BENCHMARKING THE RAPID PROTOTYPING MACHINES (RPM) FOR EDUCATION PURPOSE USING QUALITY FUNCTION DEPLOYMENT (QFD)

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ABSTRACT

The important of Rapid Prototyping Machine (RPM) in the industrial sector has made the knowledge of its operation vital to the fresh graduates. The purpose of this paper is to compare and to select the best rapid prototyping machine for academic and educational purpose. All the rapid prototyping machine specification and the customer needs are compared in the approach of Quality Function Deployment. This paper analyzes the data from the user of rapid prototyping machine in various educational institutes in Malaysia which is among lecturers and students. The result offers the best machine to be used and the characteristic that fulfill the needs of the customers. The respondents own experience is the main source of information as they are directly involved in educational field and it will be support by another research about rapid prototyping machine specifications**.** This is a very important research as all educational fields have a standard in selecting the suitable rapid prototyping machine to give an optimum and effective learning process for students. This is a first study that applies Quality Function Deployment in benchmarking the rapid prototyping machine for the educational purpose.

Keywords: Quality Function Deployment, benchmarking, rapid prototyping, educational institutions

1.0 INTRODUCTION

The development of rapid prototyping (RP) gave the consumer the ability to form prototype or a component of a prototype that can be directly used in assemblies and product testing for short or medium production with the least time consumed. Since the first rapid prototyping machine (RPM) was introduced in 1987, the rapid growth of this technique provides wide choices of machines with different performance and credit in consideration. RP is a layer technology which is widely use in industries.

RP machines exist with so many choices of capabilities and cost, there should be methods such as strategic planning tool to design a system for an intangible product like education purposes in this case. According to Maddux *et al* (1991), Quality function deployment (QFD) can be successfully applied as a strategic planning tool for the design of an intangible product such as a program or activity.

1.1 THE PROBLEM STATEMENT

The cost for each of machine is relatively high thus requiring comparative selection to suggest the suitable one to be provided by educational institution to their student so that the investment made when purchasing the RP machine is worthy. This work attempts to recommend suitable RPM for education purposes using the QFD technique.

2.0 THE RP BASIC PROCESS

Although several rapid prototyping techniques exist, all employ the same basic five-step process. The steps are:

1. Create a Computer Aided Drafting (CAD) model of the design
2. Convert the CAD model to STL format
3. Slice the STL file into thin cross-sectional layers
4. Construct the model one layer atop another
5. Clean and finish the model

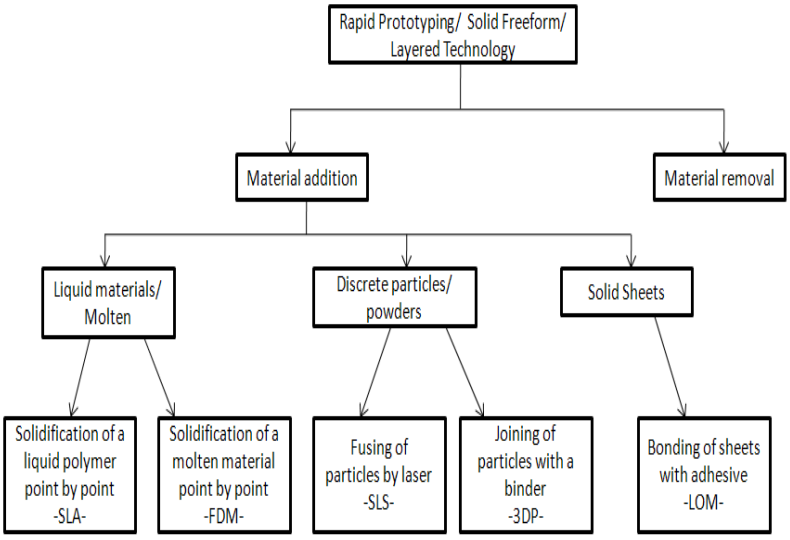


Figure 1: Classification of selected rapid prototyping methods

2.1 Different of RP process

There is a major differences in all four machines selected in this paper. The difference is based on the mechanism that specific material applied in each process must undergo in making a complete CAD model.

The process is the process involving solidification of molten material which is for *Fused deposition modeling (FDM).* Then process involving solidification of a liquid polymer which is used in Stereolithography(SLA). Next is the process involving discrete particles which are for *Three- Dimensional Printing (3DP*) and *Selective laser sintering (SLS). Lastly is the* process involving solid sheets which is for *Laminated Object Manufacturing (LOM).*

Table 1: Differences in the Build Mechanism of FDM, SL, SLS, LOM (Lee at.al, 2007)

Build mechanism / RPM	Energy source	State of Raw Material	Layer construction	Condition of Completed Part
FDM	Electromechanic	Solid-filament	Deposition	Exposed to air
SL	Laser beam	Liquid	Polymerization	Immersed in liquid
SLS	Laser beam	Solid-powder	Sintering	Buried in powder
3DP	Electromechanic	Solid-powder	Binder joint	Buried in powder
LOM	Laser beam	Solid-sheet	Subtraction	Buried in solid

3.0 QUALITY FUNCTION DEPLOYMENT

Quality Function Deployment (QFD) is a planning and problem solving tool to finding growing acceptance for translating customer requirements into the engineering characteristics product. It is graphical method that systematically looks at all of the elements that go into the product definition. QFD requires that the customers' requirements be expressed as a measurable process targets in term of engineering parameters. In term of finding a good machine for academic purpose a research has been done to benchmarking the application of quality function deployment in rapid prototyping. Refer to the research the most important criteria are planning, information gathering, incorporating information and updating the statistics.

From the research, the key of QFD is the relationship matrix, or "House of Quality". It represents the customer's requirement and the business parameter. It is important to do the assessment process to reduce bias in the analysis. The purpose of House of Quality is to show the strongest relationships so, its can be prioritized and addressed individually (Grahmani and Houshyar, 1996).

4.0 HOUSE OF QUALITY

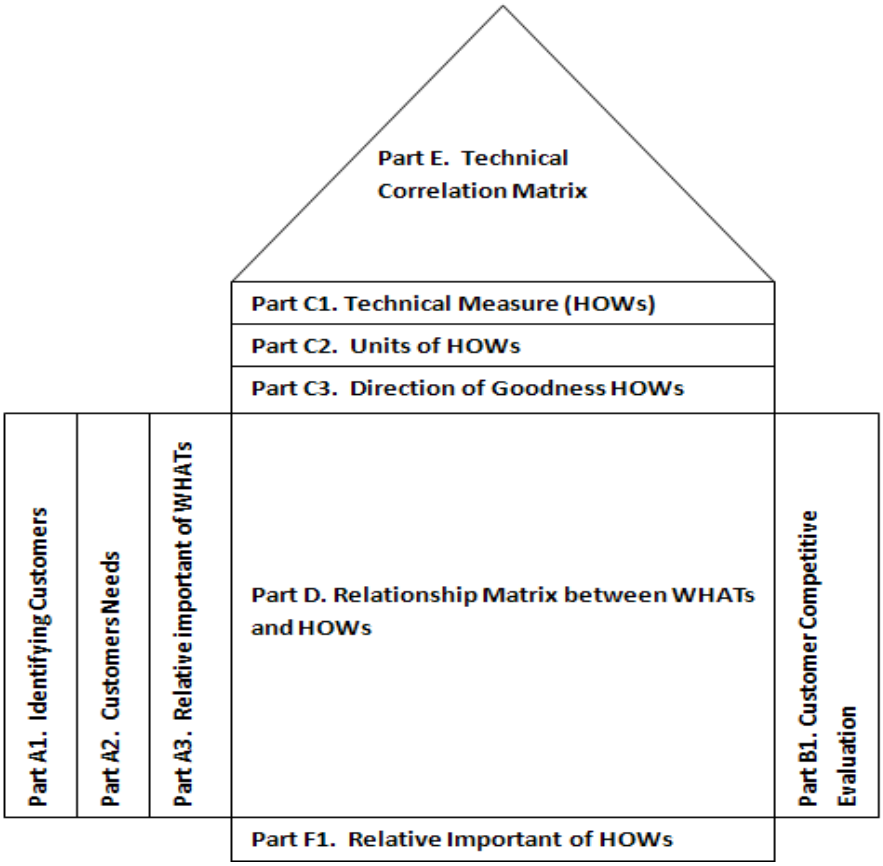


Figure 2: House of Quality

Part A. Customer Needs (WHATs)

Quality function deployment starts with the customers. The first step for a development team of a company to build an HOQ is to identify the customers of the product, collect their needs for the product and reveal the needs' relative importance perceived by the customers.

A1. The customers should be identified according to the nature of the product. In this paper the ultimate customers can be from the recipients of service, purchasers, and institutional purchasers.

A2. Customer needs are usually expressed in customers' words that can be collected by various methods by the company's marketing department or by information gathering agency. Among the methods to collect the customer's need used are survey, individual interviews, feedback and warranty data

A3. Customer needs are of different priorities for the customers, and the next QFD step is to reveal the relative importance of the customer needs identified. The company would work

on the most important customer needs and disregard the unimportant customer needs to make best use of its resources.

Part B. Competitive Evaluation Matrix

This part is customer competitive evaluations of the RP machines compared with its main competitors' similar products in terms of the products' performance on customer needs. From these comparative evaluations the we may set strategic goals for the machines to better satisfy the customer needs. The final rank order of the customer needs' strategic importance can be computed from the above information in Parts A and B.

B1. First, RP machines who produce the similar performance should be identified. Knowing the machines' strengths and constraints in all aspects of a finished product and in comparison with its main competitors is essential for a machine if it wishes to improve its competitiveness in the relevant markets. This kind of evaluative information can be obtained by asking the customers to rate the relative performance of the RP machine and its competitors on each WHAT and then to aggregate the customers' ratings.

Part C. Technical Specification (HOWs)

This part lists and structures the technical measures (HOWs) identified by the us.

C1. After the information collection and analysis in the previous parts, customer needs are transformed into technical measures (HOWs) in this step. HOWs are methods, machine measures, design requirements, substitute quality characteristics, and engineering characteristics, which can be related to and measure the customer needs (WHATs).

C2. To be properly defined, any measure should be associated with a unit and a direction, which are the next two QFD steps. Although it should not be a problem to define the units of the HOWs, it is better to give these units explicitly in the QFD matrices for both clarity and completeness. Such examples would be voltage in volts, time in minutes, length in feet, weight and force in pounds, capacity in gallons, energy in foot-pounds, resistance in pounds per square foot, process complexity in number of steps, quality in defects per thousand pieces or defects per million, and so on.

C3. As for improvement directions, three possible definitions may be adopted for different HOWs: the more the better (to increase), the less the better (to decrease), and target is best (to close to).

Part D. Relationship Matrix between WHATs and HOWs

The Relationship Matrix of WHATs vs. HOWs is a systematic means for identifying the degree of relationship or linkage between each WHAT and each HOW. Completing this Relationship Matrix is a vital step in the QFD process since the final analysis stage relies heavily on the relationship symbols or numbers at the intersections of this matrix of WHATs vs. HOWs.

Part E. Technical Correlation Matrix

The Technical Correlation Matrix is the development team's assessments of which HOWs are interrelated and how strong these relationships are, which can be obtained through engineering analysis and experience. This part is probably the most underexploited part of QFD, yet its potential benefits are great. Usually, after the HOWs have been determined, the development team will be able to see that as one HOW is changed, the others will be influenced. The degrees and directions of these influences have serious impacts on the development effort. Usually five types of technical correlations or impacts are identified in QFD: strong positive impact, moderate positive impact, no impact, moderate negative impact, and strong negative impact.

Part F. Technical Matrix

The Technical Matrix contains much technical information that is linked to both customer needs and machines characteristics in QFD's second phase. It provides the initial rank ordering of the technical measures' relative importance based on the information in the previous parts. Competitive technical assessments are conducted here to compare the machines' performance and its competitors' performance on the HOWs.

F1. The relative importance rating of each HOW is a comprehensive measure indicating the degree to which the HOW is related to all the WHATs. These ratings reflect the basic importance of the HOWs developed in relation with the WHATs, and are decided by two factors: the final importance ratings of the WHATs and the relationships between the HOWs and the WHATs.

That is, a HOW's relative importance rating is computed as the average over its relationship values with all the WHATs weighted by their final importance ratings. In addition, other more elaborate decision-making and performance measurement methods can also be used to compute the HOWs' relative importance ratings.

5.0 RESULT ANALYSIS

Survey and interview is conducted to get the data about customer requirement and it's important. The respondents are consisting of technicians and students from various universities. We have 8 interview with the technician from IIUM, UM, UniMAP, UTHM, ILP PAsir, UiTM Shah Alam and UTP. Then survey is done to 10 Mechanical Engineering Students from each universities that we visit (Please refer to Appendix A). From the survey and interview we have to rank the customer needs as the result below.

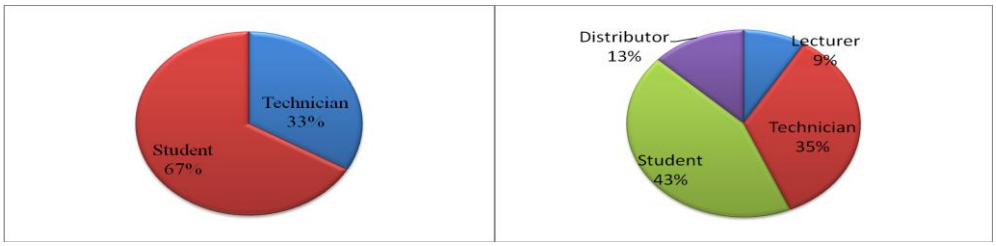
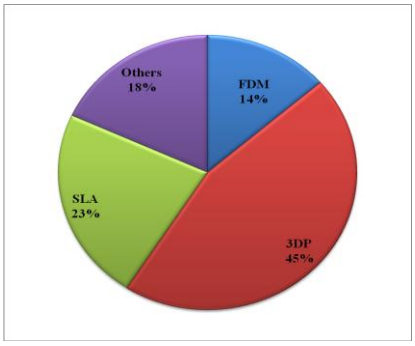


Figure 3 : Interviewee Chart and Survey Chart



FDM	3
3DP	10
SLA	5
Others	4
Total	22

Figure 4: RP User in Learning Institution

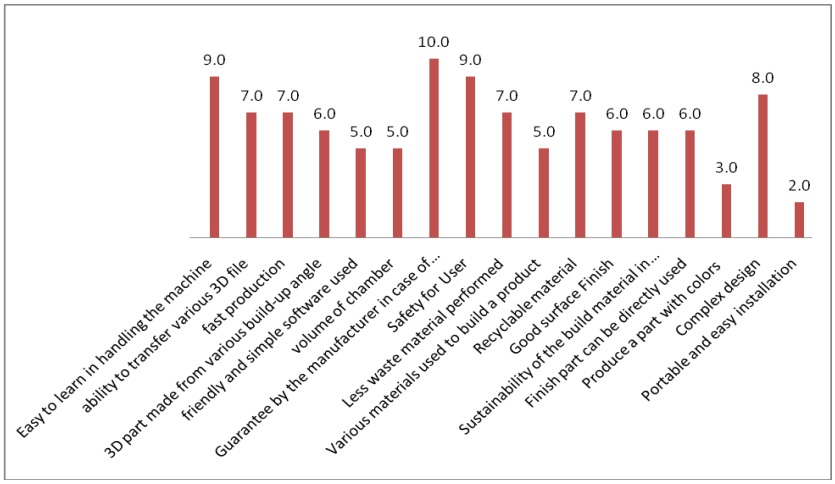


Figure 5 : Customer Needs Ranking

5.1 CUSTOMER NEEDS (WHATs)

Customer needs is divided into three important parts about the machine which are the process involve during handle the machine, material with the machine and product quality. Product quality is important as it is the main reason why the staff and student use rapid prototyping machine.

5.1.1 Process

Easy learning and handling the machine: Handling the machine means we know how to start, operate the machine until we can get the product that we want and lastly switch off the machine.

Ability to transfer various 3D file: There are many software can be use to operate the rapid prototyping machine such as Auto-CAD, I-DEAS, Unigrafics, Pro-Engineer, Solid work and others. However, some of the rapid prototyping machine just can transfer one software only while some can transfer more than one. Commonly, the machine that is used by the university uses the software that are learned by the students in the university. It will be a problem if the Kulliyyah or the Faculty changes the course or student from another university want to use the machine which they have to learn using new software.

Fast production: Most university does not have the subject or course about rapid prototyping machine. Rapid prototyping machine is used when the student or the lecturer want to produce some parts or to study about one part. Since of it is used frequently, it is important that the machine can produce the parts in a short period time.

3D part made from various build-up angles: Part form this machine can be produce from different orientation and it will give the different properties of the product especially in term of it strength.

Friendly and simple software used: It is important to use simple and friendly software; therefore student can design the product in short time and can use the machine directly. It is also related to the specification of the machine that transfers various types of 3D files.

Volume of chamber: Volume of chamber refer to range of built that part could be produced when using certain type of RP machines.

Guarantee by the manufacturer in case of break-down: It is important to the customer to make sure that the machine can be operated in long period of time. As the machine is high in its price, any problem that occurs in the machine, the manufacturer should take care of it.

Safety for User: The machine should be safe to be use. This means it will not affected the user physically and chemically. Another thing should be considered is the long term effect to human body.

5.1.2 Material

Less waste material performed: Most of the material is expensive, so the machine should produce lees waste material. Some materials are unrecyclable, so the waste cannot be used anymore.

Various materials used to build a product: There are many type of material such as wax, ABS filament, alloyed type and others. Different material will give the different properties to the part that we want to produce. If we a part design which have many division and each division have it exact strength so we have to use different material. Besides, colored part should use different material.

Recyclable material: Some material can be recycling to save the cost. However it just can be use two or three time only. If the material is reused above the allowable limit, it will affect the quality of the product that we want to produce.

Good surface finish: Good surface finish is an important specification to ensure the quality of the part.

5.1.3 Product

Sustainability of the build material in inventory: Most products that are made by this machine are a prototyping and it should have good strength. Some parts are directly used as the product especially in low quantity. Besides, there are product that be made by the exact material, so we can test the part as the real product that we want to produce.

Finish part can be directly used: Finish part should be directly used to save time. A few rapid prototyping machines has to trough finishing process

Produce a part with colors: Color is the additional features that should be considered. Some direct used part has to be colored to differentiate the division in the part. Colored part mostly used in medical field.

5.2 MACHINES TECHNICAL SPECIFICATION ANALYSIS (HOWs)

Machine cost: The cost of a machine can be derived from the technology that be implied to the machine such as laser usage and raw material heated which determine the power source cost and also the availability of other competitor who promote a better price.

Raw material cost: The parts to be produced usually differ according to the type of process used when building layer by layer, the strength required for the part and the reusability of the raw material. The process that require raw material for support purposes give high cost since the support structure will be disposed hence result to waste in cost invest.

Machine maintenance cost: The cost focus to the periods and breakdown aspect covered in manufacturer guarantee. The machines that take longer time to repair make the operating cost increase.

Processing stage cost: This cost measured from the raw material used and build speed in produce a design. The raw material cost must be minimized and the machines must have high build speed so more part can be produce within certain amount of investment.

Learning period to operate: The clear and simple instructions make the machine operation easy to handle and type of training covered by manufacturer.

Fabrication time: The times required in finishing a design .The build speed measure in layers per minute. The small layer thickness takes longer time but high accuracy.

Time for data preparation stage: The time taken to transfer the CAD models files to the RP machine fabrication format. Some machines have ability to transfer the format to .stl from various CAD file (CATIA, Rhino, SolidWork).

Time for post processing stage: The machines sometimes need for post processing stage before able to be used and this stage is cost and time consuming. Therefore the parts that need for curing process be avoided unless proven have big impacts to the parts quality.

Quality in surface finish: The smooth surface without requirement for finishing and the raw material reused time without give major defects.

Quality in giving accurate dimension: The machine accuracy depends to the type of raw material used either filament or powder. The print resolution is measure in unit: dpi

Reliability to produce complex design: The machines reliability to build a part with that has complex structure without any defects and interruption.

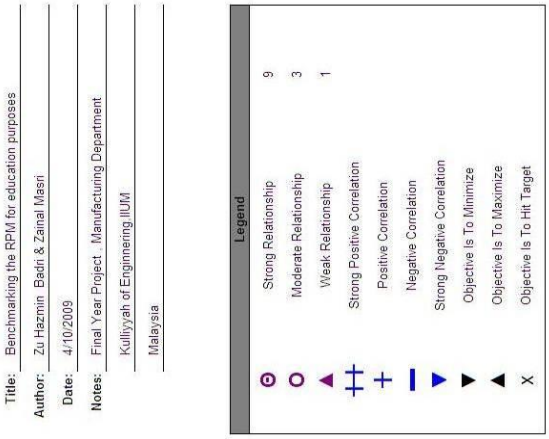
Manufacture parts with wide range of size: The intended structures varies in height, wide and long thus higher build chamber size means better for the customer.

User protection: Human physical response to raw material for fabrication, laser emit, chemical for post processing. The machine that provide safety aspects for operator and use chemical with no health effects be considered.

Equipment weight: The lower weight makes machine become office friendly and easy for installation purposes.

Level of automation: Shows how the machine can be easily handle/operate and need less

Figure 15: Result of House of Quality



5.4 CHARACTERISTIC OF RAPID PROTOTYPING MACHINE

From the result, the importance of Quality Characteristic has been identified.

Machine cost play and important aspect to be considered and for the lowest price of rapid prototyping machine is FDM, followed by 3D printing. Another machine we can classify as expensive and do not suitable with the ability of university. House of quality show we have to focus on the machine cost in selecting the machine. Most of the machine that is used in Malaysia is FDM, 3D and SLA. However this analysis will focus on two type of machine as the price of SLA machine is very high. The analysis will focus for the 2 type of machine which is FDM and 3D

Table 2 Comparison of the most suitable RP Machines to be used in higher educational

Machines/Company	**3DP (Z Corp)**	**FDM (Stratasys)**
Machine Cost	$28,800	$55,000
Maintenance cost	Services by manufacturer	Services by manufacturer
Complex design	Use powder with laser, easily to form complex design	Use filament, limitation to extrude successfully
Material cost	$3362 per unit volume	$200 per mile long spool filament
Preparation stage	Faster STL,VRML PLY file format 3D viewing, text labeling and scaling functionality	Acceptable STL file format Generate extrusion path and necessary support structure
Surface finish (layer)	Smoother (0.0030”-0.010”)	Smooth (0.0050”-0.010”)
Accuracy	Acceptable (300 x 450 dpi)	Acceptable (+/- 0.005 in)
Features	Use high performance composite. Colored prototype, Recyclable material	Use commercial high grade plastics

institutions

The second ranking is machine maintenance cost. The maintenance cost depends on the performance of the machine in term of time and application. Survey and interview show that the sensitive machine is FDM as it using nozzle that heated by the filament. Beside FDM has it further process before the part can be used compare to the 3DP machine.

The third ranking is the reliability of rapid prototyping machine to produce complex design. In comparing all rapid prototyping machines, SLA is the best machine to produce complex design and then followed by 3DP which can produce complex part with variety of colors and high resolution of printing techniques. When we compare all the quality characteristics between 3DP and FDM machine, 3DP is the best choice. Therefore we come to the conclusion to recommend 3DP rapid prototyping machine to be used in university as it will fulfill the requirement for educational purpose.

6.0 DISCUSSION

Result analysis show us that QFD could give the answer in selecting the best rapid prototyping machine for educational purpose. It shows the specification of the machine that we should consider during purchasing the machine. The specification of the machine is important to fulfill the university requirement in preparing high quality student for the university.

There are many benefits in using house of quality as tool to benchmark the best rapid prototyping for educational purpose. In house of quality, there are three important elements which are demanded quality, quality characteristic and the relation between both of them. In this study the customers needs not only base on the high authority of the university or base on the individual mind but it should cover all the user of the machine. In this study, the customer's needs are base on the lecturers, technicians and students. Lecturer is the person that prepares the course, technicians as the person that guides and handles the machine and then, the students as the person that will manipulate the course and the machine for their research or study.

After that all the customer needs will be rank and match it with the machine specification. From the survey, we found that the important customer's needs are on the cost, product quality and also the easy handling of the machine. Thus, after fulfill the relation between customers' needs and quality characteristic we find the specification of the RP machines that is important. Begin with the most prioritize specification, all type of RP machine is compared to choose the best machine. As a result, 3D Printing type of RP

machine is chosen base on fact of machine cost machine cost, machine maintenance cost, reliable to produce complex design, raw material cost and another important aspect.

In the study we also found some imitation in using house of quality. The important part is to know the customers need about the rapid prototyping machine. During surveys and interviews, we found those rapid prototyping machines are not widely use in the university. Therefore some respondents are not willingly answered the survey and the interview. Some technicians still do not well understand about the machine although they have go through a training. This situation will affect the survey and interview analysis and then also affected the result as the whole. Besides, the limitation is the user of QFD may spend too much effort in seeking the correct data. Therefore to avoid this problem, we have to understand well the rapid Prototyping process and how to implement QFD with it. Another limitation of QFD is it cannot take into account the uncertainty and ambiguity inherent in the assessment of customer requirements.

6.0 RECCOMENDATION AND CONCLUSION

6.1 Recommendation

Quality Function Deployment is used widely in industrial, trading and research especially in foreign country such as Japan and United State. Actually QFD is a good tool to measure the quality of products or services. We also can use QFD to study on the educational system in the university in term of to fulfill the student and university requirement. This is one of effective way to improve the quality sytem in the university for instance, to select the best subject for the student, to select the best software that to be used in the course and to choose other machine or equipment for educational purpose.

Besides, the QFD system itself could be improve to get precise and accurate result. The basic concept must be understood and try to improve another important aspect especially in collecting relevant data for customers and try to simplify some difficult measure in the system.

6.2 Conclusion

In determining the relative importance of educational requirements involves a high degree of subjective judgment and individual preference which collect from the survey and interview of lecturers, technician and students from engineering faculty.
Depending on their background, people can state their personal preferences in many different ways. The determination of the customer's requirement priorities is the key concept in QFD.

The usage of QFD in this paper is to improve the understanding between learning institution demands and RP machine relation where at the end some suggestions will be made on the best choice with the customer demands. At last we have benchmark 3D Printing rapid prototyping as the best machine for educational purpose.

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