STUDY OF THE IMPLEMENTATION OF ADDITIVE MANUFACTURING AT PROTON USING ANALYTIC HIERARCHY PROCESS

SITI LYDIA BINTI RAHIM

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2014

DECLARATION

I declare that this thesis entitled "Study of the Implementation of Additive Manufacturing Technology at PROTON Using the Analytic Hierarchy Process" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : …………………………..

Name : SITI LYDIA BINTI RAHIM

Date : 2 JUNE 2014

DEDICATION

This thesis is dedicated to my loving husband, Muhd Ashroff b. Abdul Munir and my parent, Mazeni bt. Md Zain and Rahim b Othman, who supported me each step of the way.

I also dedicated this thesis to my cherish friend, Nor Haniza bt. Bakhtiar Jemily, who have supported me throughout the process. Without her lifting me up when this thesis seemed interminable, I doubt it should ever been completed.

ABSTRACT

Additive Manufacturing (AM) is the direct production of finished goods using additive fabrication techniques. AM done in parallel batch production can provide a large advantage in both speed and cost. Currently, the efforts to utilize the AM concept and technology have several problems, particularly in the Malaysian automotive industry. Such existing problems have discouraged the enhancement of process development of the automotive industry. In providing the solution, by adopting the AM concept, there is potential to expedite the process development of automotive parts and move towards mass customization. These issues have been discovered through the discussion with Malaysian AM experts and also with the Malaysian automotive manufacturer which is PROTON and its vendor. This research presents an overview of the implementation of the AM and the critical decision factors in implementing AM in PROTON. The Analytic Hierarchy Process (AHP) is a theory of decision-making through pairwise comparisons and relies on the judgments of experts to derive priority scales. AHP is used in order to assess the priority scales affecting AM implementation. The four main factors that will affect the implementation were the financial aspect, which is included investment cost and maintenance cost. Technological aspect was the main factor of AM system selection and material. Employee response to change and impact on supply chain were sub-factors of the main of organization aspect, meanwhile design practice aspect was the main factor for impact on product design and operation activities. This research fulfills an identified information need and offers practical help to an organization to promote the acceptance and implementation of AM technology. PROTON and other industries can focus for further development of implementation.

ABSTRAK

Additive Manufacturing (AM) adalah pengeluaran langsung barangan siap menggunakan teknik fabrikasi bahan tambahan. AM dilakukan dalam batch pengeluaran selari boleh memberi kelebihan yang besar di kedua-dua kelajuan dan kos. Pada masa ini, usaha-usaha untuk menggunakan konsep AM teknologi mempunyai beberapa masalah, terutamanya dalam industri automotif Malaysia. Masalah yang sedia ada seperti ini tidak menggalakkan peningkatan pembangunan proses industri automotif. Dalam menyediakan penyelesaian, dengan mengamalkan konsep AM, terdapat potensi untuk mempercepatkan proses pembangunan alat ganti automotif dan bergerak ke arah penyesuaian masa. Isu-isu ini telah ditemui melalui perbincangan dengan pakar-pakar AM di dalam Malaysia dan juga dengan pengeluar automotif Malaysia iaitu PROTON dan beberapa vendor kepada PROTON. Kajian ini membentangkan gambaran keseluruhan pelaksanaan AM dan faktor-faktor keputusan kritikal dalam melaksanakan AM di PROTON. Proses Hierarki Analisis (AHP) adalah teori membuat keputusan melalui perbandingan dari segi pasangan dan bergantung kepada penghakiman pakar-pakar untuk mendapatkan skala keutamaan. AHP digunakan untuk menilai skala keutamaan yang mempengaruhi pelaksanaan AM. Empat faktor utama yang akan mempengaruhi pelaksanaannya itu ialah aspek kewangan, yang termasuk kos pelaburan dan penyelenggaraan kos. Aspek teknologi merupakan faktor utama AM pemilihan sistem dan material. Tindak balas pekerja kepada perubahan dan kesan kepada rantaian bekalan merupakan faktor kepada faktor utama aspek organisasi. Manakala amalan reka bentuk aspek telah faktor utama memberi kesan kepada reka bentuk produk dan aktiviti-aktiviti operasi. Kajian ini menghuraikan maklumat yang perlu di titikberatkan dan menawarkan bantuan praktikal kepada organisasi untuk menggalakkan peningkatan perlaksanaan teknologi AM di PROTON dan juga kepada industri lain untuk tujuan pelaksanaan dan pembangunan.

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USED ABBREVIATIONS

AM	-	Additive Manufacturing
RP	-	Rapid Prototyping
AHP	-	Analytical Hierarchy Process
PROTON	-	Perusahaan Otomobil Malaysia Berhad
SIRIM	-	Standard and Industrial Research Institute of Malaysia
FA	-	Financial Aspect
TA	-	Technological Aspect
OA	-	Organization Aspect
DA	-	Design Practice Aspect
IC	-	Investment Cost
MC	-	Maintenance Cost
AMS	-	AM System
MA	-	Material
EC	-	Employee Response to Change
IS	-	Impact on Supply Chain
IPD	-	Impact on Product Design
OPA	-	Operation Activities

LIST OF PUBLICATIONS

Paper A:

Siti Lydia Rahim, Shajahan Maidin . (2008). *Feasibility Study of Implementation of Rapid Manufacturing Technology in Malaysian Automotive Industry* , National Conference of Design and Concurrent Engineering, Mahkota Hotel, Melaka, Malaysia.

Paper B:

Siti Lydia Rahim, Tajul Ariffin Abdullah . (2009). *Rapid Prototyping Technology for Product Development; An Introduction* .Malaysian Technical Universities Conference on Engineering and Technology, Universiti Malaysia Pahang, Pahang, Malaysia.

Paper C:

Siti Lydia Rahim, Shajahan Maidin . (2013). *Feasibility Study of Additive Manufacturing Technology Implementation at PROTON using Analytis Hierarchy Process.* 4th International Conference on Machanical and Manufacturing Engineering 2013, Equatorial Hotel Bangi, Selangor, Malaysia

CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysian automotive has been left behind in the aspect of design development compared to other automotive makers. This is due to the use of traditional technology in producing mold manufacturing with a number of drawbacks, such as the time-consuming production.

Additive Manufacturing (AM) offers increasing benefits in production schedules and flexibility for manufacturing operations due to the reduction in tooling costs and design requirements Mortara, Hughes, Ramsundar, Livesey, & Probert (2009). The trend towards mass customization and agility in manufacturing has been identified as a key driver for business differentiation in the global market place Wohlers (2003). The possible benefits to consumers are also multifarious such as the fact that the consumer can choose a variety of designs produced by the manufacturers in a short period of time. However, the utilizations of AM need careful consideration in order for the benefit to be maximized.

From the above, its shows that AM is an area of interest that plays an important role in the manufacturing process today. Currently, the efforts to utilize AM concept and technology in the automotive industry have caused several problems in cost and management which discourage the enhancement of design and development activities of the industry itself. In providing solution to this problem, it is necessary to adopt AM to expedite the process design and development of automotive parts.

An initial interview was done with *Perusahaan Automobile Malaysia Berhad* (PROTON) to investigate the time taken for PROTON to produce car design and to develop the car. Furthermore the interview was conducted to investigate PROTON's knowledge on AM. Moreover, the aim of the interview is to identify the issues that arise in the course of implementing AM for mass customization.

The Rapid Prototyping & Manufacturing Centre (RPMC), PROTON, is the only department that makes up the research and development (R&D) division of Malaysia's ISO 9002 certified national automobile manufacturer. The PROTON RPMC was initially conceived to provide rapid prototyping services, in its effort to reduce the lead time and cost involved in the development of all new Proton cars. The final part of this research is to analyze the information gained from the research to enable the study of feasibility of implementing AM technology in the Malaysian automotive industry.

1.2 Problem Statement

With the increased competition from the global economy, manufacturers in general, face the challenge of delivering new customized products more quickly than before to meet customer requirements. A delayed development or delivery may lead to business failure. While focusing on the automobile industry, the manufacturer of complex components at low cost, with a short manufacturing cycle, is the key factor for the competitive automobile industry. As the traditional manufacturing techniques are complex and require long manufacturing time and high cost, the need for rapid manufacturing systems that can produce parts with adequate accuracy and quality, with reasonable cost, becomes increasingly significant day by day. AM is a promising option to tackle this issue to a remarkable extent. AM offers increasing benefits in production schedules and flexibility for manufacturing operations due to the reduction in tooling costs and requirements

(Mortara, 2009). The possible benefits to manufacturers and consumers are great, but the implementation and execution need careful consideration in order to maximize these benefits. Currently, the efforts to utilize AM concept and technology are shown to have several problems particularly in the automotive industry. Such existing problems have discouraged the enhancement of design and development activities of the automotive industry Choi & Cheung (2008). Therefore, the feasibility of implementing AM to the automotive industry needs further exploration. As the Malaysian automotive manufacturing industry is aiming at revolutionary developments, the need for a thorough investigation on the technical and economic viabilities of exploiting maximum benefits of AM techniques for the industry is quite obvious. Hence, the present study focuses on this issue, considering the case of Proton Sdn. Bhd, a well-reputed automotive industry in Malaysia.

1.3 Objectives

The aim of this project is to study the influence of AM on Malaysian automotive manufacturing, (PROTON). The objectives of this study are significantly important to the future implementation of AM in the automotive industry. The objectives are:

(1) To investigate the influence of AM on the Malaysian automotive industry.

(2) To investigate the management and the design process of using AM in the Malaysian automotive industry.

(3) To develop a framework to aid the decision-making system using the AHP (Analytical Hierarchy Process) method in order to assess the factors affecting AM implementation.

1.4 Research Scope

The scope of the research is to study the feasibility to implement AM in the automotive industry in Malaysia. The interviews were made with several expertises. Questionnaires were distributed to collect data that are used to validate the hypothesis of the research. The questionnaires have been distributed to PROTON and PROTON vendor who has already adopted AM technology at a smaller scale. The AHP will then be used to analyze the data and as a technique to aid the decision-making process for the feasibility of utilizing and implementing AM technology.

1.5 Thesis organization

This thesis is organized in 6 main chapters. After this introductory chapter, Chapter 2 takes a close look on some relevant literature on AM. The review of previous works is directed towards the implementation of AM to the automotive industry. Chapter 3 gives a detailed account of the materials and methods used in the current research. An analysis of the data obtained was presented in Chapter 4. Discussions on the results obtained from the numerical simulations are presented in Chapter 5 followed by the conclusion established in Chapter 6. The thesis ends with the corresponding references, appendices and the list of publications of the current research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Before focusing on the real issue in the current study, a careful examination of pertinent literature was performed. This chapter gives an outline of the review of previous AM and AHP literature. Important works relevant to the current study are critically reviewed and presented in a chronological order.

2.2 Additive Manufacturing (AM)

The President of Wohlers Associates, Terry Wohler who is a leading rapid prototyping analysis and consultant states that, '*AM is the direct production of finished goods from a rapid prototyping device*' Wohlers (2008). This technique adopts some additive processes to deliver finished goods from digital data; thereby removing all tooling. In this approach, it becomes feasible to decentralize the manufacturing operations and produce parts more rapidly, at more reasonable prices, and with much more flexibility. AM is also known as *direct manufacturing, direct fabrication* and *digital manufacturing*.

It cannot be denied that AM can potentially be the next frontier in rapid prototyping technology. A number of industries have already begun to adopt AM in low scales. Even though it is improbable that AM would ever attain the production capacity of processes such as plastic injection molding or sheet metal stamping, one would be led to believe that it will contribute to low scale production, for instance, the manufacturing of prosthetic devices, and of space exploration products Gibson (2005).

2.3 Potential of AM

In AM, components are manufactured layer by layer without undergoing processes of molding, casting or machining. The opportunities and advantages of AM are great. The five major advantages of AM technology are given below Jurrens (1999):

(i) Low Capital Expenditure: Parts built straight from digital data, and tooling is not necessary.

(ii) Unlimited Complexity: Building in layers enables unrestrained freedom in the design phase.

(iii) Freedom to Redesign: No penalties during production when changes are deemed vital.

(iv) Part Consolidation: Integrating various components into one.

(v) Innovation: Designs are no longer withheld by the limitations of old manufacturing techniques.

2.4 AM Generic Process

AM requires some generic steps in order to produce a part or a product. The generic steps are Yan et al. (2009) as follows.

(i) Create a 3D model with a computer aided design (CAD) program. The model is a virtual 3D-representation of an object.

(ii) Export the model, which is normally in the STL format so the AM process can manipulate the model.

(iii) Import the STL model into the AM machine and prepare for use.

(iv) The machine builds the part layer by layer until it is ready.

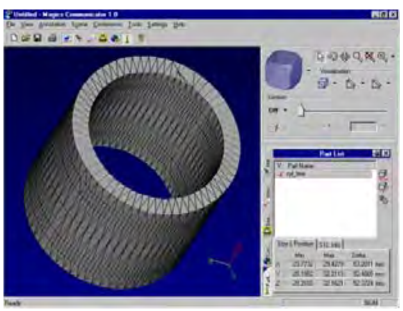
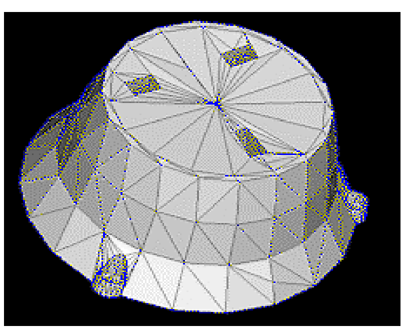
(v) When the part is complete, remove it from the machine.

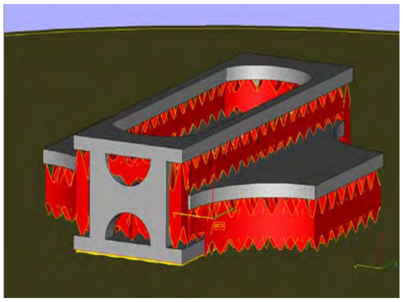
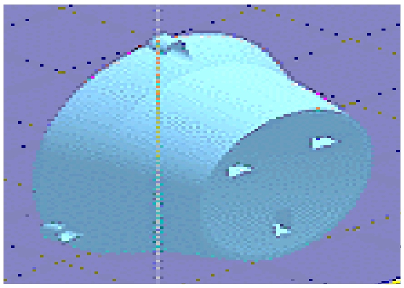
(vi) Having done that, a post-processing step may be needed.

(vii) The part is now ready to be used.

For a great deal of AM processes, there is a standard generic sequence that is adopted in order to create parts. This is shown in Table 1.

Table 1 : Generic process sequence for AM technologies (Neil, 2010)

Process step	**Description**
<u>Convert CAD model to STL format</u> 	CAD model is converted into the STL format that denotes the surface of the part made up of many triangles.
<u>Orient part (s)</u> 	By experience, the operator selects the best orientation, for example to reduce the build time or to get tolerances on key dimensions.

Generate supports if required 	Software often generates supports automatically where needed; however experienced operators would have the knowledge to edit these to reduce the need for manual support removal in the post-processing phase.
Create slice files 	Software produces the 2D profile description of each layer of the part and this includes the supports that need to be made.
Fabricate part plus supports 	2D profiles are delivered to the machine to drive the part creation, for example by controlling mirrors which allow lasers to scan across a powder bed to sinter/fuse powder where it is needed.
Post-process 	Having fabricated the parts, they have to be cleaned, in order to remove excess unfused powder or support structures. Further work in the form of sanding or electroplating may also be necessary, depending on the process applied and the application intended for the part.

2.5 Current AM Techniques and Materials

Various techniques and materials can be applied for AM. Commercial techniques are available to produce objects from a vast range of plastics, ceramics, and metals. However, the most widely used AM technologies are:

(i) Stereolithography (SLA)

(ii) Selective Laser Sintering (SLS)

(iii) Fused Deposition Modeling (FDM)

2.5.1 Stereolithography (SLA)

Stereolithography (SLA) machines were first introduced in 1986. The name was the brainchild of Charles Hull, given by him to his new process for creating solid objects from liquid resin and a computer-generated representation of the part Manu (1996). SLA is one of the first polymer prototype technologies to undergo development. SLA systems employ the 3D CAD data to change the liquid resin and composites material into solid cross-sections, layer by layer, to build extremely accurate three-dimensional parts, Egodawatta, Harrison, De Silva, & Haritos (2004).

Next, SLA systems can process a variation of polymer materials with different properties and some of these are appropriate for AM. As the mechanical properties and surface finish are accurate, the systems have become one of the most well-established AM methods Gibson (2005).

SLA works by scanning the liquid surface of a bath of the resin with an ultraviolet laser beam causing the resin to cure in the shape of the part's layer. Figure 1 illustrates the schematic diagram of Stereolithography.