Associated with Labor (in %)

The most of the respondent industry have the opinion that 20 % of the total cost is associated with the labor engaged during the process.

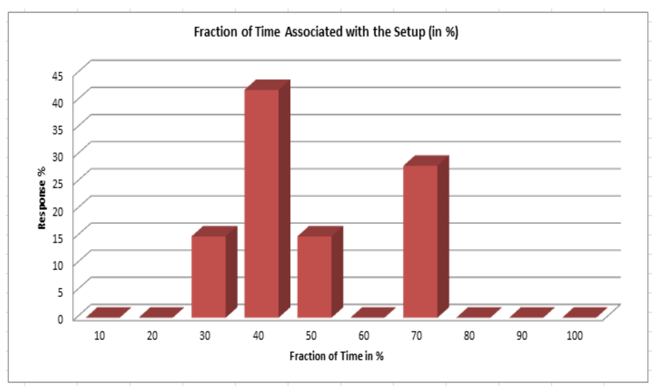

Figure 23: Fraction of Time Associated with the Setup (in%)

The most of the respondent industry have the opinion that 40 % of total time is associated with the Setup.

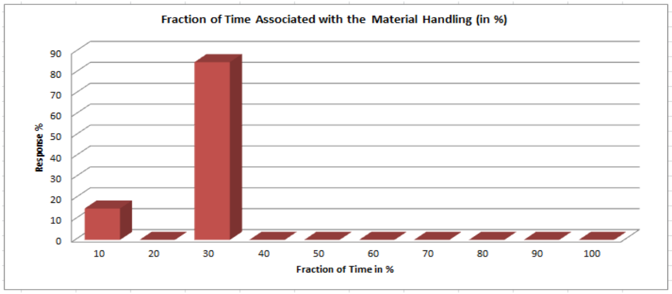

Figure 24: Fraction of Time Associated with the Material Handling (in %)

The most of the respondent industry have the opinion that 30 % of total time is associated with the Material Handling.

The most of the respondent industry have the opinion that 30 % of total time is wasted in Queuing.

CASE STUDY

The second part consists of the data (case study) which is collected for particularly prototype of V-block. The preparation of prototype of v-block is carried out in three

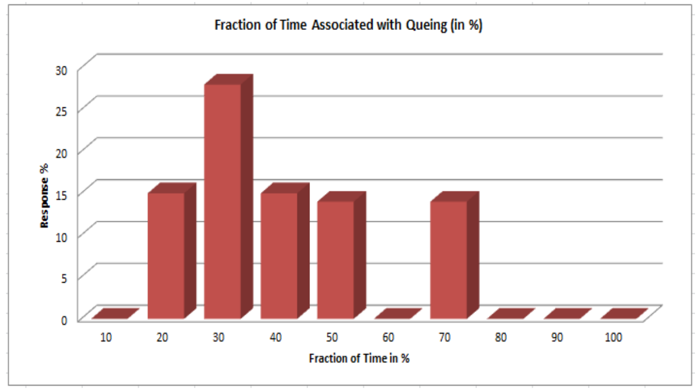

Figure 25: Fraction of Time Associated with Queuing(%)

main phases, which are further subdivided in different techniques, like Manual Prototyping in machine shop and in foundry shop comparedwith virtual Prototyping and rapid Prototyping, i.e. 3D printing and fused Deposition Modeling. The Prototype of V-Block was manufactured using traditional model making techniques (i.e. in Machine shop and Foundry) and Rapid Prototyping (i.e. 3D printing and fused deposition modeling). Cost, time, labor, electricity and KWH will be compared.

Total Time and Cost Calculated by using all Techniques

Table 2: Total Time and Cost Calculation using all Techniques	**Machine shop (MP)**	**Foundry shop (MP)**	**Virtual Prototyping (VP)**	**Rapid Prototyping RP(Selective Laser sintering)**	**Rapid Prototyping (Fused Deposition Modeling) RP**
Time	14 hrs.	18 hrs.	1 hr	1 hr. 40 min	5 hrs
Cost	Rs. 2405	Rs. 2495	Rs. 250	Rs. 1880	Rs. 1345

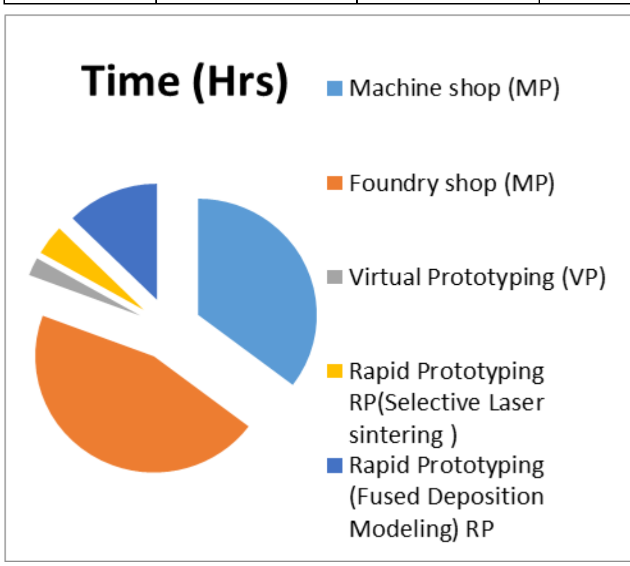

Figure 26: Comparison of the Total Time Taken by Techniques

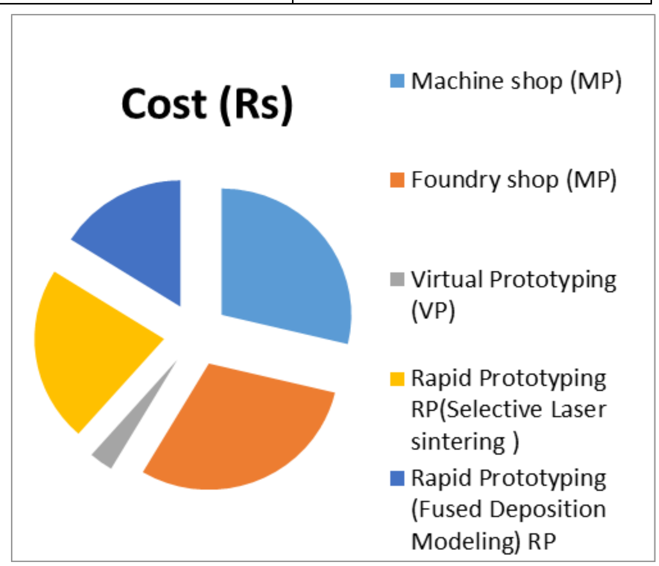

Figure 27: Comparison of Total Cost Associated with Techniques

Labor and Electricity (KWH) Cost Calculated by using all Techniques

Table 3: Labor and Electricity (KWH) Cost Calculated by using all Techniques

	Machine shop (MP)	Foundry shop (MP)	Virtual Prototyping (VP)	Rapid Prototyping (Selective Laser Sintering) (RP)	Rapid Prototyping (Fused Deposition Modeling) RP
Labor	Rs. 716	Rs. 321	Rs. 200	Rs. 30	Rs. 150
KWH	Rs. 322	Rs. 1387	Rs. 20	Rs. 10	Rs. 45

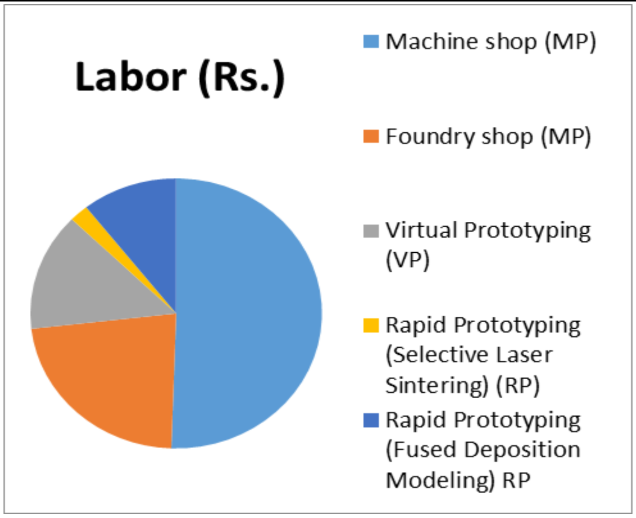

Figure 28: Comparison of Labor Cost associated with Techniques

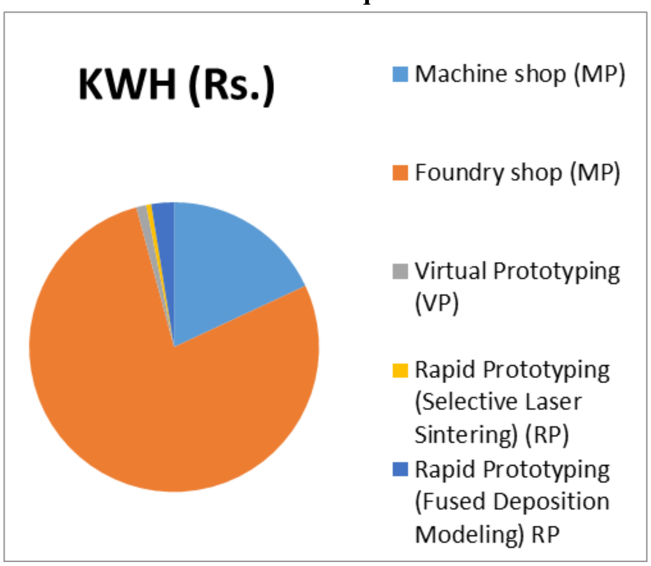

Figure 29: Comparison of KWH associated with Techniques

CONCLUSION

By using Rapid Prototyping techniques, process and machine effectiveness both can be increased, as most of the respondent industries have opinion that currently there are 40-60 percent effectiveness of processes and machine while making prototype by other techniques which can be increased. The most of the respondent industry have the opinion that degree of complexity to make prototype is 40-60 percent by using other traditional/manual prototyping techniques, while it could be improved to hundred percent by using rapid prototyping techniques. Average workforce utilization is app sixty percent resulted by the general survey in industry which can be improved by RP. By conducting general survey in surrounding industry, the most of the respondent industry have the opinion that average number of operations to make prototype is 6-9, while one or two steps/operations to make much better complex prototype by using RP techniques. All respondent industries doesn't allow design changes at later stages to make prototype as no industry give response in yes, while rapid prototyping technique can easily allow changes by just changing drawing and its dimensions The most of the respondent industry have the opinion that the level of technique's skill is skilled which can be upgraded to highly skilled level, and they easily be transferred to new emerging techniques. The system can be utilized to a great extent. More flexible prototypes can be made as flexibility is not more than sixty percent by the result of general survey. This technique is highly skilled as compared to the traditional model making techniques. Cost associated with tools, gauges and fixtures can be saved which is 40 percent of total cost while using traditional techniques. Material wastage can be minimized which is 40 percent of total cost as resulted by general survey. Queuing and material handling time can be decreased as there is no transfer of material and no need of wait for next processes on other machine in RP. Time can be four to five times less approximately when using rapid prototyping techniques than in machine and foundry shop by manual prototyping as result by physical making of v block prototype/model. Cost can be two to three time less when using RP techniques which are appeared as a result in making of physical model. Ninety percent labor and electricity can be saved by using RP technique approximately.

RECOMMENDATIONS

In order to boost up the rapid prototyping technique, following are strongly recommended for the local manufacturer. As far as the local manufacturing industry is concerned, it is unaware of the usefulness of Rapid Prototyping. They should be made aware of its importance. One main reason of unawareness is the gap between the academia and the industries. It's an emerging technique which can save both time and cost. More flexible, durable prototypes can be made within short period of time.

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