ANALYSIS ON THE EFFECT OF PROCESS CONFIGURATIONS ON MANUFACTURING SYSTEM PERFORMANCE

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

by

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DECLARATION

I hereby, declared this report entitled "Analysis on the Effect of Process Configurations on Manufacturing System Performance" is the result of my own research except as cited in references.

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Date : 27 JANUARY 2023

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

………………………………………………………

(Dr. Nadiah binti Ahmad)

ABSTRAK

Sistem pembuatan fleksibel (FMS) ialah satu penyelesaian yang membolehkan mana-mana sistem pembuatan untuk menahan perubahan keperluan pasaran. FMS ialah sistem kompleks yang terdiri daripada beberapa mesin kawalan berangka terkomputer (CNC) yang sangat automatik, sistem pengendalian bahan yang cekap dan pengendali manusia. Kertas kerja ini memberi tumpuan kepada kajian eksperimen berasaskan simulasi tentang kesan faktor seperti permintaan stokastik, bilangan kenderaan berpandu berautomatik (AGV) dan peraturan penjujukan pada prestasi FMS biasa. Dalam kajian ini, dua tahap (iaitu permintaan stokastik) dan tiga tahap (iaitu bilangan AGV dan peraturan penjujukan) dipertimbangkan untuk penyiasatan. Perisian Tecnomatix digunakan untuk mensimulasikan model FMS dalam kertas penyelidikan ini. Tambahan pula, prestasi sistem pembuatan dinilai menggunakan empat ukuran prestasi seperti jumlah pengeluaran, penggunaan mesin,masa menunggu dan penggunaan AGV. Metodologi yang dicadangkan dalam kertas kerja ini membantu dalam menentukan kombinasi tahap faktor terbaik untuk setiap parameter prestasi sistem. Menjelang akhir, skop selanjutnya diserlahkan.

ABSTRACT

A flexible manufacturing system (FMS) is one solution that allows any manufacturing system to withstand the market's changing needs. FMS is a complex system consisting of several highly automated computer numerical control (CNC) machines, an efficient material handling system and a human operator. This paper focuses on a simulation-based experimental study of the effects of factors such as stochastic demand, the number of automated guided vehicles (AGV), and sequencing rules on regular FMS performance. In this study, two levels (i.e. stochastic demand) and three levels (i.e. number of AGV and sequencing rules) are considered for the investigation. Tecnomatix software is used to simulate the FMS model in this research paper. Furthermore, the performance of the manufacturing system is assessed using four measures of performance such as total production, machine utilization, waiting time dan AGV utilization. The methodology proposed in this paper assists in determining the best factor level combination for each system performance parameter. Towards the end, the further scope is highlighted.

DEDICATION

Only

my beloved father, Md. Yusof bin Husin

my appreciated mother, Marzanah binti Sairi

my adored brothers and sister, Azim, Aliff and Atika

for giving me moral support, money, cooperation, encouragement and also understanding

Thank You So Much & Love You All Forever

ACKNOWLEDGEMENT

In the name of ALLAH, the most gracious, the most merciful, with the highest praise to Allah, I manage to complete this final year project successfully and without difficulty.

I would like to express my sincere gratitude to my respected supervisor, Dr. Nadiah binti Ahmad for the great mentoring that was given to me throughout the project. She has contributed beneficent ideas and suggestions to make this research project a favourable result.

In short, I would like to thank everyone who has contributed to this Final Year Project report including the panels, as well as expressing my apology if any inconvenience has been done

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AGV	-	Automated Guided Vehicles
AS	-	Automated Storage
CAD	-	Computer-aided Design
CAM	-	Computer-aided Manufacture
CIM	-	Computer Integrated Manufacturing
CNC	-	Computer Numerical Control
DES	-	Discrete Event Simulation
DSS	-	Decisions Support Systems
EDD	-	Earlier Due Dates
FCFS	-	First Come, First Served
FMS	-	Flexible Manufacturing Systems
I	-	Input buffer
L	-	Load Station
LPT	-	Longest Processing Times
LCFS	-	Last Come, First Served
NG	-	Number of AGV
O	-	Output buffer
PPC	-	Production Planning and Control
RS	-	Retrieval Systems
SD	-	Stochastics Demand
SPT	-	Shortest Processing Times
SR	-	Sequencing Rules
UL	-	Unloading Station

LIST OF SYMBOLS

min	-	Minute
λ	-	Lambda

CHAPTER 1

INTRODUCTION

There are a few aspects highlighted in this chapter. The background of the study provides vital information regarding the title. Current problems in the research studies are identified. The objectives of the study project are stated to provide clear guidelines for the project which is within certain focus aspects.

1.1 Background of Study

The effect of process configurations on manufacturing system performance cannot be neglected, especially when dealing with flexible manufacturing systems (FMS). This is because different configurations have different effects on a system. FMS is a complex system consisting of several highly automatic Computer Numerical Control (CNC) machines, an efficient material handling system and human operators.

Manufacturing is becoming more flexible in responding to environmental changes; product life cycles are becoming shorter, customer demand is increasing levels of customization at standard product prices, and markets are more global than ever. (Bengtsson & Olhager, 2002). Therefore, an FMS with the importance of manufacturing flexibility in responding quickly and efficiently will benefit customer needs. There are eight types of flexibility. These are machine flexibility, routing flexibility, product flexibility, process flexibility, volume flexibility, expansion flexibility, operation flexibility, and production flexibility (Ali & Ahmad, 2014).

The different manufacturing strategies used in the industry are crucial to the performance of FMS. Several strategies can be considered in evaluating the performance of the system; among them is the problem of manufacturing flexibility, lot size, part type selection, machine grouping, production ratio, resource allocation, machine loading, and scheduling (Ali & Ahmad, 2014). This study examines different manufacturing strategies, namely routing and part mix flexibility and scheduling rules. Different combinations for all these manufacturing strategies are carried out using discrete event simulation.

1.2 Problem Statement

The flexible manufacturing system provides competitive value to the manufacturer and works in making medium-volume direct products. Like any other complex system, a flexible manufacturing system (FMS) may be exposed to many internal and external uncertainties, such as random component failures. (Souier et al., 2019).

Therefore, some problems may be encountered in this FMS. Operational problems, specifically scheduling, are one of the difficulties encountered in decision making in FMS control. An FMS's production management and scheduling issues are more complex than job shops and transfer lines. (Chan et al., 2002). This is because FMS has a versatile machine and can perform different operations and produce different types of products. In addition, changes in demand that may occur rapidly and the random entry of new products with high demand also cause unforeseen events such as machine breakdowns.

In addition, routing flexibility is also one of the most common difficulties and needs to be addressed to achieve the best response in FMS performance. This is because some constraints need to be considered in routing flexibility. Precedence constraints between jobs, random arrivals, stochastic processing times, and machines' reliability levels are among them (Souier et al., 2019). It is always necessary to analyze the system state to determine how parts can be redirected to alternative machines. In turn, alternative machines will cause it to be less efficient and more congested.

Past studies have generally focused on analysing properties that distinguish FMS scheduling problems from problems found in conventional systems based on the above studies. In addition, previous papers have also focused more on the effect of part mix and routing flexibility on FMS performance. However, only a few studies focused on stochastic or random demands on FMS performance. Therefore, this research focuses on studying the effect of the key factor affecting the performance of FMS.

1.3 Objectives

The objectives are as follows:

i) To investigate the key factors affecting the performance of the FMS.

ii) To simulate the FMS model with the help of discrete event simulation.

iii) To evaluate the effect of different combinations of factor levels on the FMS performance.

1.4 Scope

The study's scope focuses on using discrete-event simulation based on experimental research on a system that arrives continuously in a random manner and with stochastic demands.

In addition, this study also examines the effects of process configuration the combination of stochastic demand, the number of Automated guided vehicle (AGV) and sequencing rules with the help of the Tecnomatix Simulator.

The studies focused only four performance measure such as total production, average machine utilization, average waiting time and average AGV utilization.

1.5 Significant of Study

There are several potential benefits that the performance of the FMS layout can gain after the completion of this study. Among them is the effect of using routing decision-making tools in FMS can increase system reliability and minimize the effects of damage without lowering the product quality and productivity of FMS. Because FMS scheduling is very complex, simulation is a valuable tool to cope with FMS scheduling in achieving high efficiency shortest production time in a system. Hence simulation helps in decision making for an optimum solution and is used as a tool for Decision Support systems (DSS) for scheduling real-world manufacturing systems (Arshad et al., 2016).

1.6 Organization of Thesis

The organization of this thesis is as follows:

Chapter 1: Introduction

This chapter begins with the background of the study. This is followed by problem statements identified through previous studies and journals. Next, the objectives to be achieved throughout the study and the scope narrow down the study area. The significance of the study is also one of the most important to improve the current problem of the study.

Chapter 2: Literature review

Supporting information for the research title had been stated. Covering fundamental theories on research topics and previous studies from journals, books and the internet related to the field of research.

Chapter 3: Methodology

The methods cover the discrete event simulation methodology, which is the physical configuration of the FMS and detailed factors that affect the FMS's performance. All the procedures used in this project are based on previous studies. Methodologies took to complete objectives 1, objective two and objective 3.

Chapter 4: Result and discussion

The result was collected by using the methodologies in chapter 3. The analysis of the results after running several experiments using Tecnomatix simulation on the FMS layout had been presented and discussed in this chapter. An optimal factor combination is also identified, which generates the best system performance.

Chapter 5: Conclusion

Discrete-event simulation models have been used to analyze the impact of some factors, i.e. stochastic demand, number of AGVs, and sequencing rule, on the performance of an FMS model configuration. The conclusion and recommendations for possible future directions of this research are examined.

1.7 Summary

The summary of this chapter primarily describes the information related to previous studies extracted as a reference and discussion based on their research on several significant factors such as stochastic demand, number of AGV and sequencing rules on FMS performance. In addition, this chapter also describes some of the constraints or problems encountered that cause the system's performance. Therefore, this study aims to analyze further the effect of process configurations on manufacturing system performance.

CHAPTER 2

LITERATURE REVIEW

This literature review chapter describes all the complications of literature review, theory, and research that various researchers have defined over the past year. Information related to previous studies had been extracted as a reference and discussion based on their research on FMS background, types of manufacturing flexibility, scheduling rules, and the application of discrete event simulation to FMS.

2.1 Flexible Manufacturing System (FMS)

FMS is a flexible industrial process that is "reprogrammable" because it can allow equipment to be used for more than one purpose and automatically produce various products. This is because this FMS has a high-efficiency technique in the production system for multiple types of products or parts. This efficient technique results in FMS being able to fully process members of one or more families parts continuously without human intervention (Mousavi, 2018).

There are two levels of flexibility available in FMS, namely dedicated FMS and random order FMS. Dedicated FMS is a system designed to produce a selection of fixed parts, while a random order FMS is an advanced setup that allows the production of complex designs. FMS is a system developed to respond to changes in production needs. The main objective of this FMS is to approach efficiency, maintain flexibility, and meet the requirements associated with the time and cost generated. The basic outline of the FMS is demonstrated in Figure 2.1.

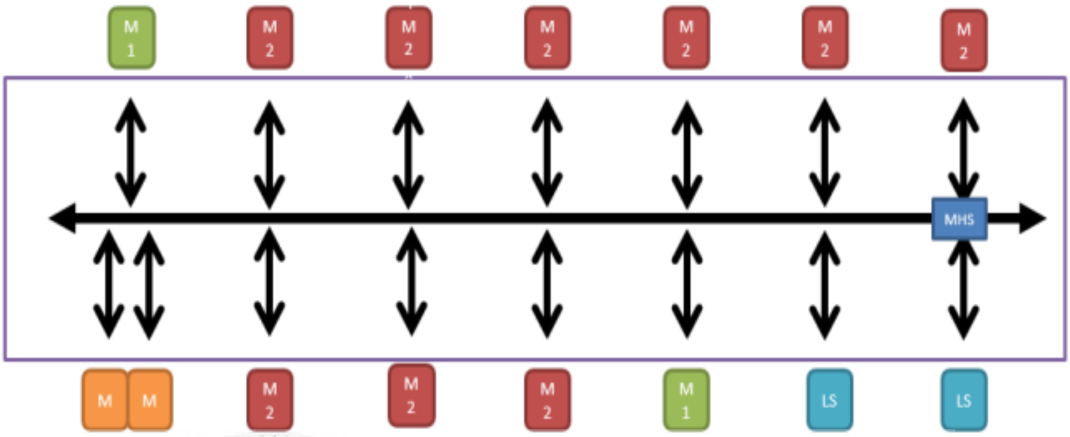


Figure 2.1: The outline of the basics of the FMS. (Rybicka, 2017)

2.1.1 FMS Layouts

Flexible manufacturing systems have different layout configurations established by material handling systems that follow the machine arrangement and part flow. This configuration can be divided into five categories. Among them:

i. In-line Layout
ii. Loop Layout
iii. Ladder Layout
iv. Open field Layout
v. Robot-centred Layout

2.1.1.1 In-Line Layout

The machine and the operating system are arranged in a straight line, as shown in Figure 2.2. Parts are transported from the workstation in an orderly manner. Figure 2.3 shows an illustration of a two-line layout with the same arrangement as the layout in In-Line. The difference in the layout of figures 2.2 and 2.3 is that figure 2.3 has machines placed on both sides of the transfer line.

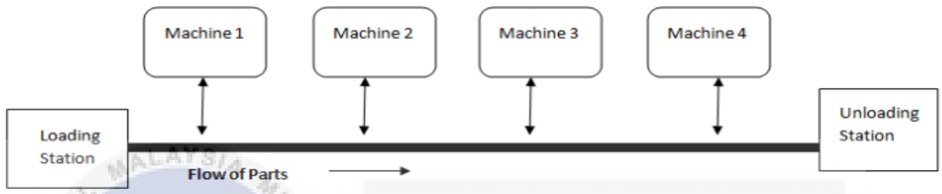


Figure 2.2: In-Line FMS Layout(Arshad et al., 2016)

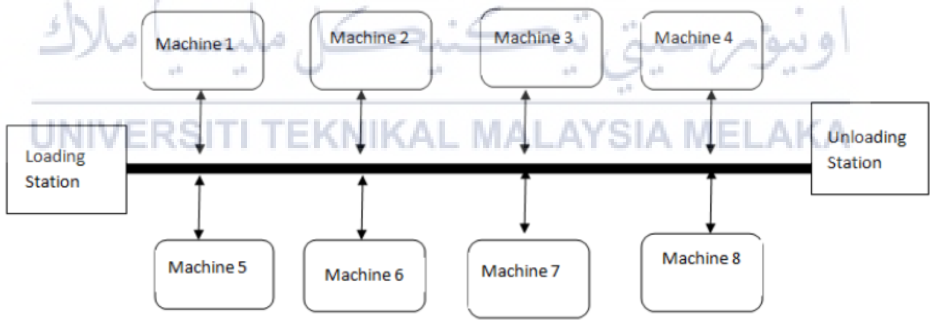


Figure 2.3: Double-Line FMS Layout (Arshad et al., 2016)

2.1.1.2 Loop Layout

The basic loop layout has a function with parts moved in a forward flow around the loop. The functions found in this basic loop layout can stop and move to any production point or station, as shown in figure 2.4.

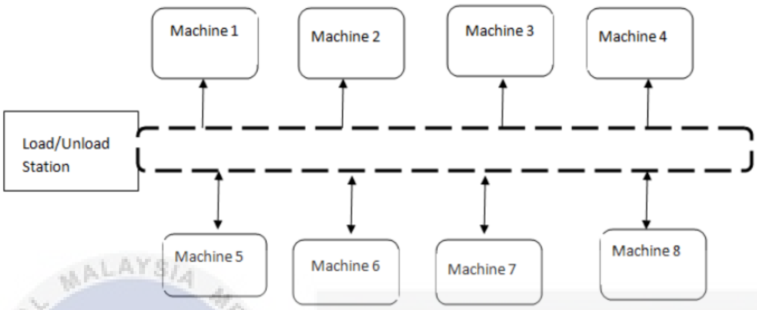


Figure 2.4: Loop FMS Layout(Arshad et al., 2016)

2.1.1.3 Ladder Layout

A ladder Layout is a layout with a basic loop configuration combined with a workstation ladder. Ladders are located on the loop section and are used to increase the transportability and route traversed by the section. This reduces traffic and the time transporting parts from one station to the next. Figure 2.5 below shows the FMS Ladder Layout.

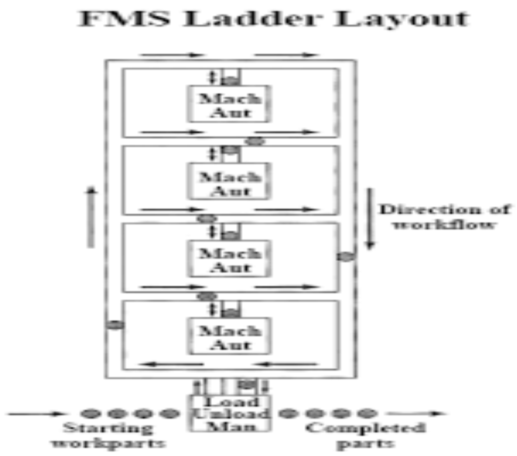


Figure 2.5: Ladder FMS Layout. (Kumar et al., 2020)

2.1.1.4 Open Field Layout

Open field layouts have multiple loops and ladders and may even include side sections. Activities such as processing a large family of parts are often performed by open field layout; although different machine types may be limited, parts are usually moved to other workstations depending on which one is available first. Figure 2.6 below shows the open field FMS layout.

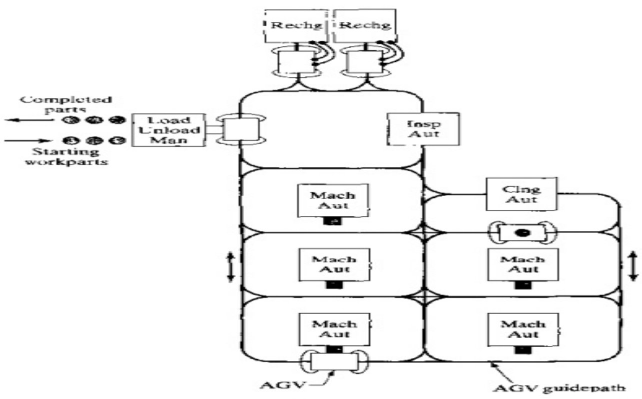


Figure 2.6: Open-Field FMS Layout(Kumar et al., 2020)

2.1.1.5 Robot-centred Layout

Robot-centred is a layout that uses one or more robots as a material control system. The robot is equipped with a gripper that assists in handling parts, especially the rotating ones. Figure 2.7 below shows a robot-centred configuration using one or more robots as the material handling system.

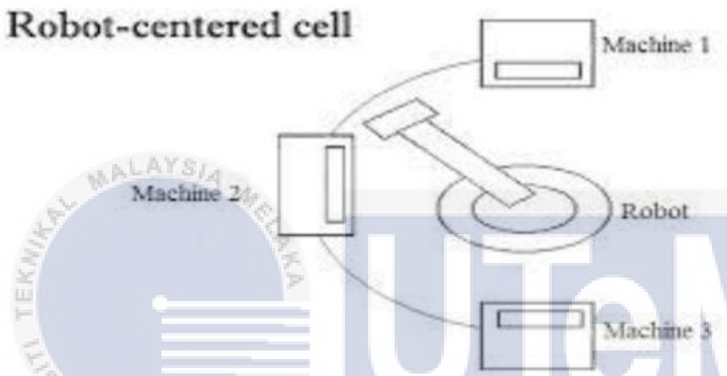


Figure 2.7: Robot-Centered FMS Layout(Arshad et al., 2016)

2.1.2 FMS Component

FMS consists of several components, and each component has its functions and characteristics. These include machine equipment tools, automated material handling, storage system, computer-controlled system, and many other components.

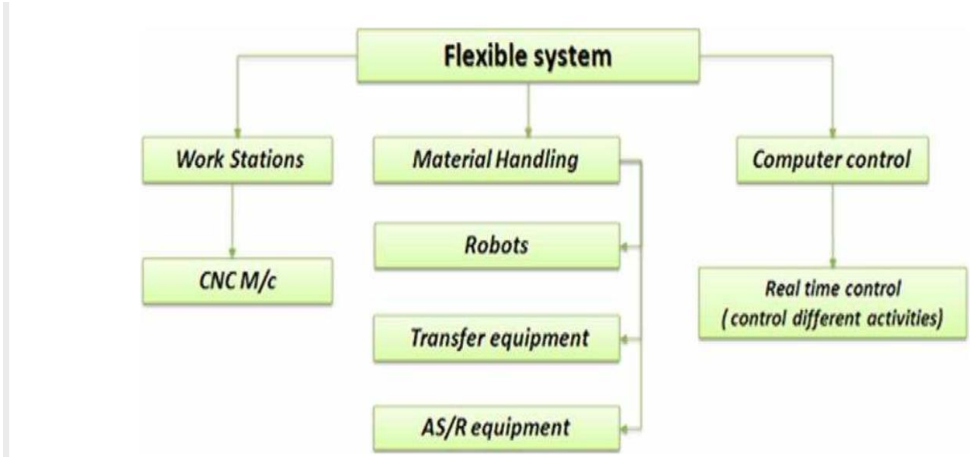


Figure 2.8: The Flexible Manufacturing System Configuration. (Santhosh Kumar et al., 2015)

i. Machine equipment tools

Computer Numerical Control (CNC) control machine tools are one of the machine equipment tools and a typical application for machining operations often used in workstations. This highly automatic CNC machine does not require significant setup time or exchange between successive jobs (Mousavi, 2018). Due to that, this CNC machining centre has features that make it compatible with FMS. Milling, drilling, drilling, tapping, reaming, turning, and groove operations are typically performed by this machine (Mousavi, 2018).

ii. An automated material handling and storage system

The second major component of the FMS is its material handling and storage system. Automated guided vehicles and conveyors are automated and flexible material handling systems used to transport products or parts from one station to another in an FMS. Meanwhile, Automated storage and retrieval systems (AS/RS) are areas of automated storage and retrieval systems used for raw materials and finished products in FMS (Saren & Tiberiu, 2016).

iii. Computer-controlled system

It is used to control the activities of the processing stations and the material handling system in the FMS. There are several functions of a computer control system, among them are:

a) Control of each workstation
b) Distribution of control instructions to workstations
c) Production control
d) Traffic control
e) Work operation and monitoring system
f) System performance monitoring and reporting

2.1.3 Benefit of FMS

Numerous researchers have detailed the potential of FMS as a high-tech manufacturing system that is mainstream in accommodating new changes and, at the same time, able to compete in the market. In today's scenario, customer demands and specifications for any product change very quickly. FMS is expected to be flexible enough in being competitive to respond to small batches of customer demands (Mishra et al., 2019). Therefore, using a manufacturing system that has this flexibility must provide an advantage in response time to solve customer demand and reduce the cost of products and services.

Next, FMS is called 'flexible' because this system has the benefits of flexible work and is very efficient in producing different types of parts in different workstations simultaneously with the volume low to moderate. This system also has good for improving product quality, increasing productivity, and reducing lead time in manufacturing. Therefore, FMS can have economic output from a wider variety of parts and, at the same time, can help consumers survive in the market and remain competitive. Ultimately, the application of FMS in this industry can be widely recognized in various fields, especially in the manufacturing area.

2.2 Manufacturing Flexibility

Based on previous studies, various definitions of manufacturing flexibility have been defined and can be worn as a reference to date.

Table 2.1: Definitions of manufacturing flexibility

Author	Definition
(Ali & Saifi, 2011)	This flexibility also responds to slight penalty changes in time, effort, or cost.
(Singh et al., 2018)	Flexibility is the ability to adapt to any situation or situation and processes that change rapidly for customer needs without wasting production records.
(Khan & Ali, 2017)	Manufacturing flexibility is a system that can respond to the economy in changes in volume, machine status, mixing requirements, and processing capacity.
(Mishra et al., 2019)	This flexibility does not come from machine capabilities alone, but flexibility is a cocombinesal features, operational results, information integration, and management practices.

The interdependency of these flexibilities is shown in figure 2.9.

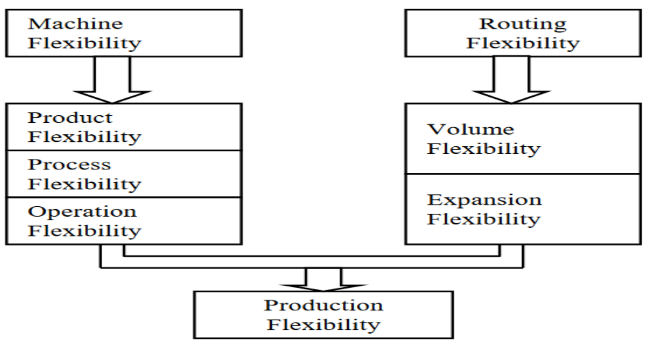


Figure 2.9:The interdependencies of Manufacturing Flexibilities. (Singh et al., 2018)

Following Manufacturing flexibility represents the most comprehensive classification mentioned in Table 2.2.

Table 2.2: Classification of Flexibilities. (Singh et al., 2018)(Mishra et al., 2019)

Manufacturing flexibility	Definition
Machine	The system measures the ability to adapt to various products and has the facility to make changes between machines required to produce a particular set of parts.
Product	It is a system with the facility of part mix that can be changed to manufacture or reassemble new products. The volume of the set of part types can be manufactured in a system with a minor setup.
Process	It measures the capability of a system that can produce a specific set of parts, which are likely to use materials without reconfiguring in different ways. The system also measures part types that can be produced without changing any setup.
Operation	Ability to measure adaptability in changing the sequence of several alternatives or different operations for each type of part. The number of different operating sequences will measure the processing of this part type.
Routing	This system uses different alternative routes that can be followed by parts effectively in performing the same operation on one part by using multiple machines. In addition, the system can handle breakdown to produce a specific part consistently and determine the number of potential paths.
Volume	The system can operate efficiently and profitably at the production level of the part type. It had quantified according to the volume range for a good run.
Expansion	The Modular & expandable capability of a system is measured by the time or cost required for the system's expansion to a given capacity.
Production	The manufacturing system can produce all types of parts without a significant investment in capital equipment.

The potential of flexible and alternative production routes in manufacturing systems is one of the critical features of flexibility. This is because different types of equipment used in this potential route can perform the same operation or use different manufacturing processes. This study focuses on the effect of the machine and routing flexibility on the performance of flexible manufacturing systems.

2.2.1 Machine Flexibility

Machine flexibility is the ability to adapt a particular machine or workstation to various production operations and parts in a system (Singh et al., 2018). Therefore, table 2.3 below shows the present work focuses on the effect of machine flexibility on the performance of a flexible manufacturing system

Table 2.3: Effect of machine flexibility on performance of FMS

Author	Effect
Semra Tunali (1997)	Evaluate spare routing policies in Scheduling FMS workshop types subject to unexpected machine breakdowns.
Barad et al. (2003)	machine flexibility is the most basic flexibility and is an easy-to-understand concept. Measured on the range and dimensions of the response
Singholi, Md Ali (2010)	To study the effect of machine flexibility on FMS performance.
Mohammed Ali (2014)	Significantly improve the performance of flexible manufacturing systems by exploring the effects of applying different manufacturing strategy decisions simultaneously.

2.2.2 Routing Flexibility

Routing Flexibility is the ability to create parts through alternate workstation sequences in response to equipment failure, tool failures, and other disruptions (Singh et al., 2018). The table below shows the leading research on the effect of routing flexibilities on the FMS performance with their specific effect.

Table 2.4: Effect of routing flexibility on the FMS performance

Author	Effect
Garavelli (2001)	Several manufacturing system performances can be analyzed using simulations of a specific degree of routing flexibility. For example, better performance in lead time and work in progress can be seen in limited flexibility systems.
ElMaraghy (2003)	System deadlock caused by machine breakdowns and downtimes is avoided using flexible routing.
Chang (2007)	Routing flexibility can be measured by proposing a multi-attribute approach that combines routing efficiency, versatility, and variety.
Mohammed Ali (2012)	Analyzed the effects of pallet routing and flexibility on the manufacturing range in FMS.

2.3 FMS Scheduling

An FMS is made up of extensive interconnected hardware and software components. Some FMS issues may arise due to variables such as the management of production orders, improper organization of components routing and sequencing, machine scheduling, and the administration of system performance and corrective action (Arshad et al., 2016). According to (Arbel & Seidmann, 1984), the problem of scheduling the flow section optimally throughout the FMS is also a challenge in running the FMS system. Therefore, FMS adheres to scheduling rules for parts and machines to a large extent.

Scheduling rules like the Dispatching Rule are well-known operations widely used by the literature for their reactivity and ease of implementation. This scheduling is an essential thing in the planning problem, which is an important thing that needs to be implemented before the manufacturing system, i.e., FMS can start producing parts. According to (Gaurav Kumar & Trilok Singh Bisoniya, 2015), this scheduling rule applies a sequencing process that determines the process of adding start and end time information to a work order. This sequencing process plays a role in obtaining the order of work carried out on the machine.

2.3.1 Approaches for FMS Scheduling

In general, there are several approaches available to solve FMS scheduling problems. The heuristic approach, the simulation-based approach, and the artificial-intelligence-based. These approaches have their respective functions and roles in solving FMS scheduling problems.

1) The heuristics approach

Heuristic approaches are scheduling and dispatching rules common in solving FMS scheduling problems. This is because the advantage provided by this heuristic rule is that it offers good results with very low effort. These heuristic rules also do not have a defined set of optimal rules for each FMS. This is because the success of this rule depends on the specific FMS available (Sharma, 2012). Therefore, these heuristics rules are essentially related to sequencing, routing, and priority.

2) The simulation-based approach

The simulation analysis approach is used to evaluate the dispatching rules in FMS. According to (S. Gogi & Badarinarayana, 2016), discrete event simulations are used as a scheduling tool and decision support in bridging the gap to real-world situations. In turn, simulation analysis that serves as this control strategy will become more powerful when industry engineering techniques such as sequencing and routing analysis, congestion, and facility layout analysis are used together to improve the performance of flexible manufacturing systems. This is because this simulation approach, a decision support system for real-time scheduling of flexible manufacturing systems, is effective in the operation of FMS (Gaurav Kumar & Trilok Singh Bisoniya, 2015).

3) The artificial-intelligence-based approach

Artificial intelligence is one of the most widely used approaches in completing FMS operations. Next, problem development that has a large search space is also one of the engagements that AI's technique needs to do. Therefore, according to (S. Gogi & Badarinarayana, 2016), AI uses two techniques, namely expert systems and planning. This Artificial intelligence technique is used to plan scheduling rules to achieve the required goals in an FMS. General-purpose problems and case studies in FMS operations are problems that are often helped by using the AI Technique application(S. Gogi & Badarinarayana, 2016).

2.3.2 Sequencing Rules

Sequencing rules are rules used in the FMS environment to select the next part of a machine queue. The function of this rule is to minimize the timeframe for the processing of parts and their expiration date. This is because this FMS environment has machines arranged in a standard layout; however, each processed job operates differently. Therefore, there are rules selected from many existing priority scheduling rules to obtain the optimal sequence.

1) First Come, First Served (FCFS) - In FCFS, the first job will enter the first service to process the part. This rule is the most common and quick because the top of the queue does not have to wait much longer and is picked up first by the machine to be processed.

2) Shortest Processing Times (SPT) - According to SPT, jobs are processed in increasing chronological order. Jobs that have a minimum operation time will enter service first to process parts and then work with a minimum time of the second, and so on. This rule aims to optimize the job's average lateness and flow time.

3) Longest Processing Times (LPT) - Jobs are processed in decreasing order of time; for example, the job with the longest processing time is taken first by the machine to process the part and then followed by the next maximum time.

4) Earlier Due Dates (EDD) - In EDD rules, jobs are processed according to their deadlines. Jobs that have an earlier expiration date will be treated first by the machine and then followed by the next earliest expiration date. This rule is intended to minimize delays.

2.4 Discrete Event Simulation (DES)

Simulation is one way to study the system. Its quantitative discrete event simulation, which is often used as one of the tools in simulating its dynamics based on an event-by-event basis, provides the generation of detailed performance reports. Usually, this system is studied through two types of experiments: experiments with actual models or with actual system models. Based on the perspective of Law and Kelton's 2000 clarification system study, the way to study the system is introduced in Figure 2.3. According to Robinson, 2004, "Experimentation with a simplified simulation of the experiment (on a computer) of an operating system as it evolves, for better understanding and improving the system" is a definition of simulation. Therefore, figure 2.10 is an illustration of the way to study the system.

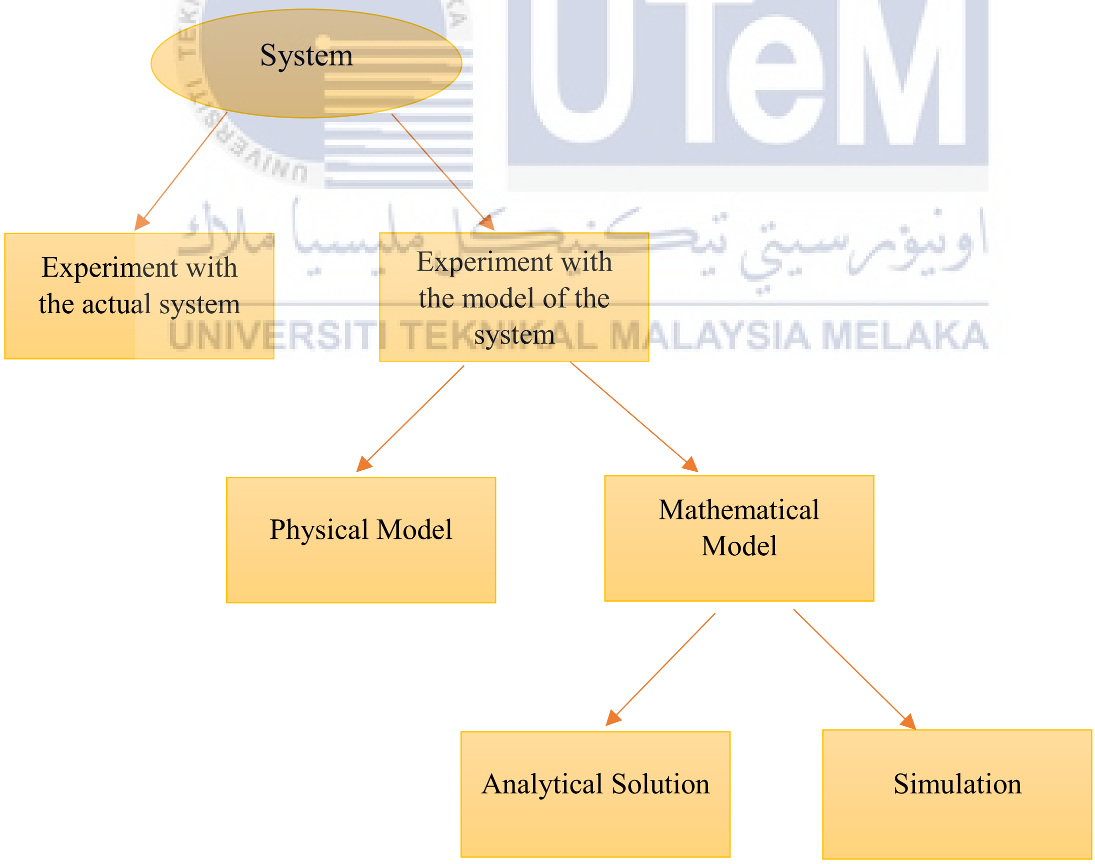


Figure 2.10: The Ways to study a system(Rybicka, 2017)

2.4.1 Advantages and Disadvantages of DES

Discrete Event Simulation (DES) is a popular method for studying and analyzing industrial processes. A DES tool, in general, may be used to model, simulate, optimize, and visualize production processes, systems, material flows, logistics operations, and other operational activities (Huynh et al., 2020).

The main advantage of DES in this industry is that it is beneficial for companies because it can conduct experiments that cannot be done on real manufacturing systems. (Kampa et al., 2017) also mentioned that designing this simulation helps gain knowledge and leads to real system improvement in the industry.

In addition, the use of DES is beneficial because this simulation allows the study and experimentation of complex systems and shows benefits with lean manufacturing throughout the system. This shows a good illustration of the future of how this new system might look (Gerdin et al., 2018).

Nevertheless, this DES is often associated with the fact that so many random inputs are associated with simulations. Therefore, observations are difficult to distinguish whether the results are of interrelationships or randomness relevance. According to (Gerdin et al., 2018), the construction of this simulation model requires special training due to the substantial disadvantages that simulations are often associated with randomness. This study also explains the disadvantages of this simulation, such as mimicking the inconsistent variables of the production line. Human errors and skills are also among the factors that need to be considered for this simulation.

2.4.2 Application Areas

A discrete event simulation is a traditional tool that has long been used in the industry sector. However, the use of these simulations is rapid development in line with developing technologies in industrialized countries, such as Computer-aided Design (CAD), Computer-aided Manufacture (CAM), Flexible Manufacturing System (FMS), Computer Integrated Manufacturing (CIM), and Automated Guided Vehicle (AGV) (Goti, 2012). The simulation application in this industry sector positively impacts every production manager who wants to increase productivity in terms of higher processing power. Therefore, the simulation can assess the behaviour of the manufacturing process quickly.

Furthermore, this discrete event simulation software is widely used in the manufacturing sector as, for example, this simulation can design and evaluate new manufacturing processes. However, this software is not limited to only use in the manufacturing industry; it can also be applied in the service sector. Among the service sectors often involved in the simulation of discrete events are banking and finance services, healthcare and hospitals, logistics and transportation, and the public sector(Goti, 2012)

2.5 Simulation Modelling

Sometimes, the actual operation of the real system needs to be experimented with to study the effects of changes that can lead to a more efficient system and improve the current system. The simulation modelling should be built from a real system to draw the best conclusions. According to Goti, 2012, this simulation model can be defined as a system representative studying the actual system.

Next, Rybicka, (2017) explains in the study that there are four stages of development listed as simulation research work: conceptual modelling, simulation development, experimentation, and analysis. Figure 2.4 is an example of simulation project activities. This process focuses on problem understanding, data collection, and selection of simulation approaches. Next, the basis of the conceptual model will be formed, and a simulation model can be built, verified, and validated. Experimentation is conducted based on the analysis of the problems obtained, and the main simulation stages will be discussed in more detail in chapter 3 of the methodology.

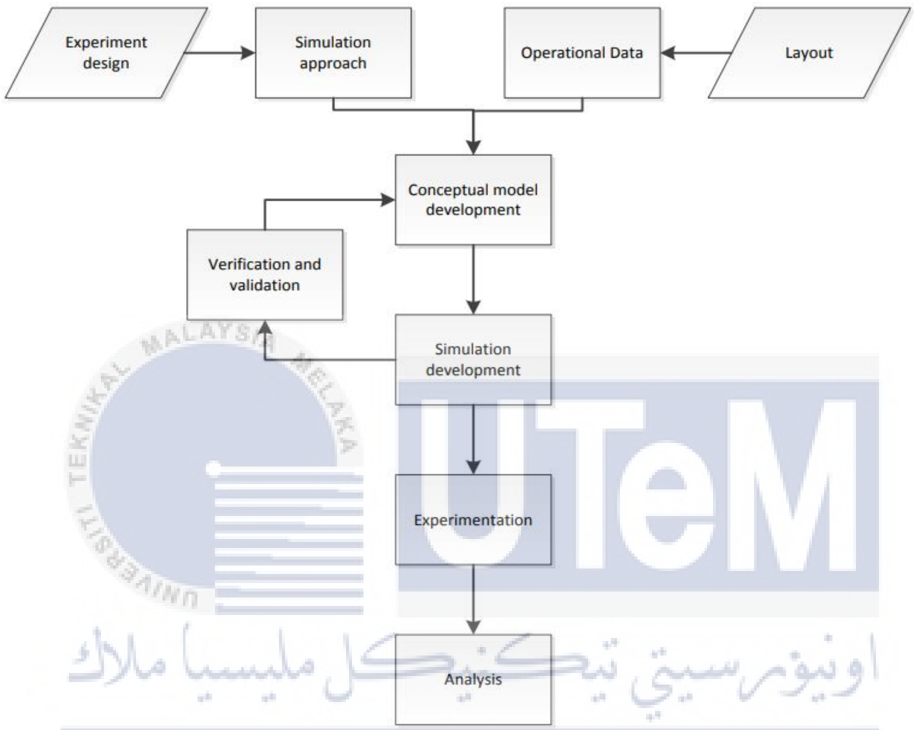


Figure 2.11: Example of the simulation project activities (Rybicka, 2017)

2.5.1 Modelling and Simulation Procedure

Modelling is an essential part of simulation studies. Therefore, simulation procedures in simulation development are critical to a project. Based on (Yin & McKay, 2018), this designed simulation procedure helps guide research and experimental activities. This is because this procedure can solve case studies of real-world problems.

Thus, the figure below shows the twelve procedures introduced by (Banks et al., 2010) and each step is described in the following steps.

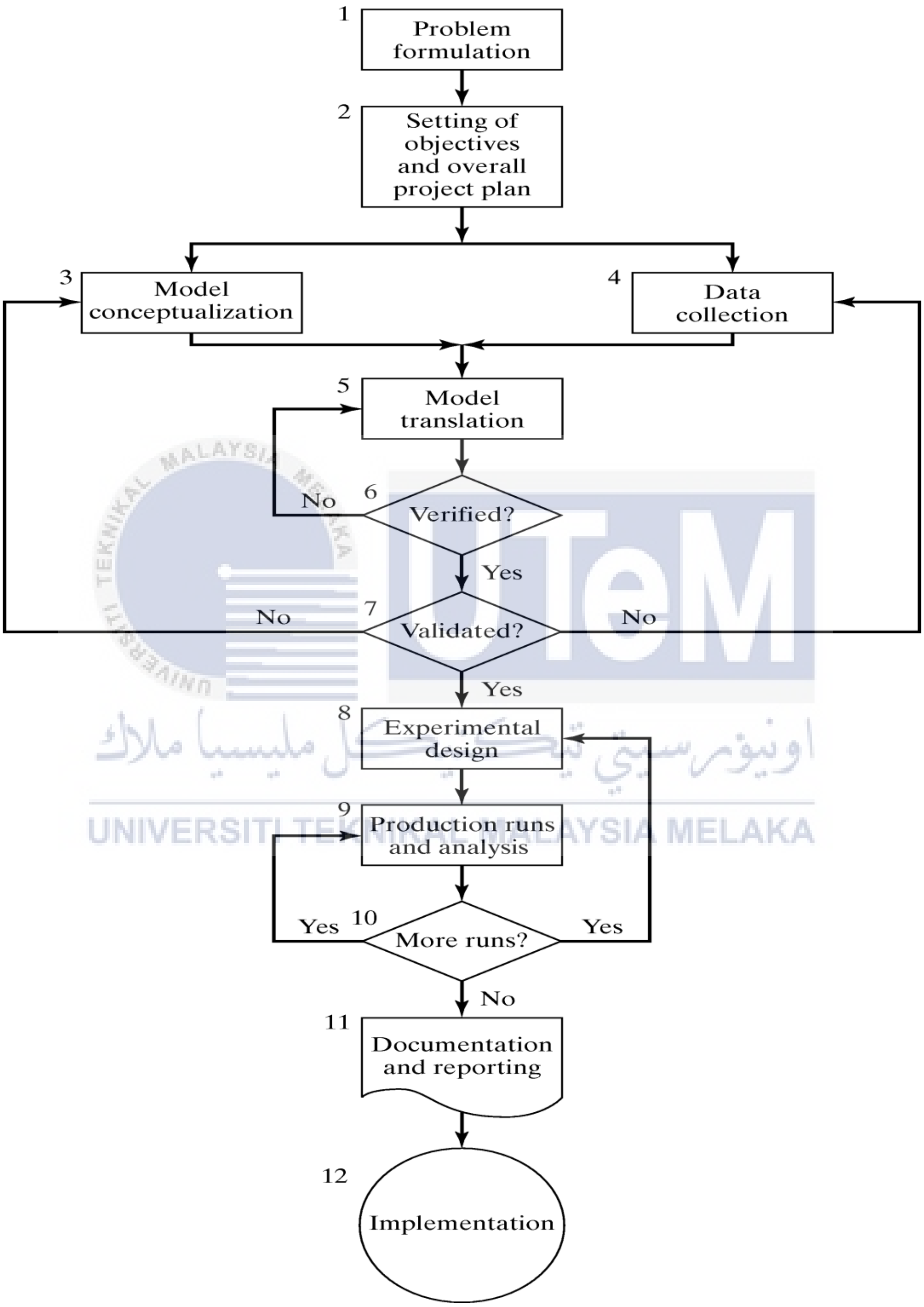


Figure 2.12: Steps of simulation modelling study(Banks et al., 2010)

Table 2.5 shows the 12 steps involved in developing a simulation model, designing a simulation experiment, and performing a simulation analysis.

Table 2.5 Step in the simulation study(Yin & McKay, 2018)(Balsamo, 2014)

Procedures	Descriptions
1. Problem formulation	The problem statement needs to be well stated and identified as it is the starting point in the simulation study. This problem must be formulated as accurately as possible and understood as it is involved in simulation studies.
2. The setting of objectives and overall project plan	The overall objectives of the study and some specific issues that need to be addressed need to be determined and stated in this second step. Each problem to be studied needs to be checked whether the simulation is the most suitable tool for a study. This is important in determining the criteria of the simulation system in the simulation study.
3. Model conceptualization	The conceptual model is a step where a system model that is being studied will be developed. And built depending on the purpose of the simulation study research.
4. Data collection	Data collection is a critical phase in a simulation program where the required collected data needs to exist in an appropriate and accessible form. According to (Balsamo, 2014), ongoing trace collection from the system pass is necessary for the problems stated in the simulation study.
5. Model translation	The translational model phase is the step in which the simulation model is translated into the simulation program. The use of special simulation tools will be used in studying simulation models. This tool provides a graphical user interface that uses the modeller to build a simulation program through direct visual manipulation of graphical entities.
6. Verified	The simulation model needs to undergo verification experiments to check and ensure that this simulation model gives a reliable output; in other words, it does not contain errors.

7. Validated	Validated experiments were conducted using a revised simulation model. This experiment aims to ensure that this model accurately represents the real system where it can be replaced with the real system with the goal of a simulation study. (Balsamo, 2014)
8. Experimental design	This step is essential in a simulation project to simulate a real operating scenario. This experimental design is a step to determine parameters such as the length of the simulation run, the number of replications per run to be performed and the length of the start period.
9. Production runs and analysis	Production runs are used to estimate the parameters of interest of the simulation study(Balsamo, 2014)
10. More runs	Additional runs may be required in this Step even if production runs have been analyzed. This is because this step is necessary for deciding the design that the additional run should follow.
11. Documentation and reporting	Documenting the overall executions of the simulation at the final stage is necessary for the simulation procedure. Simulation programs and progress reports are the documentation required in this simulation study. The progress report describes the decisions that have been taken and the work that has been done in various phases.
12. Implementation	In the final phase, where implementation is carried out, The results and implications of the study are discussed. The best course of action is identified, recommended, and justified.

2.5.2 Simulation Tools

Simulation software is a tool capable of designing the required model and analyzing system performance. Discrete event simulation software is used in flexible manufacturing systems to simulate the desired system using different criteria. Recently, simulation tools have been prevalent and relevant among researchers for use in FMS.

These simulation tools save time, cost, and effort before implementing the actual system. This simulation can help acquire knowledge and lead to the improvement of the real system in the industry. Several simulation tools use discrete event system software. Among them:

1. Tecnomatix Plant Simulation
2. ARENA
3. FlexSim
4. Simcad Pro
5. Enterprise Dynamic

Therefore, Table 2.1 introduces leading research in discrete event simulation relevant to their specific objectives and simulation.

Table 2.6: Discrete event simulation literature.

Author	The article objectives	Simulation tools
(Patel & Sormaz, 2012)	To study the simulation of FMS samples with the integration of two types of flexibility: route flexibility and scheduling flexibility.	ARENA and VBA
(Arshad et al., 2016)	The effect of FMS layouts and different scheduling rules on the output measure using discrete event simulation.	ARENA
(Florescu & Barabas, 2020)	To study flexible manufacturing systems' technical and economic achievements using modelling and simulation techniques.	Tecnomatix Plant Simulation
(Gaurav Kumar & Trilok Singh Bisoniya, 2015)	a suitable fitness function is designed for optimum values of factors affecting FMS objectives and maximization of system utilization with maximization of throughput of the system	ARENA
(Debta et al., 2017)	The objective is to compare and minimizes the makespan when scheduling with various dispatching rules.	SIMUL8
(Santhosh Kumar et al., 2015)	The bottleneck technique has been applied to compare and verify the results obtained from the simulation techniques to analyse its performance measures.	FlexSim

2.5.2.1 Tecnomatix Plant Simulation

Tecnomatix Plant Simulation is a discrete event simulation tool that allows to quickly and intuitively create a realistic digital logistics system. Tecnomatix is also a modelling software tool that is easy to understand and user-friendly. The software enables users to feel free to build the desired simulation model and conduct experiments on that model.

In addition, bottleneck analysis, statistics, and charts are features of the advanced analytical tools available in this plant simulation (Siderska, 2016). This analysis can be used in various scenarios that occur in the industry, such as evaluating different production scenarios.

Next, Tecnomatix Plant Simulation is also a tool that allows statistical data analysis. The original algorithm and script programming (method) is also a significant advantage in using this software because it simplifies every user who uses this program (Siderska, 2016). The figure below shows an example of a Tecnomatix plant simulation application.

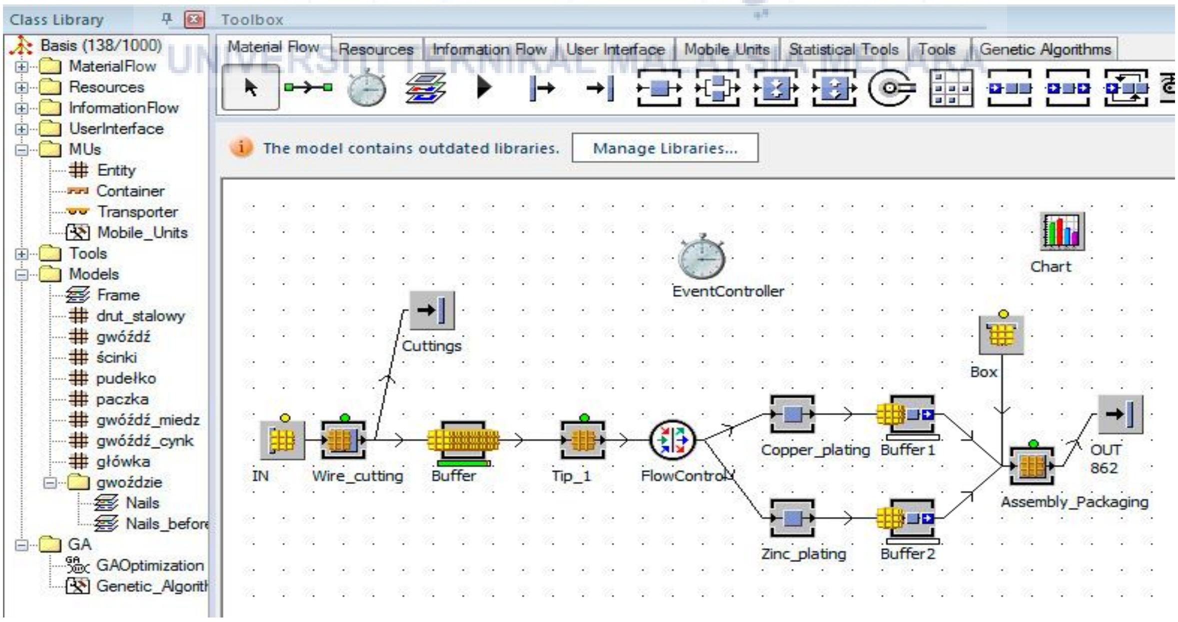


Figure 2.13: Example of a Tecnomatix plant simulation application. (Siderska, 2016)

2.5.3 Related Studies

Based on (Chan & Chan, 2004), there have been more and more researchers using simulation in developing various strategies in manufacturing operations and control in recent years. These simulations are becoming increasingly popular and are widely used as a modelling design tool for FMS. Moreover, (Jahangirian et al., 2010) also share the same opinion that DES is a very well-known technique often used by researchers in manufacturing and business. (Jahangirian et al., 2010) also added that this simulation technique is a crucial factor to consider in real-world applications. DES is claimed to be one of the tools commonly used in a wide spectrum, such as analyzing activities and understanding the dynamics of manufacturing systems. (Negahban & Smith, 2014)

Next, (Semini et al., 2006) explain that this DES had been used as an approach in the study to focus more on the logistic results of real-life manufacturing. (Semini et al., 2006) also explained that research such as production policy, planning, scheduling, and inventory policy had been identified, and the use of DES developed the most popular. Instead, according to on (Jeon & Kim, 2016), this researcher's study focuses on simulation modelling techniques in production planning and control (PPC), such as production and process design, purchasing and supply management, and capacity planning.

2.6 Summary

FMS is a "reprogrammable " system and an automated manufacturing system that can produce various products in the manufacturing sector. FMS consisting of various machining cells are connected through loading/unloading stations by automated transport systems such as AGV systems and conveyors. Therefore, it provides many facilities and advantages to industry managers in generating a lot of demand and good quality for customers.

In addition, among the factors that affect this FMS is manufacturing flexibility which is the main target in making this system more efficient and competitive. This is because the definition of manufacturing flexibilities is the ability to adapt to any situation or situation and processes that change rapidly for customer needs without wasting production records. For example, the potential of flexible and alternative production routes in manufacturing systems is one of the critical features of flexibility. Different types of equipment used in this potential route can perform the same operation or use other manufacturing processes. Therefore, increasing manufacturing flexibilities is a critical strategy in this FMS to efficiently increase market responsiveness in uncertain future product demand.

Finally, DES applications used in FMS also play an essential role in this system. DES, a support tool in designing this simulation model, is the most effective in the global manufacturing and knowledge economy. Thus, an understanding of how to support FMS decisions is potentially supported by DES. Therefore, taking into manufacturing and FMS allows for further broadening of the knowledge of how DES potentially supports FMS decision support.

CHAPTER 3

METHODOLOGY

This methodology is the system of the method used in the research study. This study is carried out using discrete-event simulation software. The procedure of simulation study is used as a methodology to study the key factor affecting the performance of the FMS.

3.1 Relationship between Objectives and Methodology

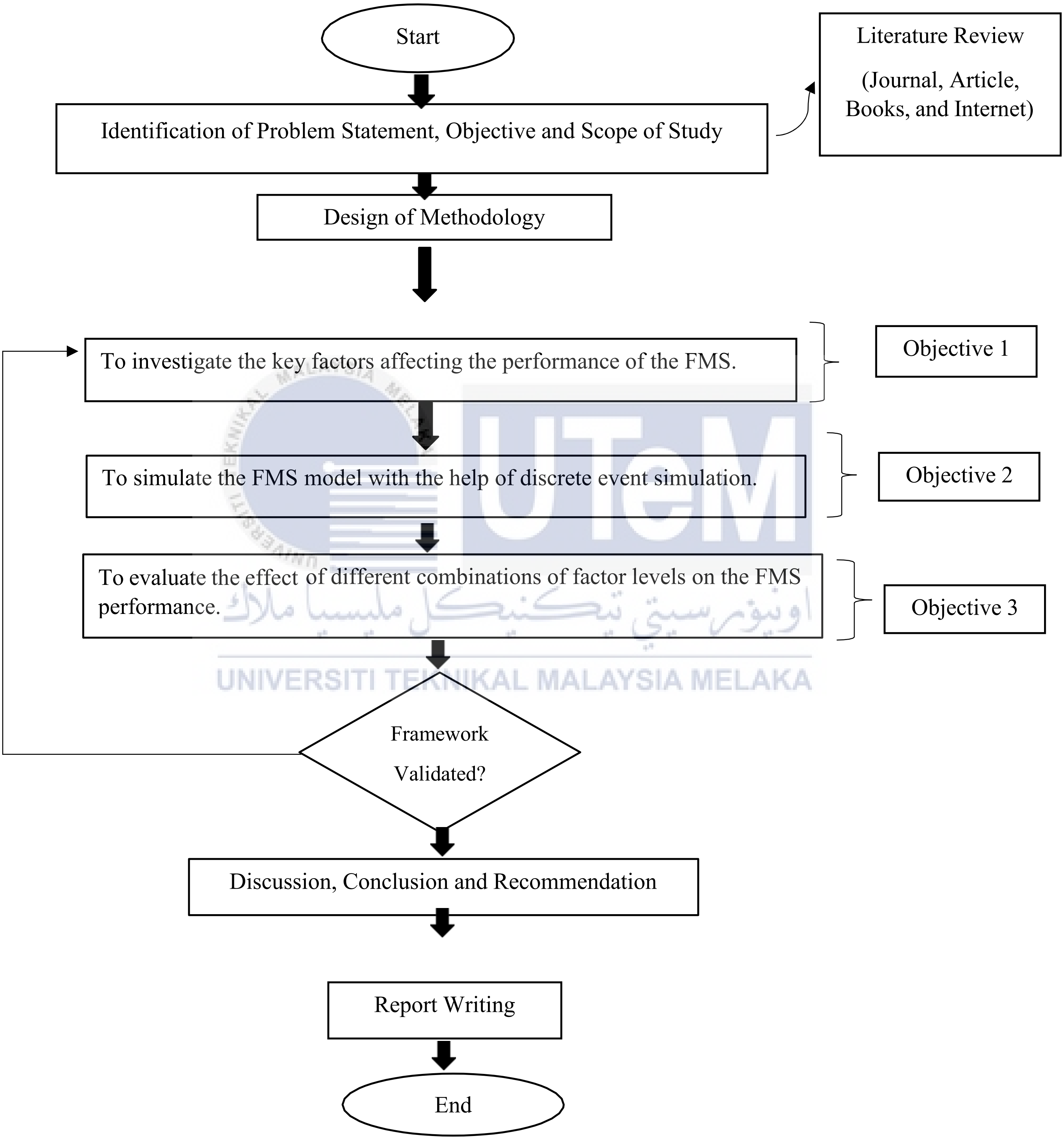
Table 3.1 shows the relationship between objectives and methodology. Thus, it proves how the process can achieve the objectives.

Table 3.1: Relationship between Objectives and Methodology

Objectives	Stages	Methodology
1) To investigate the key factors affecting the performance of the FMS.	Problem Formulation	a)Secondary sources b)Data collection
2) To simulate the FMS model with the help of discrete event simulation.	Simulation modelling	a) Model translation b) Model verification and validation
3) To evaluate the effect of different combinations of factor levels on the FMS performance.	Evaluation	a) Experimental design b) Production runs and analysis
	Implementation	a) Documentation and reporting

3.2 Project Flow Chart

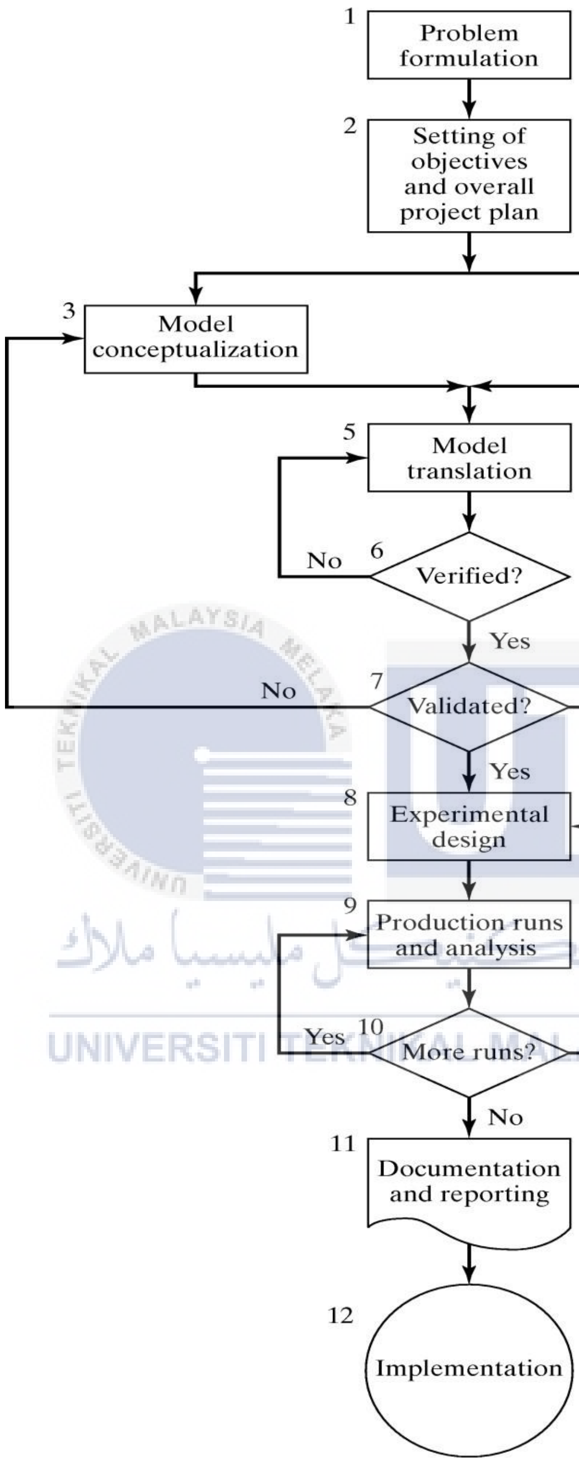
Figure 3.1 shows the project flowchart, which includes all the processes involved in completing the Final Year Project.



3.3 The Procedure of Simulation Study

Discrete event simulation is used in this project to design the desired model; several steps need to be done before implementation. This procedure is essential in this project to ensure that this developed model is successfully implemented. This is because the success of the implementation depends on the success of the completion of the previous phase. Therefore figure 3.2 shows the flow chart of analysis of the FMS Simulation is a crucial phase to ensure that the designed model is successfully simulated.

3.3.1 Flow Chart of procedure of the FMS Simulation



1,2,3,4	**Objective 1**
5,6,7	**Objective 2**
8,9,10, 11,12	**Objective 3**

Figure 3.2: Procedure of FMS simulation study

3.4 Objective 1: To investigate the key factor affecting the performance of FMS.

Research studies were conducted based on several research journals and adapted to this study. This study requires a step simulation study to complete this project. Therefore, this research study uses the existing methodology based on the study's experimental design. Table 3.2 show the stages involved in objective 1.

Table 3.2: Relationship between the stages in Objective 1 and Methodology

Objectives 1	Stage	Methodology
To investigate the key factor affecting the performance of FMS	Problem Formulation	a)Secondary sources b)Data collection

3.4.1 Problem formulation

In the problem formulation stage, two methodologies are set to be implemented in the project to achieve objective 1. Methodology such as the following had been decided to use in this stage of research:

a) Secondary sources
b) Data Collection

3.4.2 Secondary Sources

Secondary sources allow research to be supported by previous research done by other researchers. Books, journals, articles, and the internet are the secondary sources used in this study. In this phase, the objectives of the study research and some specific issues that need to be addressed the need to be determined. The conceptualization model process is one of the sources obtained through the reference of secondary sources and adapted in this study.

3.4.2.1 Model conceptualization

Model conceptualization is the main phase after the objective, and the overall project pis are defined for this project. This phase is essential in simulating a model because it is an abstraction of the world system being modelled, in other words, choosing what to model. Next, the selection of model conceptualization is the most challenging task as it requires scrutiny of either selecting an actual case study or using concept modelling presented from past studies. Therefore, the concept modelling for this project is by choosing concept modelling based on some previous research.

3.4.2.2 Physical Configurations

The flexible manufacturing system (FMS) configuration used in this study has been established based on several previous researchers. This FMS layout consists of five flexible machines(M) with input (I) and output (O) buffers. The system also consists of one load station (L)and one unloading station (UL). The system also has AGVs as material handling systems that are part of the transportation. Figure 3 illustrates the configuration of the flexible manufacturing system under consideration.

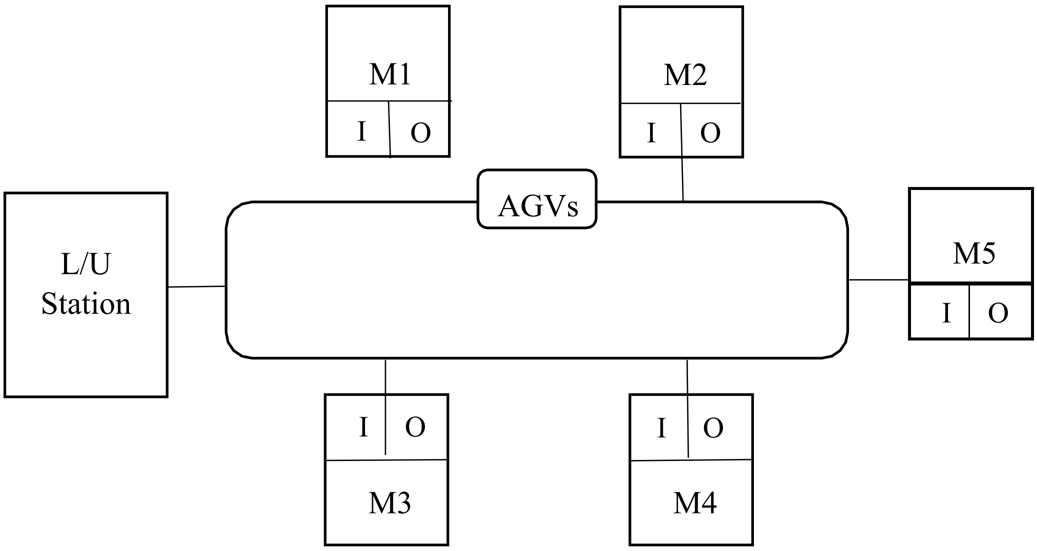


Figure 3.3: The physical configuration of the FMS (Joseph & Sridharan, 2012)

3.4.3 Data Collection

Data collection is the next phase in designing a simulation model for this project. This method is critical for validating the model at the validation stage. Next, the data collected and information for key factors in this project were obtained through several research studies. Therefore, data from past studies will be implemented in this project. Subsequently, improvements from previous studies will also be adapted in this project, especially in the stochastic demand factor.

3.4.3.1 Part Data

Ten parts are considered for processing in the system, namely P1, P2, P3, P4, P5, P6, P7, P8, P9, and P10. Details for each of these part types are described below:

i. Each of these part types have four operations.
ii. This part performs certain operating operations.

The table below shows ten types of parts with four operations to be performed and the processing time performed on each machine.

Table 3.3: The processing times for different part types.

Part Type	Operation 1		Operation 2		Operation 3		Operation 4	
	M/c	Time(min)	M/c	Time(min)	M/c	Time(min)	M/c	Time(min)
1	1	1:00	3	2:00	5	1:00	2	1:00
2	2	2:00	3	1:00	5	2:30	4	2:00
3	5	2:00	1	2:15	4	3:00	2	1:30
4	4	3:00	2	2:30	5	2:30	3	2:50
5	1	1:00	3	1:00	2	2:00	4	1:30
6	3	2:30	2	1:30	1	2:00	5	2:00
7	4	1:00	5	1:15	1	1:30	2	1:00
8	5	1:30	4	2:15	3	1:30	1	2:00
9	2	2:30	1	1:30	5	1:30	4	2:50
10	3	1:15	1	1:00	4	1:15	2	1:00

3.4.3.2 Stochastic Demands

Orders for the ten types of parts in this study will be generated, arriving at the system at random or stochastic demand. The category of FMS considered in this study belongs to random type FMS or known as non-dedicated FMS. Therefore, the exponential distribution is used in this study to model the random time between order arrivals when arrivals were completelyrandom. Two levels of stochastic demand are considered in this study. Table 3.4 below shows the level of average interarrival time (λ) of the exponential distribution.

Table 3.3:The level of average interarrival time (λ) of the exponential distribution.

Part Type	First level (λ)	The second level (λ)
1	0.5	1.0
2	0.5	1.0
3	0.5	1.0
4	0.5	1.5
5	0.5	1.5
6	0.5	1.5
7	0.5	1.5
8	0.5	2.0
9	0.5	2.0
10	0.5	2.0

3.4.3.3 System Capacity

The size of the input and output buffer of the machines represents the capacity of the manufacturing system. The system capacity is considered so that 30 pats are present in the system for processing. (Ali & Khan, 2019).

3.4.3.4 Development of AGV

This section describes the movements AGV uses in this model development system. The conditions and limitations are determined and considered in the AGV movement in this model. Therefore, the following conditions are defined:

i. The different number of AGVs have the same unit load capacity throughout the procedure.
ii. The AGV only carry one part at a time.
iii. This AGV will carry parts in each buffer in this AGV, operating continuously without damage.
iv. Problems such as traffic, violations, or conflicts are avoided by the hardware and are not considered in this study.
v. The AGV has a constant speed.

3.4.3.5 Part Launching

The First Come, First Served (FCFS) rule is used in part launch decisions involving processing parts from loading/unloading stations. The FCFS rule is operated from a loading station to send parts into the corresponding machine input buffer, provided space is available.

3.4.3.6 Sequencing Rules

The part sequencing rules are required to schedule the waiting parts in the machine input buffer. Scheduling rules are necessary for selecting the parts to be processed on the machine. Therefore, the table below shows the scheduling rules used for this study.

Table 3.5: The sequencing rules.

Sequencing Rules	Explanation
First-come-first-served (FCFS)	The part that comes first in the machine buffer will be selected for processing.
Shortest processing time (SPT)	Part having the shortest processing time among parts present in the machine buffer will process first.
Last-come-first-served (LCFS)	The part that comes last in the machine buffer will be selected for processing.

3.4.3.7 System Performances

There are two performances measures for evaluation are described in table 3.4 below:

Table 3.6: The system performances

Performance Measures	Explanation
Total production	The number of parts being produced.
Average machine utilization	The average percentage utilization of the machine.
Average waiting time	The average waiting time for the parts spent in the input buffer of the FMS.
Average AGV utilization	The average percentage utilization of the AGV.

3.5 Objective 2: To simulate FMS model using discrete event simulation

Table 3.7 highlights the methodology involved in the simulation modelling stages in objective 2 which is evaluate the model translation, verification, and validation.

Table 3.7: Relationship between the stages in Objective 2 and Methodology.

Objective 2	Stages	Methodology
To simulate FMS model using discrete event simulation	Simulation modelling	c) Model translation d) Model verification and validation

3.5.1 Simulation modelling

In this stage of research, the methodology such as the following has been decided to be implemented: -

a) Model translation
b) Model verification and validation

3.5.1.1 Model Translation

Tecnomatix Plant Simulation is a discrete event simulation package used for modelling and simulation for this study. These simulations can produce various types of experimental models. Therefore, the study of this methodology is to construct a model that represents the process of performing a particular task. This is because the model built in this simulation can resemble the real environment model due to its high automation capability. The construction of the model in this simulation environment also explains the transportation movement, i.e., AGV. This study will describe the characteristic features of FMS model development based on the objectives of this study.

3.5.1.2 Model Verification and Validation

Simulation models developed in this study are based on the modification of the research carried out by (Joseph & Sridharan, 2012) in FMS. The layout of the FMS model shown in figure 3.1 is designed to produce ten different parts, and each part must be processed through four operations. Only one part type can be processed at a time. The sequence of operations of each part is shown in table 3.1. For example, machine one is used for the first operation of a type 1 part. Therefore, in this situation, the first operation of a type 1 part must be performed on machine 1. Next, after completing the first operation, the fully processed type 1 part will be at the output buffer 1 before being transported by material handling, which is AGV, to machine 3 for the second operation. The third operation and the following sequence for the type 1 part are machines 5 and 2. This is a fixed operation sequence scenario.

In this simulation system, the AGV acts as transportation and will perform the task by transporting each type of part that has completed the process on a set machine and transported to the next operation. However, this AGV will carry out the task of transporting parts if the transportation is accessible and did not busy. This AGV process will continue until these ten types of parts have completed each part of its operation. The following is the flow chart of the FMS Operation for this project study.

3.5.1.3 Flow Chart of the FMS Operation

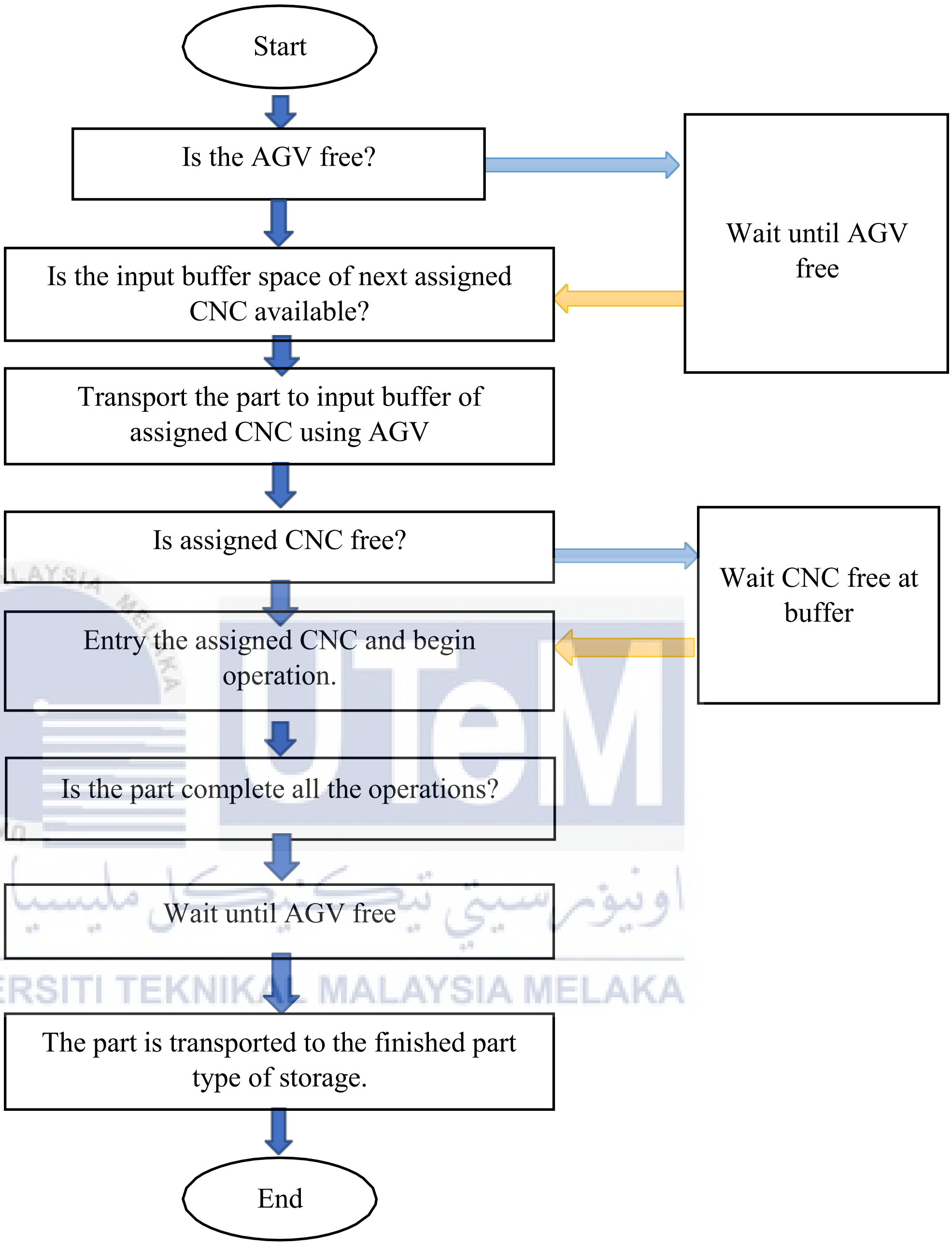


Figure 3.4: Flow Chart of the FMS Operation

3.6 Objective 3: To evaluate the effect of different combination of factor level in FMS performance

In this stage, the effect of different combination of factor level in FMS performance be evaluated. Table 3.8 shows the relationship between effect of different combination of factor level in FMs performance and the methodology at this stage.

Table 3.8: Relationship between the stages in Objective 3 and Methodology.

Objective 3	**Stage**	**Methodology**
To evaluate the effect of different combination of factor level in FMS performance	Evaluation	a) Experimental design b) Production runs and analysis
	Implementation	a) Documentation and reporting

3.6.1 Evaluation

In this stage of research, the methodology such as the following has been decided to be implemented:

a) Experimental design
b) Production runs and analysis

3.6.1.1 Experimental Design

In this section, the experimentation of the proposed integrated framework is explained. Tecnomatix simulation software is used for the experimentation of the proposed manufacturing model. This work aims to determine the effects of stochastics demand, the difference number of AGV, and sequencing rules on the system's performance and highlight the impact of these factors under different conditions. Hence, in the simulation experiments, three replications are performed for each setting. There are 12 experiments arising from the combination of two SD, two NG, and three SRs. Ten replications are made for each combination, and the performance measures are evaluated. The table below shows several factors and their levels that have been performed for this study.

Table 3.9: The details factor and their level.

S.No	Factor	Factor level
1	Stochastics Demand (SD)	1
		2
2	Number of AGV (NG)	1
		2
3	Sequencing Rules (SR)	FCFS
		SPT
		LCFS

3.6.1.2 Production run and analysis

The production runs will be performed as specified in experimental design. Simulation results are analyzed and discussed. Potential management solutions are considered to address the specified research problems.

3.6.2 Implementation

Methodology such as documentation and reporting has been decided to use in this stage of research.

3.6.2.1 Documentation and reporting

Documenting the overall executions of the simulation at the final stage is necessary for the simulation procedure and to complete the methodology. The results and implications ofthe study will be discussed in the chapter 4 result and discussion.

CHAPTER 4

RESULT AND DISCUSSION

This chapter focuses on the results obtained throughout the experimental methodology and data collected. The overall progress of the project, e.g., experimental analysis, is briefly stated in this chapter to get a better understanding. In the next part of this chapter, simulation results obtained using Tecnomatix software are presented to elaborate on the validity of the proposed model. Next, the performance measure of simulation models, such as total production, average machine utilization and average waiting time, are discussed.

4.1 Objective 1: To investigate the key factor affecting the performance of FMS.

To fulfil the study's first objective, several factors have been chosen by reviewing the literature and referring to table 4.1. Therefore, table 4.1 shows the literature on the key factor affecting the performance of FMS.

Table 4.1: The literature on the key factor affecting the performance of FMS.

Author	The key factor affecting the performance of FMS	The performance measure
(Ali & Khan, 2019)	Deterministic demand, routing flexibility, system capacity, system load and sequencing rules	• Make span • Resource Utilization • Work-in-process
(Chawla et al., 2018)	Deterministic demand, The differences in the size of FMS layout, routing flexibility, and scheduling rules.	• Average Work Centre Utilization • Average AGV Utilization (%)
(Sreenivasulu et al., 2016)	Part launching rule	• Average Flow time • Make span • Average Machine Utilization • Average AGV Utilization
(Ali & Ahmad, 2014)	Deterministic demand, routing flexibility, dispatching rule, sequencing rule, product volume and part mix flexibility.	• Make span
Joseph, O.A.; Sridharan, R. (2011)	Deterministic demand, routing flexibility, sequencing flexibility and sequencing rules.	• Average waiting times • Average flow time
(Chan & Chan, 2004)	Deterministic demand, routing flexibility, scheduling rules, system capacity and part mix ratio.	• Make span • Average Machine utilization • Average flow time • Average delay at local buffer

Based on Table 4.1, some literature has been reviewed and investigated. In all the past studies above, most researchers consider deterministic demand as the main factor. In addition, routing flexibility and scheduling rules are among the popular ones researchers use in their studies.

Therefore, to fulfil the first objective of the study, stochastic demand has been chosen in this study. This is because, based on the problem statement of this study, stochastic demand is one of the factors that has been considered too little in past studies compared to the use of deterministic demand, which is often used by other researchers, as shown in Table 4.1.

Apart from that, sequencing rules have also been selected by reviewing the literature because this factor is often used by past studies. So on, the development of AGV has also been considered as material handling, which helps to transfer the part in the proposed model of the study.

Lastly, The conceptual basis of this developed model to obtain a smooth flow of information has been described in methodology chapter 3. (Refer to table 3.3 until table 3.6). This developed model is to make sure to define a set of criteria that have the potential to produce a practical model that matches the actual environmental situation.

4.2 Objective 2: To simulate the FMS model using discrete event simulation

To achieve the second objective of the study, Tecnomatix Software is used in developing and simulating the Physical configuration of the FMS model that has been described in the methodology chapter (Refer to figure 3.3)

4.2.1 Model Translation

Tecnomatix Plant Simulation is a discrete event simulation package used for modelling and simulation for this study. Therefore, the following figure shows the FMS's physical configuration using Tecnomatix Plant Simulation.

Figure 4.1: The physical configuration of FMS created using the Tecnomatix Simulator.

Based on figure 4.1, this model has been successfully built with the help of the Tecnomatix Simulator. Several important criteria have been highlighted and set in this model to produce a model resembling an actual environment model. The following Table 4.1 is the criteria that become variables for this project.

Table 4.2: The constant variable that considers in the model.

Constant Variable	Constant
System Capacity	30 parts
Speed of AGV	2m/s
Part Launching	First Come, First Served (FCFS)

In addition, the dimensions of the model and AGV are also stated in table 4.3 below.

Table 4.3: The dimension of the model and AGV.

Type of the criteria of the model	Dimension
The layout model	x = 9 m , y= 6.4m
Distance between L/U station to the Machine 1 and Machine 3	2 m
Distance between L/U station to the Machine 2 and Machine 4	5 m
Distance between L/U station to the Machine 5	9 m
Distance between marker input buffer to the output buffer	1 m
AGV size	Length = 1.6 m Width = 0.8 m Height = 0.4 m

4.3 Objective 3: To evaluate the effect of a different combination of factor levels on FMS performance.

4.3.1 Experimental Design

In the second objective, the conceptual model and its main features have been discussed and successfully simulated with consideration as in the methodology (Refer to figure 3.1). This model is simulated with ten types of parts by taking eight hours of work time.

This model is also developed and run on different combinations of factors. Different factors and their levels are as follows; Stochastics Demand (SD); SD=1, SD=2, Number of AGV (NG); NG=1, NG=2 and Sequencing Rules (SR); First Come First Served (FCFS), Shortest Processing Rules (SPT), Last Come First Served (LCFS) which have been clarified are also identified to generate the best system performance.

In this study, to get the best combination of factors and their levels are based on the simulation results of the model.

4.3.2 Performance Evaluation

To predict the combination factors of FMS performances, 12 experiments have been involved in this project. Among them are two SD, two NA, and three SRs that will undergo the production run process. Ten replications have been made for each experiment to measure the system's performance. Four performance evaluations have been used as measurements in this project: Total production, Average Machine Utilization, Average Waiting Time and Average AGV Utilization. The simulation results are shown in Tables 4.3, 4.4, 4.5 and 4.6, respectively.

Table 4.4: Simulated results for total production at different stochastic demand levels.

	1 AGV			2 AGV		
SD LEVELS	SPT	FCFS	LCFS	SPT	FCFS	LCFS
SD 1	278	273	265	291	283	270
SD 2	266	258	251	269	265	256

Table 4.5: Simulated results for average machine utilization at different stochastic demand levels.

	1 AGV			2 AGV		
SD LEVELS	SPT (%)	FCFS (%)	LCFS (%)	SPT (%)	FCFS (%)	LCFS (%)
SD 1	95.23	92.72	91.50	93.34	92.47	90.98
SD 2	87.10	78.89	76.62	78.51	77.00	75.98

Table 4.6: Simulated results for average waiting time at different stochastic demand levels.

	1 AGV			2 AGV		
SD LEVELS	SPT (%)	FCFS (%)	LCFS (%)	SPT (%)	FCFS (%)	LCFS (%)
SD 1	7.7	8.2	34.2	4.8	5.5	22.6
SD 2	12.2	13.7	22.7	7.2	7.5	13.7

Table 4.7: Simulated results for average AGV utilization at different stochastic demand levels.

	1 AGV			2 AGV		
SD LEVELS	SPT (%)	FCFS (%)	LCFS (%)	SPT (%)	FCFS (%)	LCFS (%)
SD 1	74.0	74.0	83.0	44.0	44.0	55.0
SD 2	62.0	62.0	62.0	38.0	38.0	41.0

4.3.2.1 Total production

The bar graph of the total production is presented in Figures 4.2 and 4.3.

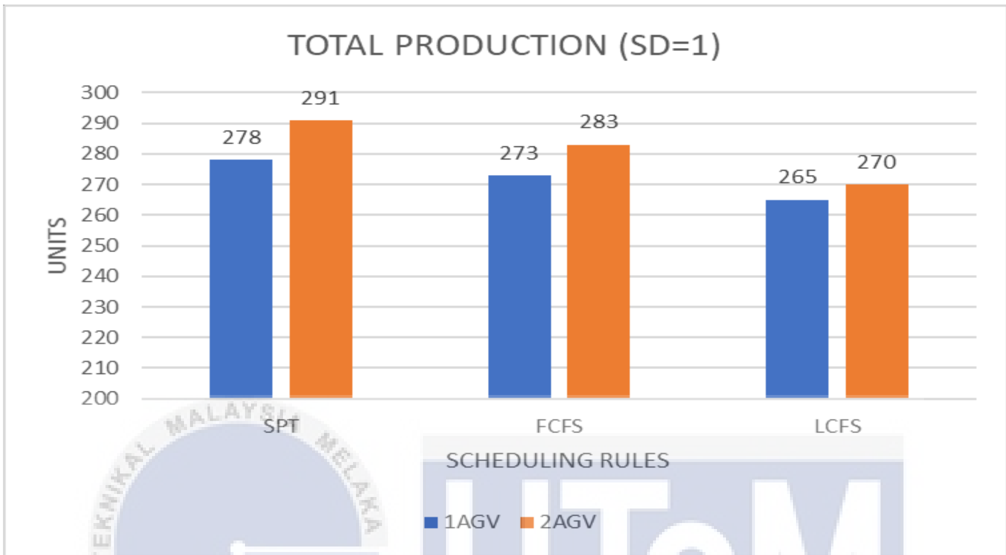


Figure 4.2: The total production under SD=1.

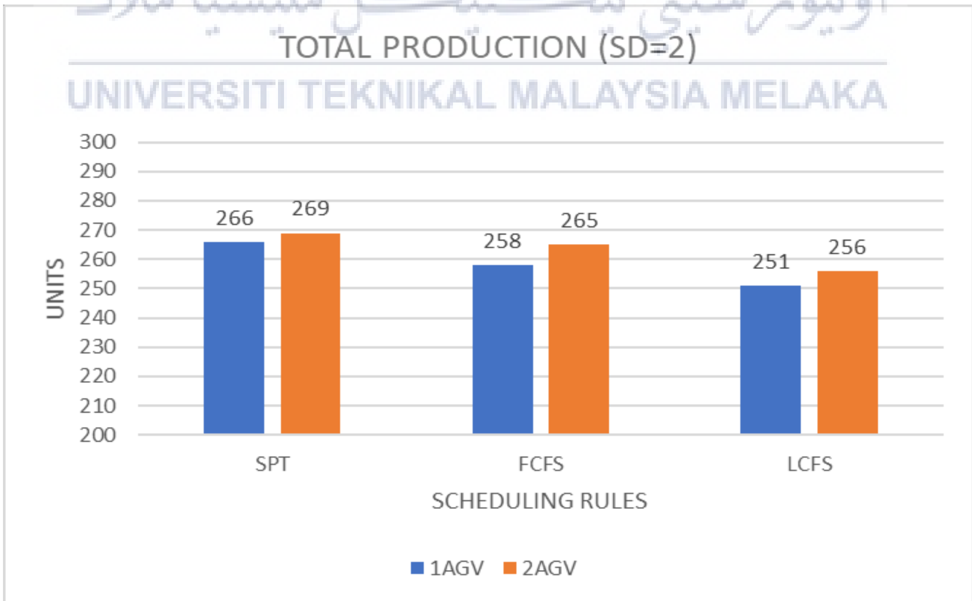


Figure 4.3: The total production under SD=2.

Based on figure 4.2, the graph shows the variation of total production in the SD=1 level against the type of sequencing rules. As can be seen, the overall production graph shows that the total production increases drastically with the increase in the number of AGVs. At NG=1, the amount of production is the least. Nevertheless, this graph shows a slightly increased trend at NG=2.

Further, for the amount of production at the level of SD=2, the graph trend is similar to figure 4.2 because there is an increase in the amount of production at the Number of AGVs. But the variation of total production between NG=1 and NG=2 shows an insignificant rise, as shown in figure 4.3.

Based on Figures 4.2 and 4.3, the stochastic demand considered in this study shows a relatively significant amount of production where there is a dramatic decrease at level 2 compared to level 1. At level 1, the stochastic demand is set at λ=0.5 for each part, and if observed, the randomized pattern is the same in each part. While at level 2, the stochastic demand is different between λ=1.0 λ=1.5 and λ=2.

The performance of various sequencing rules for total production at SD=1 and SD=2, respectively, are also shown in Figures 4.2 and 4.3. At SD=1 and SD=2, it is observed that the SPT scheduling rule provides good FMS performance under stochastic demand and is followed by FCFS and LCFS. Therefore, the effect of two levels of stochastic demand on the sequencing rule gives the same result that SPT is the sequencing rules that produces a higher total production.

Therefore, the difference in stochastic demand level can be considered the main role in improving the system. This is because stochastic level 1 provides reasonable system performance in a high production volume compared to stochastic level 2. At stochastic level 2, the system performance does not respond well and shows no difference between NG=1 and NG=2.

4.3.2.2 Average Machine Utilization

Figures 4.4 and 4.5 show the summary result of the average machine utilization by using a bar graph.

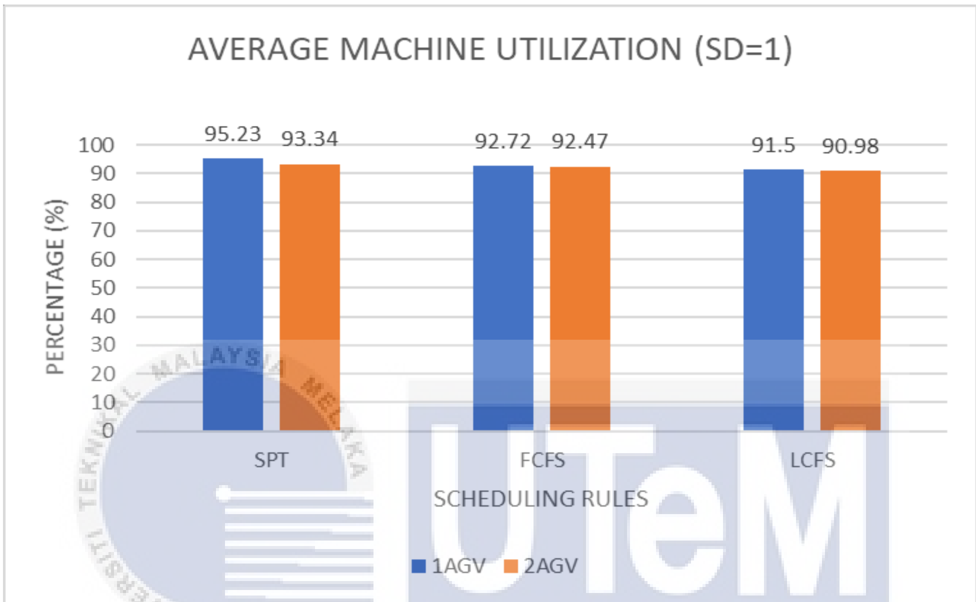


Figure 4.4: The average machine utilization under SD=1.

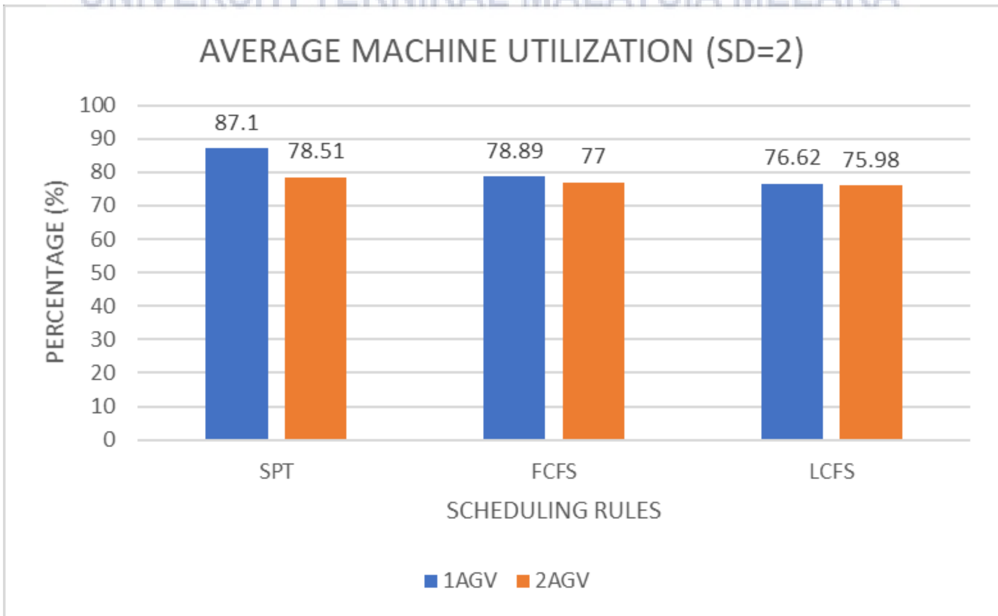


Figure 4.5: The average machine utilization under SD=2.

Figure 4.4 and figure 4.5 show average machine utilization at SD=1 level. All types of sequencing rules generally show a reasonable average machine utilization, with SPT leading closely followed by FCFS and LCFS rules. In general, the average use of machines does not show noticeable changes with different numbers of AGVs either at SD=1 or SD=2 levels.

Another observation that can be found in figure 4.5 is that the average machine utilization at the level of SD=2 shows a significant decrease compared to SD=1. As expected, it finds that with stochastic demand change SD=2, there is a steady decrease in average machine utilization. However, the superiority achievement of all three scheduling rules performed well in the number of AGVs, and the average machine utilization tended to decrease in the large number of AGVs.

4.3.2.3 Average Waiting Time

The bar graph of the average waiting time is presented in Figures 4.6 and 4.7.

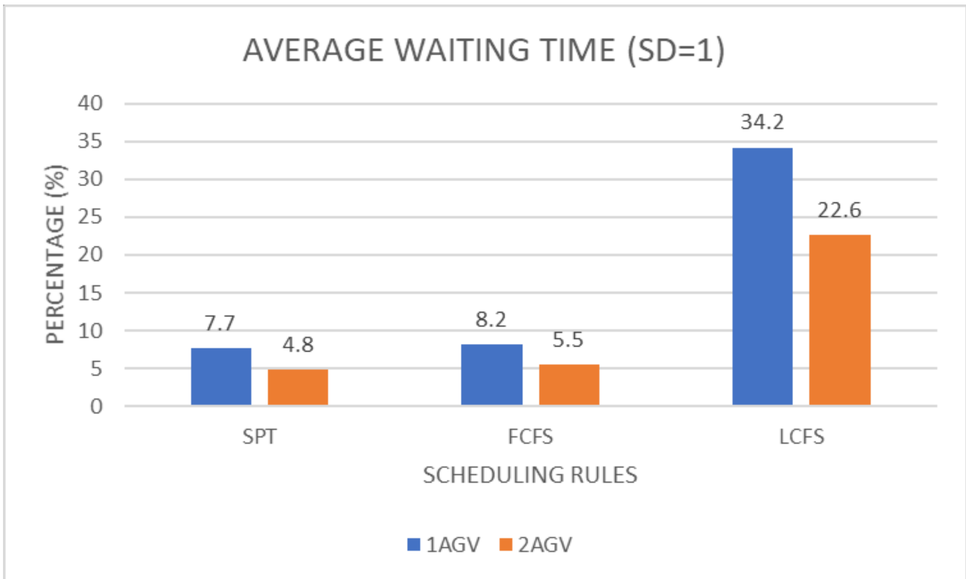


Figure 4.6: The average waiting time under SD=1.

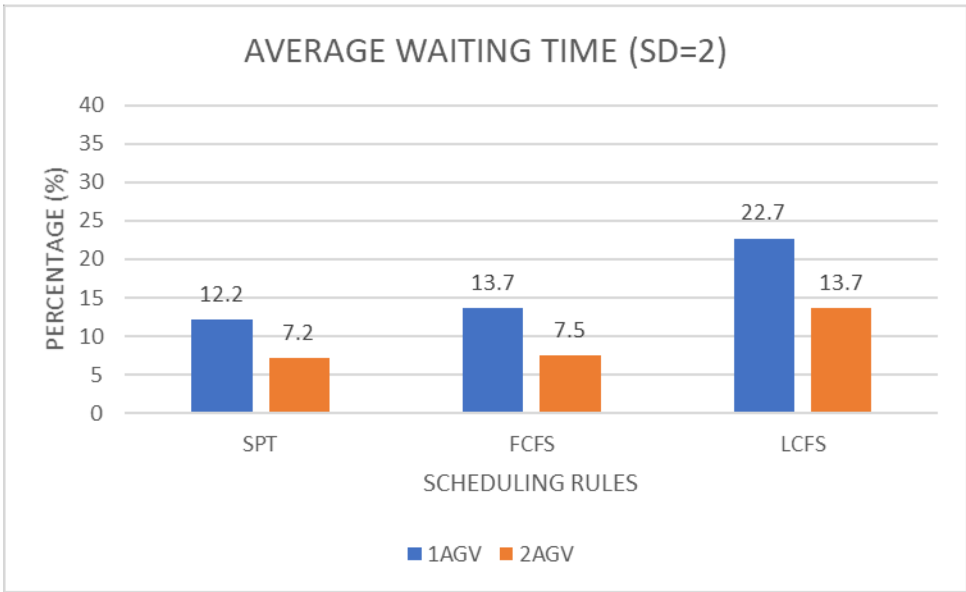


Figure 4.7: The average waiting time under SD=2.

Figures 4.6 and 4.7 illustrate the performance of various sequencing rules for average waiting time on SD=1 and SD=2, respectively. At SD=1, it is observed that SPT scheduling rules provide exemplary performance in FMS performance due to their low results and follow the rules of FCFS and LCFS. And the same results were also shown in SD=1, where SPT topped the first place.

In addition, if both SD=1 and SD=2 are observed, it can be concluded that as the number of AGVs increases, the average waiting time for the parts to be produced for the machine decreases. Because of that, the total production at these two levels at NG=2 has increased compared to NG=1. This matter is closely related to the average waiting time; therefore, as expected, the SPT rule is the reasonable-performing scheduling rule at SD=1 and SD=2.

4.3.1.4 Average AGV Utilization

Figure 4.8 and 4.9 shows the average AGV utilization for SD=1 and SD=2.

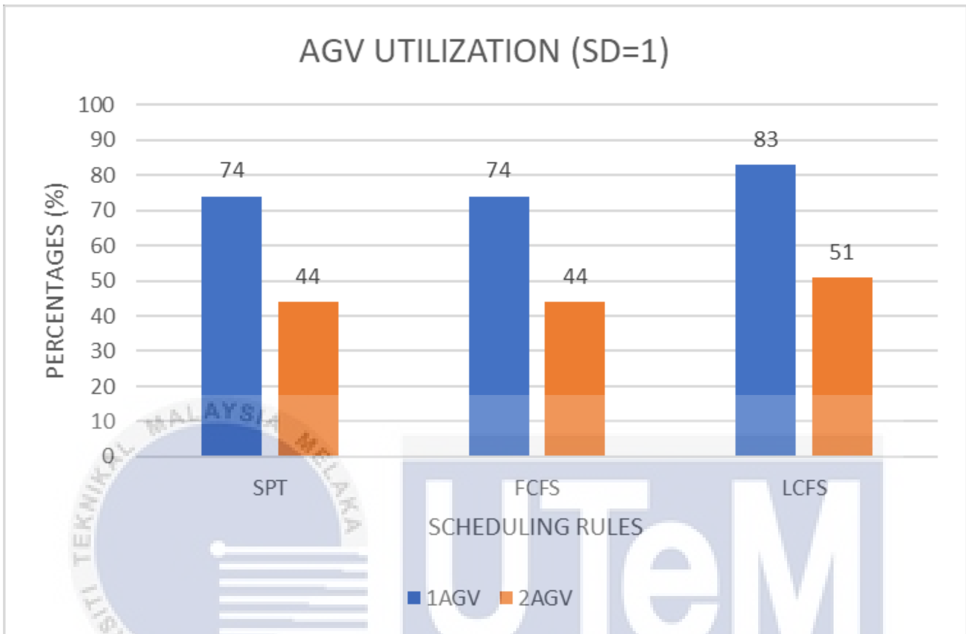


Figure 4.8: The average AGV Utilization under SD=1.

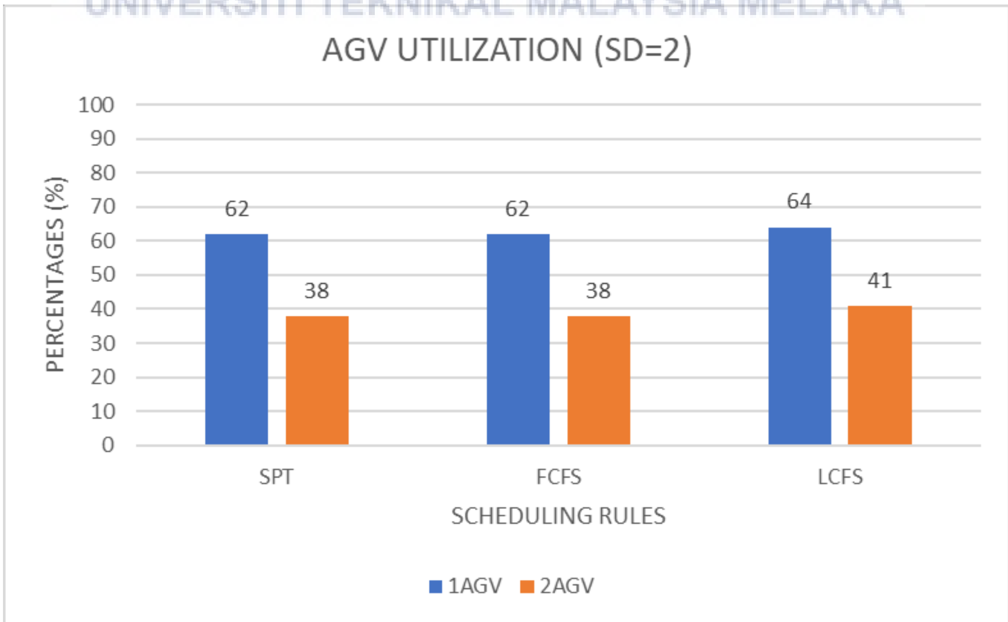


Figure 4.9: The average AGV Utilization under SD=2.

The average AGV utilization for different scheduling rules in SD=1 is shown in Figure 4.8. Generally, in SD=1 for NG=1, the third result of the three scheduling rules showed no noticeable results. In fact, the increase between LCFS and FCFS does not show a drastic increase. A similar trend is also shown in figure 4.9, which is the average AGV utilization under SD=2.

However, if it is observed that if NG increases, that is NG=2, the performance of average AGV utilization shows a noticeable decrease. The same observation can also be applied to figure 4.9, SD=2, where the results show the same trend in figure 4.8. Clearly, the influence of different scheduling rules does not affect average AGV utilization. Nevertheless, the effect of the number of AGVs is important to performance measures.

4.4 The effect of Stochastic Demand (SD).

The effect of stochastic demand is explored to significantly affect system performance with the presence of varied stochastic demand. From figures 4.2 and 4.3, it can be observed that total production sharply decreases from stochastic demand 1 to 2. This indicates that different demand changes at level 2 will dramatically impact the total output of a manufacturing system. In general, stochastic demand will give a different amount of production if the demand is too stochastic.

In addition, comparing the average utilization for all machines, as shown in Figures 4.4 and 4.5, one may be concluded that the SD=1 has the benefit of performing uniformly regardless of the selected scheduling rules, which may be beneficial in the system, especially to the product production results.

Hence, a system with stochastic demand with the same pattern for each part performs better. This will show that the FMS system with the same stochastic demand pattern (SD=1) performs better than the system with the varied stochastic demand pattern (SD=2).

4.5 The effect of the Number of AGV (NG)

The different numbers of AGVs influence AGV utilization and average waiting time. Therefore, the effect of changing the number of AGVs on system performance is evaluated, and two levels of the number of AGVs are considered, namely NG=1 and NG=2. Based on figures 4.6 and 4.7 shows the reduction in average waiting time when NG=2 is considered. And the effect of this decreased waiting time will increase total production, as shown in figures 4.2 and 4.3. This result can improve system performance by reducing the average waiting time.

Next, the effect of using 1AGV still shows good performance to AGV utilization. AGV utilization for all three scheduling rules is good and does not affect total production and average waiting time. This is because both performance measures on 1AGV still show good performance.

However, there is no denying that the increase in total production if 2AGV is considered also shows a relatively positive effect even though at the SD=2 level, the increase in AGV is insignificant. However, 2AGV still has a good impact on the system.

Thus, using NG=1 and NG=2 shows good performance and benefits for all four performance measures. It is clear that changing the number of AGVs also affects FMS performance.

4.6 The effect of Sequencing Rules (SR)

Sequencing rules significantly impact the performance of total production, as shown in figure 4.2. In this regard, SPT shows the most significant effect compared to FCFS and LCFS. Whereas figure 4.6 shows the minimum average waiting time shown on SPT. Therefore, it is clear that the selection of scheduling rules has importance on the performance measure. This matter is also explained (Sharma, 2012), where most cases of SPT show the best performance in real-time.

In addition, the effect of this sequencing rule has an importance on the performance measure where the SPT rule has a shorter manufacturing time; this has advantages and significance to the work that leads to high total production.

Subsequently, total production is indirectly related to average parts waiting time and average AGV utilization. It has been found that the LCFS that schedules parts using the LCFS rule provides the most value for AGV utilization and produces the least value for total production. This is because when the part has to wait for a long time, as in the case of the LCFS rule, where the part that arrives early has to wait for a long time in the input buffer.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This chapter comprises the summary of the study related to the method used, the solution and the data obtained from this study as references for other researchers in the future. Moreover, the recommendations are also included and stated in this section, and additional further improvements from the researcher are proposed.

5.1 Conclusion

The unique contribution of this study is its methodology which summarizes how different factors influence FMS system performance under stochastic demand. Therefore, this study aims to evaluate the effect of different combinations of factor levels on FMS performance. This study has three objectives, and all of them have been achieved by conducting 12 experiments with the help of Tecnomatix Simulation, as mentioned in the previous chapter.

The first objective, to investigate the key factors affecting the performance of the FMS, has been achieved through several methods consisting of the help of secondary sources where the literature study is very important in the data collection session. In this work, some literature is used as a reference and applied in this study where the data collected has been listed as a key factor to be investigated. Among the data collected are the FMS model's physical configuration, processing time, scheduling rules, and the number of AGVs. Meanwhile, stochastic demand, which is the main factor in the problem statement of this study, has been determined by choosing an exponential distribution with λ=0.5, λ=1.0 λ=1.5, λ=2.0.

Next, the second objective is to simulate the FMS model with the help of discrete event simulation. To design the physical configuration simulation of this FMS model, Discrete event simulation has been applied in this study. A simulation model has been developed to simulate the real FMS discussed in the first objective using the Tecnomatix Simulation simulation package.

Finally, the third objective is to evaluate the effect of different combinations of factor levels on the FMS performance. In this study, the investigation for the evaluation of the four performance measures against the factor level combination was carried out by a simulation experiment. Two different FMS stochastic demand levels have been modelled and simulated in Tecnomatix simulation software. By using the proposed model, it has been clearly shown that the level of stochastic demand is not the only way to improve system performance. Finally, it is observed that the scheduling rule SPT has been adopted in producing the best performance compared to FCFS and LCFS used in both levels of stochastic demand FMS.

5.2 Recommendations

There are some limitations in this study, which can be taken up by other researchers. Among them is the physical configuration model proposed; this model is limited to loop layout only. It only functioned with parts being moved in a forward flow around the loop. Although the work has been done, further work can be suggested with other FMS layouts, such as line, ladder, and open field can also be included in future work.

Next, the main limitation of this study is that this model is only simulated by taking eight hours of working time, which is equivalent to 1 shift according to the actual industry. Therefore, this limit can be changed in the mind of future work by considering a longer simulation time to 2 shifts, which is 16 hours or three shifts, which are 24 hours.

Finally, AGVs that experience problems such as traffic, violations, or conflicts are avoided by the hardware and are not considered, as explained in chapter 3, have been used for model development in this incident. Therefore, considering the AGVs and machine breakdowns where in the event of an AGV/machine breakdown, the AGV will be stranded on the route, or the machining process will be stopped, and it will block all AGVs on duty. Considering such criteria in the model to observe the breakdowns will improve the model's real resemblance.

5.3 Sustainable Design and Development

Sustainability has three main pillars: economy, environment, and social. These three pillars are referred to as people, planets and profits.

A simulation is the imitation of the operation of a real-world process or system over time. Tecnomatix simulation is a discrete event simulation package used for modelling and simulation for this study. Using simulation, which is also digital manufacturing, has helped researchers automate their production processes by assisting users in creating virtual models of products and equipment to simulate. Therefore, this simulation successfully identifies potential process problems before they occur without providing a physical prototype. The advantages of using digital manufacturing in this studies are that it can save time and money and, at the same time, it is environmentally friendly. This is because it reduces environmental issues that often occurring when prototype preparation is carried out.

Afterwards, human creativity, linked to the desire to improve the standard of living permanently, is the basis for the development of society. Therefore, introducing Tecnomatix Simulator will provide more job opportunities to many people. When researchers have creative skills in the field of simulation, this will simultaneously improve social skills such as, for example, communication between design and production teams. This matter indirectly helps to increase the profit of a company.

Tecnomatix Simulator is also an essential and valuable tool for any manufacturer who wants to stay competitive in today's market. This is because this platform is very flexible and can be easily adapted to changing market methods as it increases productivity by a large industrial company. Therefore, this Tecnomatix cannot be taken lightly because industrial producers use this platform to be sustainable and gain profit while stimulating the economy.

5.4 Complexity

There are some difficulties faced by the researcher after completing this study. First of all, achieving objective 2 requires skills in simulating the FMS model with the help of Tecnomatix Simulation. This is because the creation of this FMS model is challenging. After all, mistakes often occur in the programming or simulation rules of the model. Next, time may be needed to understand the results of developing this FMS model because this simulation is too complex and causes people's reactions to this model not to be realistic or reliable.

Furthermore, there are 12 experiments have been involved in this project. Each of these experiments was simulated by taking eight hours of work and ten replications were made for each experiment to measure system performance. Therefore, it becomes a complication and a problem for researchers because it takes a very long time to interpret the simulation results and extract them into a bar graph, as in chapter 4.

5.5 Life Long Learning and Basic Entrepreneurship

Fortunately, the Physical Configuration of the FMS built with the help of Tecnomatix Simulator can be continuously improved in improving the proposed model's quality and increasing productivity for this study. Therefore, persistent efforts are required by increasing the simulation time to work optimally.

Next, using Tecnomatix sharpens the researcher's skills in producing models that resemble real environment models. This is one form of an effective learning exercise to gain more knowledge about digitizing manufacturing and turn researchers' innovative ideas into transformative products.

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