DEVELOPMENT OF DECISION MAKING PROCESS FOR FUSED DEPOSITION MODELING MACHINES SELECTION

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Manufacturing Design) (Hons.)

by

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I hereby, declared this report entitled "Development of Decision Making Process for Fused Deposition Modeling Machines Selection" is the results of my own research except cited in references.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the Bachelor of Manufacturing Engineering (Manufacturing Design) (Hons.). The member of the supervisory committee is as follow:

……………………...……………..

(Supervisor)

(DR. ZULKEFLEE BIN ABDULLAH)

ABTRACK

Laporan ini merupakan kajian tentang Integrasi AHP dan MOORA dalam proses pemilihan mid-end Fused Deposition Modeling (FDM) mesin yang terbaik. Pemilihan untuk mid-end Fused Deposition Modeling (FDM) mesin yang terbaik berdasarkan spesifikasi yang dikehendaki agak meragukan dan sangat penting untuk membuat keputusan yang sesuai dengan pelbagai kriteria dan sifat-sifat. Sebuah mesin sesuai digunakan untuk proses Fused Deposition Modeling (FDM) boleh meningkatkan kecekapan mesin, prestasi, kualiti serta mengurangkan kos pengeluaran. Objektif utama projek ini adalah untuk menentukan mesin yang sesuai dengan mengenal pasti kriteria penting seperti yang dikehendaki menggunakan Integrasi AHP-MOORA sebagai rangka kerja pada pemilihan mid-end Fused Deposition Modeling (FDM) mesin. Pemilihan mesin adalah berdasarkan kepada spesifikasi yang sedia ada dan pengumpulan pangkalan data mengenai mid-end Fused Deposition Modeling (FDM) mesin di pasaran. Kriteria utama yang diperlukan untuk pemilihan mid-end Fused Deposition Modeling (FDM) mesin boleh diklasifikasikan kepada empat aspek seperti prestasi, kos, kualiti, dan kapasiti. Dalam aspek prestasi mesin, terdapat tiga sub-kriteria yang perlu dipertimbangkan seperti Kekuatan Tegangan (TS), Pemanjangan (E), dan Heat Pesongan Suhu (HDT). Sementara itu, Mesin Kos (MHC) dan Kos bahan (MC) adalah ketara sub-kriteria dalam aspek kos. Walau bagaimanapun, Print Parameter (PP) dan Membina Size (BS) adalah sub-kriteria yang mempengaruhi kualiti dan keupayaan masing-masing. mesin enam calon dipilih berdasarkan keperluan yang dinyatakan. Pertama sekali, AHP telah digunakan untuk menentukan berat kriteria pemilihan. MOORA telah digunakan untuk melaksanakan ranking alternatif. Penggunaan integrasi AHP-MOORA dibukti sangat berjaya dalam pelbagai kriteria membuat keputusan proses yang melibatkan banyak kriteria dan alternatif dalam pemilihan FDM pertengahan akhir. Kesimpulannya, mesin calon, Mesin 5, CubePro oleh pengeluar 3D Systems telah dipilih sebagai alternatif terbaik berdasarkan prestasi, kualiti, kos, dan perspektif kapasiti dengan menggunakan integrasi AHP-MOORA.

ABSTRACT

This report was study about integration of AHP and MOORA approach in selection of best mid-end Fused Deposition Modeling (FDM) machine. The selection for the best Fused Deposition Modeling (FDM) machine based on required specification can be very indecisive and very important to make an appropriate decision with variety of criteria and attributes. A suitable machine used for required Fused Deposition Modeling (FDM) process can enhance machine proficiency, performance, quality as well as reducing production cost. The main objective of the project was to determine the suitable machine by identifying the important criteria as required using integrated AHP-MOORA as framework in mid-end FDM machine selection. The machine selection was based on the existing specifications and collection of database about mid-end FDM machines in the market. The main criteria that required for the mid-end Fused Deposition Modeling (FDM) machine selection could be classified into four aspects such as Performance, Cost, Quality, and Capacity. In the aspect of machine's performance, there were three sub-criteria to be considered such as Tensile Strength (TS), Elongation (E), and Heat Deflection Temperature (HDT). Meanwhile, Machine Cost (MhC) and Material Cost (MC) were significant sub-criteria in the aspect of cost. However, Print Parameter (PP) and Build Size (BS) were sub-criteria affecting the quality and capacity respectively. Six candidates machine were selected based on the requirement mentioned. Firstly, AHP approach was used to determine the weight of the selection criteria. MOORA approach was then used to perform the ranking of alternatives. The integrated AHP-MOORA approach was proven very successful in multi-criteria decision-making processes which involved many criteria and alternatives in mid-end FDM selection. In conclusion, the candidate machines, Machine 5, CubePro by manufacturer 3D Systems was selected as the best alternative based on its performance, quality, cost, and capacity perspective by using integrated AHP-MOORA approach.

DEDICATION

Dedicated to my beloved late-father, Chew Choon Hin,
my appreciated mother, Leong For Moy
and my adored family members for giving me moral support, cooperation, encouragement,
and understandings.
Thank You So Much

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LIST OF ABBREVIATIONS

AM	-	Additive Manufacturing
ABS	-	Acrylonitrile Butadiene Styrene
AHP	-	Analytical Hierarchy Process
ASTM	-	American Society of Testing and Materials
CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
CMM	-	Coordinate Measuring Machine
CNC	-	Computer Numerical Control
FDM	-	Fused Deposition Modeling
LOM	-	Laminated Object Manufacturing
MADM	-	Multiple Attribute Decision-making
MCDM	-	Multi-Criteria Decision-making
MODM	-	Multiple Objective Decision-making
MOORA	-	Multi-Objective Optimization Basis of Ratio Analysis Method
NIST	-	National Institute of Standards
SL	-	Stereolithography
SLS	-	Selective Laser Sintering
SPC	-	Statistical Process Control
STL	-	Standard Tessellation Language
TRIZ	-	Theory of Inventive Problem Solving
TOPSIS	-	Technique for Order Performance by Similarity to Ideal Solution
UTM	-	Universal Testing Machine
3D	-	3- Dimensional

LIST OF SYMBOLS

mm	-	Millimetres
mm^3	-	Millimetres Cube
MPa	-	Mega Pascal
%	-	Percentage
℃	-	Degree Celsius
USD	-	US Dollar

CHAPTER 1

INTRODUCTION

This chapter includes the basic research background to determine a deep understanding about the problem of the issue. It will directly support the proposes and objectives in the entire research so that a clearer picture of the scopes be solidified.

1.1 Project Background

The specification of machine focuses on tightening printing quality due to high demand of 3D printing necessity in rapid manufacturing industry. The suitable quality candidate machines will be selected based on their performance, cost, and capacity requirements to achieve expected quality 3D printed product. AHP is a useful and flexible decision-making process as it provides opportunity to select the best alternative of FDM machine by considering with multi attributes both in tangible (objective) as well as non-tangible (subjective) attribute measures. This paper proposes a unified and verifiable framework by which consumers can evaluate the different alternatives of FDM machine to meet the desired criteria. However, there are several examples of the implementation of a standard test part to compare the print quality among a pool of AM machines. Jayaram *et al.* (1994) printed a standard part to introduce a scientific procedure in the comparison of four different 3D printing platforms. A standard part to differentiate the print quality among four different polymeric-based AM platforms was used by Ghany and Mahesh *et al.* in the year 2004. According to Moustafa (2006), a standard part was applied to distinguish the capability of four different laser-based metal powder bed fusion units. Moylan *et al*. (2012) as hallmarked the National Institute of Standards (NIST), a standard test part was used for the analysis of AM machines. An effective way to choose the suitable specifications for required quality and cost reduction is to tailor the best mid-end FDM machine based on features of respective machine in data base and manufacturer's sources.

An integrated Analytical Hierarchy Process (AHP) and Multiple Objective Optimization on the Basis of Ratio Analysis Method (MOORA) are the multiple-criteria decision making methods (MCDM) that can be applied in the machine selection decision making process of mid-end FDM machine. The AHP approach is used to determine the weight of the selection criteria, while MOORA approach is used to perform the ranking task and it proposes the best solution among the candidate machines (Mansor et al., 2014b).

Analytical Hierarchy Process (AHP) is developed by Saaty in 1980. The essence of the process is decomposition of a complex problem into a hierarchy with goal (objective) at the top of the hierarchy, criterions and sub-criterions at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy. Elements at given hierarchy level are compared in pairs to assess their relative preference with respect to each of the elements at the next higher level. The verbal terms of the Saaty's fundamental scale of 1–9 is used to assess the intensity of preference between two elements. The value of 1 indicates equal importance, 3 moderately more, 5 strongly more, 7 very strongly and 9 indicates extremely more importance. The values of 2, 4, 6, and 8 are allotted to indicate compromise values of importance. Ratio scale and the use of verbal comparisons are used for weighting of quantifiable and non-quantifiable elements. The method computes and aggregates their eigenvectors until the composite final vector of weight coefficients for alternatives is obtained. The entries of final weight coefficients vector reflect the relative importance (value) of each alternative with respect to the goal stated at the top of hierarchy. A decision maker may use this vector due to his needs and interests.

Multi-objective optimization is the process of simultaneously optimizing two or more conflicting criteria (objectives) subject to certain constraints (Brauers, 2004). In a real time, decision-making scenario, different decision makers with varying interests and values, make a decision-making process much more difficult. In a decision-making problem, the objectives (criteria) must be measurable and their outcomes can be measured for every alternative candidate. Among the conflicting criteria (objectives), some are beneficial (where maximum values are desired) and some are non-beneficial (where minimum criteria values are always preferred). The multi-objective optimization on the basis of ratio analysis (MOORA) method (Brauers & Zavadskas, 2006; Chakraborty, 2011; Karande & Chakraborty, 2012) considers both beneficial and non-beneficial objectives (criteria) for ranking or selecting one or more alternatives from a set of available options.

In this project, integrated of AHP and MOORA approach were used in the machine selection process of mid-end FDM machines under certain criteria and a wide range of alternatives. By combining both methods, a more efficient way in analyzing the decision structure as well as determining the criteria weight can be achieved especially in dealing with practical and theoretical problem.

1.2 Problem Statement

The selection for the best Fused Deposition Modeling (FDM) machine based on required specification can be very indecisive and very important to make an appropriate decision with variety of criteria and attributes. A suitable machine used for required Fused Deposition Modeling (FDM) process can enhance machine proficiency, performance, quality as well as reducing production cost. An effective way to choose the suitable specifications for required quality and cost reduction is to tailor the best mid-end FDM machine based on features of respective machine in data base and manufacturer's sources. Machine selection for the best mid-end Fused Deposition Modeling (FDM) machine is a multiple criteria decision-making problem, priority in selecting criteria and candidates for machine selection of FDM are very important. The methodology used in machine selection must be able to solve the multiple- criteria decision making problem.

1.3 Objectives

Main objective of the project was to determine the suitable machine as criteria required for mid-end FDM machines, to specify the objective was as follow:

- To identify important criteria in mid-end FDM machine selection
- To apply Integrated AHP-MOORA as framework in mid-end FDM machine selection

1.4 Scopes of the Research

The machine selection of mid-end machines for the Fused Deposition Modeling (FDM) process is based on existing specification provided by manufacturers. The specification of machine focuses on tightening printing quality due to high demand of 3D printing necessity in rapid manufacturing industry. The suitable quality candidate machines will be selected based on their performance, cost, and capacity requirements to achieve expected quality 3D printed product. AHP is a useful and flexible decision-making process as it provides opportunity to select the best alternative of FDM machine by considering with multi attributes both in tangible (objective) as well as non-tangible (subjective) attribute measures. Therefore, this project will focus on the application of integrated AHP- MOORA approach in multi-criteria decision-making processes which involved many criteria and alternatives in the machine selection procedure.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter studies the literature review about the integration of AHP-MOORA approach in mid-end Fused Deposition Modeling (FDM) machine selection. Secondary sources such as books, journals and online researches are used to get related information regarding the project. This chapter will provide detailed understanding about existing mid-end FDM machines used in rapid prototyping and their related machines' specifications, as well as the method that is most appropriate for machine selection.

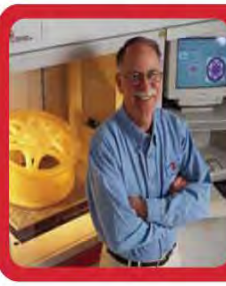
2.2 Definition of Rapid Prototyping

According to ASTM International (2013), rapid prototyping or additive manufacturing (AM) is a technique of fusing materials to make objects from 3D Computer-Aided Design (CAD) data by layer upon layer, as opposed to subtractive manufacturing terminologies.

2.3 Introduction and History of Rapid Prototyping in Development

Rapid prototyping was introduced in the year of 1984. This is a technique of fabricating models or parts as prototype in general. Usually it is making layer by layer to physical object in 3D with CAD software. One of the earliest additive manufacturing (AM) processes is rapid prototyping. The advantages of this process are the time and cost reduction, lower the product development cycle, support better design complexities. However, at the mean time it is only be adopted by companies, professionals as well as public. With advancement of rapid prototyping, academicians can build and analyze models for theoretical comprehension and studies from CAD files rapidly. Medical professionals can build artificial organs to replace the damage one and plan better procedure in medical research and application, market researchers can foresee and predict the trend of new product in market. It makes convenient for users to demonstrate their talented innovations.

In 1984, the applications and innovations on the inkjet concept is transformed to printing with materials. With more than 40 years, a variety of 3D printing technology have been invented in various industries. A brief history about the development of rapid prototyping is shown in the schematic timeline in Figure 2.1 (T.Rowe Price, 2012).



1984
THE BIRTH OF 3D PRINTING

Charles Hull, later the co-founder of 3D Systems, invents stereolithography, a printing process that enables a tangible 3D object to be created from digital data. The technology is used to create a 3D model from a picture and allows users to test a design before investing in a larger manufacturing program.

1990s

'92 BUILDING PARTS, LAYER BY LAYER

The first SLA (stereolithographic apparatus) machine is produced by 3D Systems. The machine's process involves a UV laser solidifying photopolymer, a liquid with the viscosity and color of honey that makes three-dimensional parts layer by layer. Although imperfect, the machine proves that highly complex parts can be manufactured overnight.

'99 ENGINEERED ORGANS BRING NEW ADVANCES TO MEDICINE

The first lab-grown organ is implanted in humans when young patients undergo urinary bladder augmentation using a 3-D synthetic scaffold coated with their own cells. The technology, developed by scientists at the Wake Forest Institute for Regenerative Medicine*, opened the door to developing other strategies for engineering organs, including printing them. Because they are made with a patient's own cells, there is little to no risk of rejection.

'05 OPEN-SOURCE COLLABORATION WITH 3D PRINTING

Dr. Adrian Bowyer at University of Bath founds RepRap, an open-source initiative to build a 3D printer that can print most of its own components. The vision of this project is to democratize manufacturing by cheaply distributing RepRap units to individuals everywhere, enabling them to create everyday products on their own.

2000s

'02 A WORKING 3D KIDNEY

Scientists engineer a miniature functional kidney that is able to filter blood and produce diluted urine in an animal. The development led to research at the Wake Forest Institute for Regenerative Medicine that aims to "print" organs and tissues using 3D printing technology.