UNIVERSITI PUTRA MALAYSIA

A COMPREHENSIVE FUZZY DECISION-MAKING METHOD FOR DETERMINING OPTIMUM MACHINING STRATEGY IN PRODUCTION LINE IMPROVEMENT

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By

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September 2021

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The manufacturing sector plays a significant role in utilizing the economy of a country. Statistically, more than 37.4% of the GDP of Malaysia belongs to industries. Having a production strategy, which relies on the reality of an industrial environment, will enhance the success of that business. Therefore, it is crucial to propose methods to skyrocket the production factors such as production time. An in-depth review of the literature during the last half-century found that many research studies have been carried out to utilize the production line performances. One major gap found by the literature review is that many industries do not pay enough attention to the factors that can enhance productivity. Such ignorance yields too many problems and sometimes failing to manufacture enough products to fulfill the market demand. Such problems often can be found in small and medium-scale companies in developing countries. Besides, in the real industrial environment, most factors are uncertain and can get various values depending on different conditions. Such phenomena even worsen the condition for forecasting the effective factors in an industrial company. The primary objective of current research is to develop a comprehensive fuzzy decision-making method for determining the optimum machining strategy in order to utilize the completion time of a product. For this purpose, finding the effective factors on completion time in production lines and identifying the correlations between factors are considered the next objectives. For this purpose, using the library study and interview with the experts, a list of factors was found. Then a questionnaire is designed and distributed to the academic and industry experts. According to the findings, the effective internal factors in minimizing product completion time can be divided into five main clusters: Technology, Human Resource, Machinery, Material, and Facility Design. Then using the statistical analysis, the correlations between factors are found. It is found that there are positive correlations exist between most of the factors in a range between -0.048 and 0.636 at a significant level of 0.05 which means they may have positive or negative interactions while happens at the

same time in an industrial environment. In continue, using the regression method, the impact of each factor on the dependent variable for the research (product completion time) is determined. Using the data gathered from the experts, a Fuzzy Inference System (FIS) model was developed, which could reflect the uncertainty of the factors in decreasing (or increasing) the product completion time in manufacturing systems. Then, a hybrid Fuzzy-TOPSIS based heuristic is developed using MATLAB to solve the case studies. In order to evaluate the performance of the proposed heuristic method, a number of experiments are designed and solved by Taguchi Method (DOE). Then, the performance of the method was evaluated using several indicators, including completion time. Our findings showed that the Human resource, Machinery, Material, Technology and Social Environment positively minimize product completion time, respectively. It is found that the proposed Fuzzy-TOPSIS heuristic is capable of reducing the product completion time in a range between 0 and 10.3%.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KAEDAH KOMPREHENSIF FUZZY MEMBUAT KEPUTUSAN BAGI MENENTUKAN STRATEGI PEMESINAN OPTIMUM DALAM PESANAN UNTUK PENAMBAHBAIKAN JAJARAN PENGELUARAN

Oleh

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Sektor pembuatan memainkan peranan penting dalam memanfaatkan ekonomi sesebuah negara. Secara statistik lebih daripada 37.4% KDNK Malaysia adalah dari industri. Mempunyai strategi pengeluaran yang bergantung pada realiti persekitaran industri akan meningkatkan kejayaan perniagaan. Oleh itu, adalah mustahak untuk mencadangkan kaedah bagi menambahbaik faktor pengeluaran seperti masa pengeluaran. Tinjauan mendalam terhadap literatur selama setengah abad terakhir, ditemukan bahwa ada banyak penelitian yang telah dilakukan untuk memanfaatkan pertunjukan jajaran produksi. Namun, terdapat banyak industri yang tidak memberikan perhatian yang cukup terhadap faktor-faktor yang boleh meningkatkan (atau menurun) produktiviti. Kejahilan seperti itu menghasilkan terlalu banyak masalah dan kadang-kadang gagal mengeluarkan produk yang mencukupi bagi memenuhi permintaan pasaran. Masalah seperti ini sering dijumpai di syarikat kecil dan sederhana di kalangan negara membangun. Selain itu, dalam persekitaran perindustrian sebenar, kebanyakan faktor adalah tidak pasti dan dapat memperoleh pelbagai nilai bergantung kepada keadaan yang berbeza. Fenomena seperti itu malah memperburuk keadaan untuk meramalkan faktor-faktor berkesan dalam syarikat industri. Satu persoalan penting yang harus dijawab dalam penyelidikan ini ialah apakah faktor dalaman terpenting dalam syarikat yang signifikan dalam menurunkan atau meningkatkan masa penyelesaian produk? Sebagai tambahan, bagaimanakah menggunakan waktu penyelesaian produk dalam sistem pembuatan? Tujuan penyelidikan adalah untuk mencari faktor-faktor yang berkesan pada masa penyelesaian di jajaran pengeluaran dan kemudian mengembangkan baik kaedah membuat keputusan fuzzy yang komprehensif untuk menentukan strategi pemesinan yang optimum bagi memanfaatkan waktu penyelesaian produk. Untuk itu, dalam penyelidikan ini, dengan menggunakan kajian perpustakaan dan wawancara dengan pakar, terdapat senarai factor yang boleh diambilkira. Kemudian borang soal selidik dirancang dan diedarkan kepada ahli akademik dan industri. Hasilnya kemudian dianalisis. Menurut hasil

kajian, faktor dalaman yang berkesan dalam meminimumkan masa penyelesaian produk dapat dibahagikan kepada 6 kelompok utama, iaitu Teknologi, Sumber Manusia, Mesin, Reka Bentuk Bahan, Kemudahan dan Faktor Sosial. Kemudian dengan menggunakan analisis statistic bagi menyelidik hubungan antara faktor. Didapati bahawa terdapat korelasi positif antara kebanyakan faktor yang bermaksud mereka mungkin mempunyai interaksi positif atau negatif sementara berlaku pada masa yang sama dalam persekitaran industri. Selanjutnya, menggunakan kaedah regresi, kesan setiap faktor terhadap pemboleh ubah bersandar untuk penyelidikan (masa penyelesaian produk) ditentukan. Dengan menggunakan data yang dikumpulkan dari para ahli, model Sistem Inferensi Fuzzy dikembangkan, yang dapat mencerminkan ketidakpastian faktor-faktor dalam menurunkan (atau meningkatkan) waktu penyelesaian produk dalam sistem pembuatan. Kemudian, heuristik berasaskan Fuzzy-Topsis hibrid dikembangkan menggunakan MATLAB untuk menyelesaikan kajian kes. Untuk menilai prestasi kaedah heuristik yang dicadangkan, sejumlah eksperimen dirancang dan diselesaikan dengan Kaedah Taguchi (DOE). Kemudian, prestasi kaedah dinilai menggunakan sejumlah petunjuk termasuk masa penyelesaian. Kaedah ini kemudian digunakan oleh sebuah firma pembuatan untuk mengesahkan fungsinya dalam persekitaran perindustrian sebenar. Didapati bahawa kaedah yang dicadangkan dapat diterapkan dengan mudah dalam praktikal. Hasil kajian ini menunjukkan bahawa Sumber Manusia, Mesin, Bahan, Teknologi dan Persekitaran Sosial mempunyai pengaruh positif bagi meminimumkan masa penyelesaian produk masing-masing. Didapati juga bahawa menggunakan kaedah hibrid yang dicadangkan; masa penyelesaian produk dapat dikurangkan dengan ketara.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Date: 9 December 2021

Declaration by graduate student

I hereby confirm that:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

ACO	Ant Colony Optimization
AGV	Automated Guided Vehicles
AHP	Analytic Hierarchy Process
AM	Additive Manufacturing
ANN	Artificial Neural Network
APP	Aggregate Production Planning
ART	Adaptive Resonance Theory
CLT	Central Limit Theorem
CMS	Cellular Manufacturing Systems
CNC	Computer Numerical Control
CTF	Cycle Time Forecasting
DEA	Data Envelopment Analysis
df	Degree Of Freedom
DOE	Design Of Experiments
e-SCM	Electronic Supply Chain Management
FIS	Fuzzy Inference System
FO	Fuzzy Output
FP	Fuzzy Input
GA	Genetic Algorithm
GDP	Gross Domestic Product
GIS	Geographic Information System
GP	Goal Programming
GT	Group Technology
HR	Human Resource
IP	Integer Programming

IPP	Integrating Procurement/Production
K-S	Kolmogorov–Smirnov
LP	Linear Programming
MADM	Multi-Attributed Decision Making Model
MCDA	Multi-Criteria Decision Analysis Methods
MCDM	Multi-Criteria Decision Making Model
MILP	Mixed Integer Linear Programming
MISO	Multi-Input Single-Output
MODM	Multi-Objectives Decision Making Model
MRP	Material Requirements Planning
NL-MILP	Non-Linear Mixed Integer Linear Programming
NSGA-2	Non Dominated Sorting Genetic Algorithm 2
OCT	Order Completion Time
OEE	Overall Equipment Effectiveness
OPC	Product Machine Sequence
PCTRI	Product Completion Time Reduced Index
PPC	Production Planning And Control
PSO	Particle Swarm Method
QAP	Quadratic Assignment Problem
RFID	Radio Frequency Identification Device
SA	Simulated Annealing
SCM	Supply Chain Management
Sig.	Significant
SOM	Self-Organizing Map
Std. Deviation	Standard Deviation

SWOT	Strengths, Weaknesses, Opportunities And Threats
TOPSIS	Technique For Order Preference By Similarity To Ideal Solution
TS	Tabu Search
VIKOR	Visekriterijumska Optimizacija I Kompromisno Resenje

CHAPTER 1

INTRODUCTION

1.1 Introduction to Chapter

The manufacturing sector plays a key role in utilizing the economy of a country. According to the statistics that are reported by the "Statista" website, more than 37.4% of the Gross Domestic Product (GDP) of Malaysia belongs to industries (Figure 1.1).

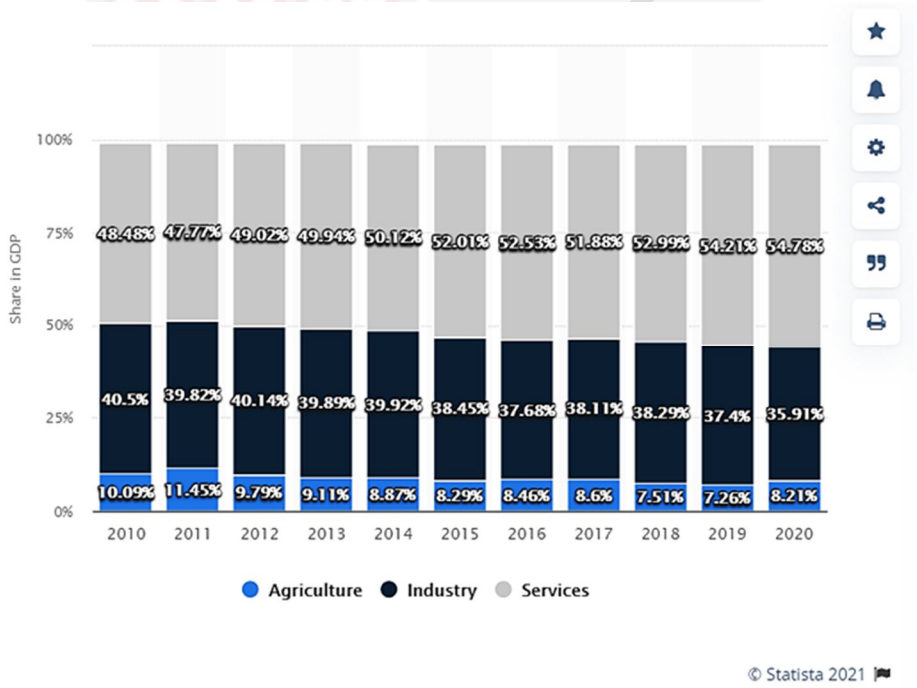

Figure 1.1: Malaysia Share of economic sectors in the GDP from 2009 to 2019. (Source: https://www.statista.com/statistics/318732/share-of-economic-sectors-in-the-gdp-in-malaysia/- Retrieved in 01/08/2020).

Therefore, empowering manufacturing systems, as the engines of industries in a country's economy, must take full consideration by researchers.During the last half-century, many research studies have investigated the various objectives of manufacturing companies. Table 1.1 shows some of the objectives that are more frequently considered in the literature review:

Table 1.1: The most frequently used objectives in the literature of the manufacturing field

No.	Objective
1	Processing time of a Task
2	Completion time of a product (Cycle time)
3	Manufacturing Costs (Fixed Costs)
4	Manufacturing Costs (Operations Costs)
5	Defect Rate
6	Customer Satisfaction
7	Human Resource (HR)
8	Market Share
9	Maintenance and Repair Costs
10	Transportation and Logistics
11	Material Transferring Costs
12	Outsourcing
13	Facility Location
14	Facility Allocation
15	Set Covering
16	Bullwhip Effect (for supply chains)
17	Lost Sale/ Back Order

The variety of objectives taken into consideration by researchers shows the wide range of research studies that were investigated and still should be.

1.1.1 Uncertain Conditions That Surround the Manufacturing Firms

One important thing that must be considered about manufacturing firms is that the factors that can influence the production rate of manufacturing companies may be different from one company to another due to their surrounding environment. The Cambridge dictionary defines uncertainty as “a situation in which something is not known, or something that is not known or certain.” Obviously, such unknown conditions may decrease scheduling accuracy and may impose adverse results on a manufacturing system. Therefore, uncertainty must be considered during any decision-making process in a manufacturing system.

In this chapter, the problem statement of the research will be discussed first. Then the importance of the research for developing countries will be discussed, and the innovation of the research will be illustrated. Afterward, the hypothesis, questions, and objectives of the research will be explained accordingly. At the end of the chapter, the flow diagram of the research will be drawn.

1.2 Problem Statement

In manufacturing industries, it is essential to know each step of a product's lifecycle and be prepared for each stage (Figure 1.2). However, it seems that many industries do not pay enough attention to the factors that can enhance (or decline) productivity. Such ignorance yields to many problems and sometimes failing to manufacture enough products to fulfil the market demand.

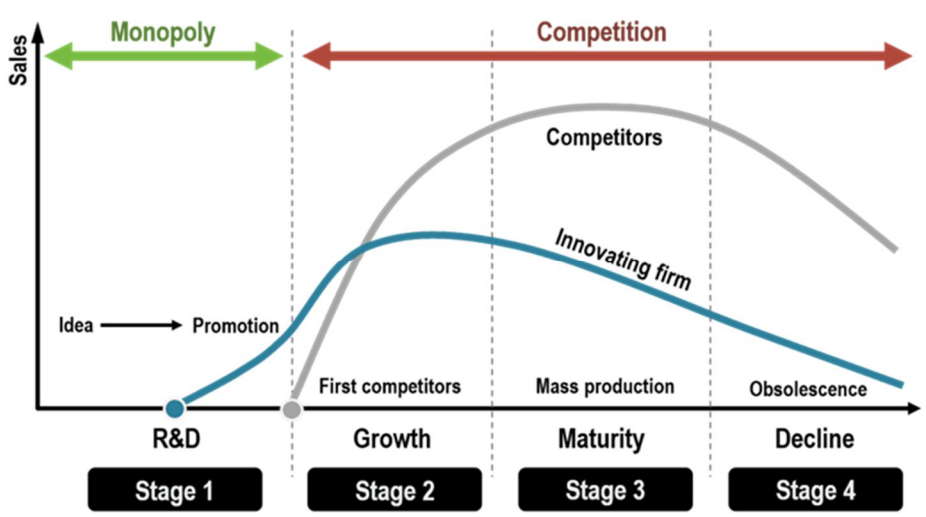

Figure 1.2: The life cycle of a product in a manufacturing firm. (Source: https://transportgeography.org/contents/chapter7/freight-transportation-value-chains/product-life-cycle/)

Such problems often can be found in small and medium-scale companies in developing countries. Figure 1.3 represents the number of bankrupted companies in Malaysia in 2019.

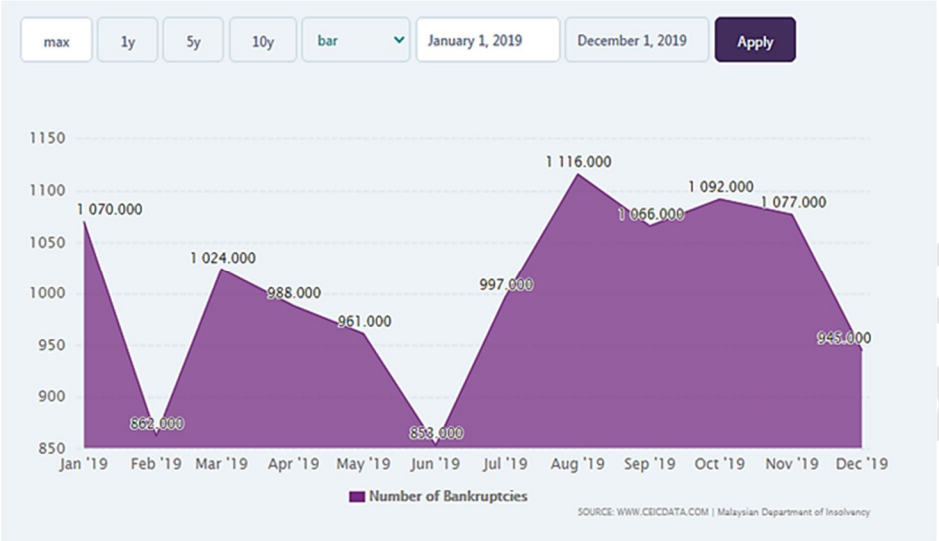

Figure 1.3: Diagram of Bankruptcies in Malaysia in 2019. (Source: https://www.ceicdata.com/en/malaysia/number-of-bankruptcies/number-of-bankruptcies)

It is obvious that such phenomena can lead to bankruptcy or at least slow the growth of a company. Successful firms, by contrast, have handy strategies to improve and develop their businesses. Besides, failing to pay enough attention to success factors in production can cause immediate bankruptcy for many young businesses.

1.2.1 Uncertainty Can Increase the Risk of Bankruptcy in Manufacturing Companies.

Some preconceptions show positive correlations between increasing uncertainty and the chance of bankruptcy in a manufacturing firm (Figure 1.4). However, this idea will be reviewed in chapter 2. Uncertainty can increase the entropy in manufacturing companies, and this research aims to find which uncertainty factors will be play critical roles in a completion time of a product (as the main goal of this research) in a company and then how to prevent such uncertainty in manufacturing companies using the fuzzy method.

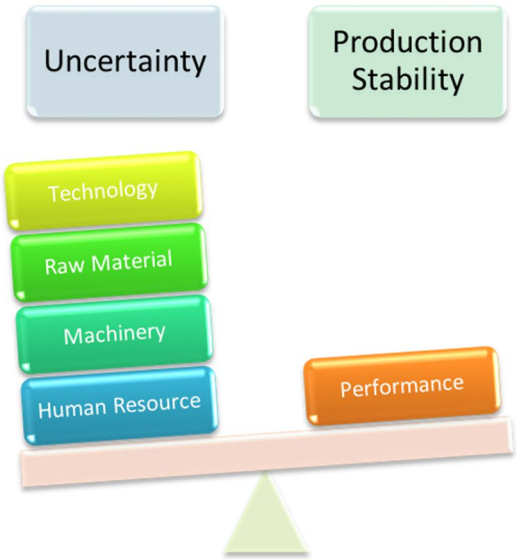

Figure 1.4: Uncertainty can influence the performance of a manufacturing company.

The issue of minimizing product completion time is among the primary objectives in manufacturing companies that leads to more production rate and more benefits accordingly. It seems that in order to minimize product completion time, many internal factors are involving. Besides, as mentioned above, such factors are uncertain in real circumstances and may take different values depending on the conditions. Such uncertainty increases the complexity of considering internal factors for minimizing product completion time.

As a result, choosing the best set of internal factors in uncertain conditions of manufacturing systems that could minimize the product completion time is an important problem that has been less developed before. Therefore, this research tries to find the significant factors in minimizing the processing time of the manufacturing firms in Malaysia and then propose a new method to choose the best manufacturing strategy according to the real production environment of a company.

1.3 Importance of the Study

Impacts of Minimizing Completion time on Micro and Macro Economy of a Country. In today's world, the entire or important part of the developing countries' economy mostly relies on their industries. The more advanced industries mean more products in terms of both quantity and quality, which can result in less import and more export of goods (Figure 1.5).

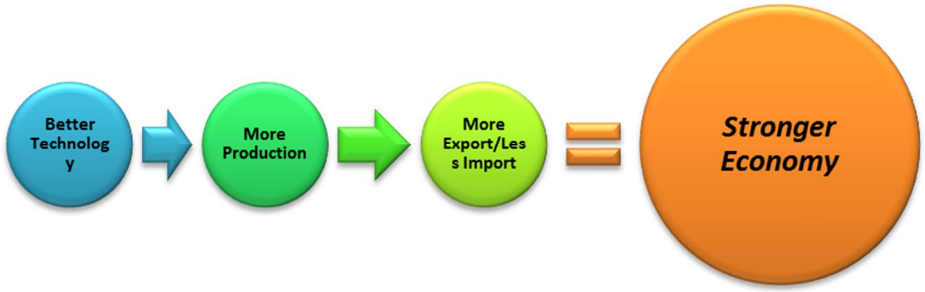

Figure 1.5: Impact of manufacturing industries on economy of a country.

Therefore, it is important to propose methods to skyrocket the production factors such as time. During the last half-century, many research studies have been carried out to utilize the production line performances.

1.4 Hypothesis of the Research

This research tries to prove the following hypothesis.

$$\begin{cases} H_0: \text{An effective fuzzy decision making method can minimize the completion time of product in production lines} \\ H_1: \text{The opposite side is true} \end{cases}$$

In continue, and if the above hypothesis is true, after identifying the effective factors on completion time in terms of machinery performance, a new decision-making method will be proposed to minimize the completion time of machines in production lines that can influence the project success in the future.

1.5 Research Objectives

According to the problem statement that is mentioned above, the following objectives will be defined (Figure 1.6):

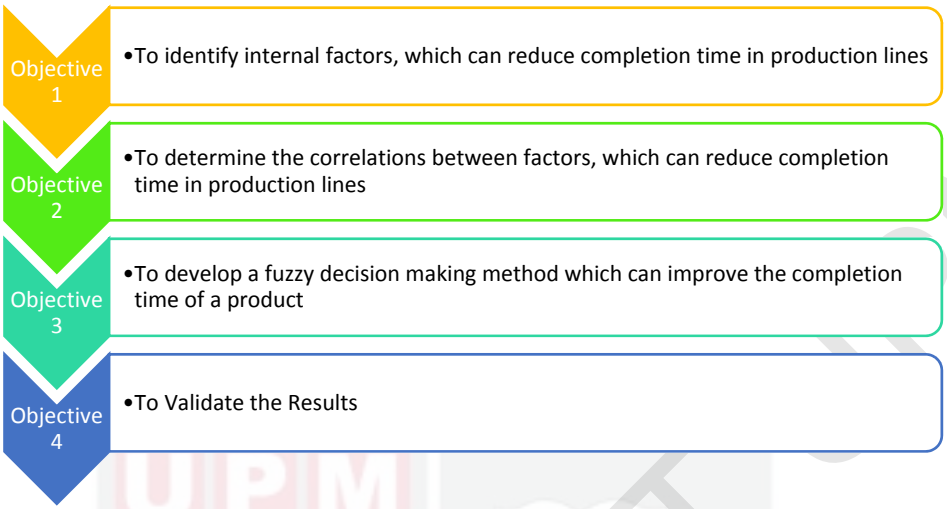

Figure 1.6: The main aims of the research in brief

1.6 Scope and Limitation of Work

Similar to all research studies, this research will consider the special situation, which must be clarified in advance. In continuing, a number of limitations that shows the exact scope of the project will be shown:

i. The scope of the research is on manufacturing systems.
ii. This project will specifically focus on production lines (and not the trading sector).
iii. Only internal factors of a manufacturing system will be taken into consideration.
iv. Although the project's outcomes can be used anywhere globally, for the field study (questionnaire and the validation sections in chapter 3), the project will be carried out in Malaysia.

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LIST OF PUBLICATIONS

Journal

Alazemi, F. K. A., Na'im Abdullah, M., Ariffin, M. K. A. M., Mustapha, F., & Supeni, E. E. (2021). Optimization of Cutting Tool Geometry for Milling Operation using Composite Material–A Review. Journal of Advanced Research in Materials Science, 76(1), 17-25.

Alazemi, F. K. A., Ariffin, M. K. A. M., Mustapha, F., Supeni, E. E., & Delgoshaei,A. (2021). A Comprehensive Fuzzy Decision Making Method for Determining Optimum Machining Strategy to Utilize the Completion Time in Production Lines. Fuzzy Sets and Systems.

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Conference

Alazemi, F. K. A., Na'im Abdullah, M., Ariffin, M. K. A. M., Mustapha, F., & Supeni, E. E. (2021). Optimization of Cutting Tool Geometry for Milling Operation using Composite Material–A Review. 5th International Conference on Computational Methods in Engineering and Health Sciences (ICCMEH-2019) July 16-17, 2019.

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