

DEVELOPMENT OF A SIMULATION AIDED RECONFIGURE TOOL FOR HYBRID ASSEMBLY SYSTEM



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DECLARATION

I hereby, declared this report entitled "Development of A Simulation Aided Reconfigure Tool for Hybrid Assembly System" is the results of my own research except as cited in reference.

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APPROVAL

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



ABSTRAK

Sistem pemasangan hibrid adalah kaedah yang bertuju kepada produk-produk yang berbeza yang ada di pasaran. Sistem ini digunakan untuk melengkapkan proses pemasangan di kedua-dua stesen iaitu stesen pemasangan manual dan juga automatik. Dalam industri semasa, susunan peralatan manual kebanyakannya dikendalikan oleh operator. Para operator hanya bergantung penuh pada bakat dan kemahiran mereka untuk memasang komponen dan sub-pemasangan untuk menghasilkan produk yang lengkap. Masalah ini dapat ditangani dengan kaedah konfigurasi semula untuk sistem pemasangan secara hibrid dengan bantuan simulasi serta membuat penilaian terhadap keberkesanan kaedah konfigurasi semula dengan mengurangkan peratusan penyekatan sebelum proses kesesakan. Selaras dengan objektif penyelidikan ini, model simulasi ini telah dibangunkan dengan bantuan Tecnomatix Plant Simulation, yang merupakan sebuah perisian yang menyerupai sistem sebenar sesebuah proses pemasangan yang nyata. Pemahaman yang lebih mendalam mengenai komponen sistem pemasangan, analisis komponen dan kajian terhadap masa pemprosesan produk telah dijalankan. Seterusnya, konfigurasi semula struktur proses pemasangan dijalankan setelah analisis tersebut dipertimbangkan. Proses konfigurasi semula struktur dicapai dengan menggunakan model simulasi, dimana melibatkan penyusunan semula urutan proses yang berbeza dan yang mampu berjaya. Akhir sekali, susun atur konfigurasi semula yang sesuai berjaya ditemui untuk setiap produk dan susun atur yang dikonfigurasikan semula dipilih dengan mempertimbangkan peratusan penyekatan minimum sebelum proses kesesakan dan peratusan kerja tertinggi dalam sesebuah sistem pemprosesan.

ABSTRACT

A hybrid assembly system is a method aimed toward the product variation present in the market. This system uses both manual and automated assembly stations to complete the assembly process. In the current industries manual equipment arrangement is mostly conducted by human operators who use their inherent talent, skill and judgment to assemble the components and subassemblies into a finished product. In order to solve this issue, this study aims to develop a simulation-aided reconfigure tool for hybrid assembly systems and to evaluate the effectiveness of reconfigurable tools by minimizing the blocking percentage before the bottleneck process. In accordance with the objectives of this research, simulation models were developed with the help of Tecnomatix Plant Simulation, a software that simulates the actual system in a computer environment. In addition, to gain a better understanding of the assembly system components, part analyses and time studies of product and process processing times were conducted. Then, a structural reconfiguration takes place while the analysis is considered. The structural reconfiguration was achieved by utilizing a simulation model, which involved rearranging the many process sequences that could take place. Finally, a suitable reconfigured layout was discovered for each product. The reconfigured layouts are chosen by considering the minimum blocking percentage before the bottleneck process and the highest working percentage.

DEDICATION

Only

my beloved father, Rajandren

WELAYS my appreciated mother, Nirmala

my adored sisters, Uthaya Chandrika, Latha Raj, Lalitha Raj and

my supportive fiance, Viswa Ram

for giving me moral support, encouragement and also understanding.

اونيۆمرسيتي تيڪنيڪل مليسيا ملاك

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LIST OF ABBREVIATIONS



CHAPTER 1 INTRODUCTION

1.1 Research Background

Customers' requirements are becoming more variable and customized as time goes on (Koren *et al.*, 2018). Thanks to the advancement of computer-aided manufacturing simulation, customized items can be made at an affordable price, moving the manufacturing paradigm away from large-scale customization and toward large-scale individualization (Ashima *et al.*, 2021). One of the most significant challenges for mass individualization is the large number of different modules combined into a complex product (Koren *et al.*, 2015a). As a result, the manufacturing system must be able to manufacture a huge number of unique models, and it must be a Reconfigurable Assembly System (RAS) (Cohen *et al.*, 2017).

Assembly is a procedure that brings subassemblies and components together to construct a finished product. Assembly lines in which products are moved from one station to another are typical of arranging stations in various industries, including manufacturing (Bi *et al.*, 2008). The finished product takes shape gradually, beginning with a single component known as the base section. The remaining components are assembled at various stages throughout the process (Pierre De Lit, 2003). The reconfigurable tools for assembly systems are commonly manual processes based on human experience or logic, which is still the most common and traditional assembling method for current industries (Ali-Qureshi and ElMaraghy, 2014a).

In assembly, the RAS concept is a variation of the Reconfigurable Manufacturing System (RMS) concept (Huettemann *et al.*, 2016). RAS should be scalable to meet greater demand variations and it should be convertible to manage multiple variants and new items (Koren *et al.*, 2015b). RAS design concerns involve a complex interaction between different machines, line balance and production schedule. In addition, new metrics are required to quantitatively evaluate the complexity of the system configuration and the product's features and functions (Hu *et al.*, 2011a). A new system layout for the present RAS should be developed to improve the system's efficiency while also lowering operating costs. Depending on many product variants, different combinations of components should be installed for the sequence the process takes (Antzoulatos *et al.*, 2017). Several stations serve multiple product varieties in the systems and all of them will share it.

Every simulation programme is now employed almost in manufacturing industries (Yolanda Carson and Maria, 2015). Programs that simulate manufacturing processes are used to test the consequences of various model decisions and evaluate production capabilities, duration of operations, and other manufacturing characteristics (Roci *et al.*, 2022). Additionally, the simulation eliminate the chance of introducing a change into a process that would damage the overall system (Václav *et al.*, 2017a). One of the most important goals of the simulation is to represent the real system virtually (Olexová and Gajdoš, 2016). Therefore, Discrete Event Simulation (DES) models for each of the reconfiguration scenarios were developed to evaluate the effectiveness of the reconfiguration tools and carry out the last steps of the decision-making logic, which were to be decided among the reconfiguration solutions (Michalos *et al.*, 2016).

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1.2 Problem Statement

It is common for customer requirements to evolve quickly in today's production environment. To compete in today's market, most manufacturing companies must offer many product variations with short lead times. Therefore RAS are getting more complex and facing more challenges (Orta and Ruiz, 2014a). Manufactured components and subassemblies are assembled to make a unit of a product. In the case of complex products in terms of the number of parts, Flexible Assembly Systems (FAS) are also designed as Manual Flexible Assembly Systems (Cohen *et al.*, 2017b). Manual equipment arrangement is mostly conducted by human operators who use their inherent talent, skill and judgment to assemble the components and subassemblies into a finished product (Ali-Qureshi and ElMaraghy, 2014b). These assembly systems generally involve thousands of different pieces with various qualities. For example, employees must handle dimensions, weight, shape and frequency of use during assembly operations for every different piece to ensure that the system functions properly. In a manual assembly system, the quality of the parts has considerable impact on worker performance, productivity (Neumann *et al.*, 2010).

1.3 Objective

The objectives are as follows:

- I) To develop a simulation aided reconfigure tool for hybrid assembly system
- II) To evaluate the effectiveness of reconfigurable tools by minimizing the blocking percentage before the bottleneck process.
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The scopes of research are as follows: IKAL MALAYSIA MELAKA

- DES technology will be used to model and reconfigure tools depending on many product variants with different combinations of components for the sequence the process takes in the assembly system at the Teaching Factory.
- II) Reconfiguration scenarios were developed to evaluate the effectiveness of the reconfiguration tools and carry out the last steps of the decision-making logic, which were to be decided among the reconfiguration solutions.

1.5 Important of study

A huge amount of money and other resources are being spent on producing products that require different tools and configurations throughout the assembly line. So each tool is being changed or replaced by the workers according to the production requirements; the whole assembly line needs to be paused for a certain period. When reconfigurable assembly tools are present in that assembly line, the worker performance and productivity of products will increase; thus, human errors can be totally prevented. The RAS will take over the reconfiguration of tools while the assembly line will continue without being held. Moreover, this research can ease the workers or labour and management by making the assembly process more effective without errors. Eventually, it can prevent resource wastage and it will be more sustainable. In addition, this study can provide a permanent solution for the industry towards spending resources to produce products that need different tools and configurations on an assembly line.



CHAPTER 2

LITERATURE REVIEW

2.1 Simulation

Simulation is an experimental method that replaces a computer model for an existing system in completing the experiment (Vaclav *et al.*, 2019). This simulation model can carry out several experiments, assess how well the system works, make adjustments to how the system is designed, and then apply those changes to the actual system. There is no alternative approach or theory that would enable people to conduct experiments with a complicated system before it is placed into action. No other method would make it possible to perform complex processes on the computer as a simulation that takes weeks or months when it is done manually. It is the preferred tool for decision-making in many different departments in a company (Orta and Ruiz, 2014b). The use of simulation has the benefit of being applicable virtually everywhere, besides the complexity of the system being modelled. Despite this, simulation analysis in companies located in underdeveloped countries is incredibly rare. Since simulation can simulate and model any business process, whether physical, informational, or decisional, it can assist us in various areas, including design, management, decision making, and production system (Mourtzis, 2020).

2.1.1 Discrete event simulation

DES is the process of developing a real system model and then using it to experiment, which is to better understand the system's behaviour or evaluate its performance. The experiment with the actual system and the experiment with a model of actual the stage can better understand the system (Babulak, E., and Wang, 2010a). Figure 2.1 shows the ways to study a system.



different working conditions

VII) Simulation

- Performance of a model in terms of time or space, which assists in the evaluation of the process of an existing system

2.1.1.1 Advantages of (DES) in assembly system

Implementing DES in assembly systems is beneficial because models can duplicate an existing system's operation and propose a new system that modifies the existing design (Detty and Yingling, 2000). According to Johansson (2014) DES is a tool to enhance the design of flexible assembly systems and the author's approach was focused on optimising the simulation process.

2.1.1.2 Simulation software

Tecnomatix Plant Simulation is an object-oriented 3D tool used to simulate discrete events. It enables users to design realistic digital logistic systems, thus allowing users to evaluate the features of the systems and optimise their performance. The programme is produced by the German company Siemens PLM Software, the established software supplier for Product Life cycle Management (PLM) and Manufacturing Operations Management (MOM). Production companies may find an efficient way to achieve their digital enterprises and apply innovations using the solutions that Siemens offers as part of its Smart Innovation Portfolio. Using digital models, it is possible to conduct experiments and test "what if" scenarios without disrupting the work of production systems or, in the case of the planning process, long before their assembly. This is made possible by the fact that digital models make it possible to perform experiments and test "what if" scenarios (Siemens. Plant Simulation, 2016).

2.1.1.3 Procedure of simulation

Simulation modelling aims to help the person who will ultimately be responsible for finding a solution to a problem. As a result, to become an effective simulation modeller, one needs to combine an effective problem-solving strategy with effective software engineering practices. The following procedure was developed based on the steps proposed by Shannon (1998a) in Figure 2.2.



Figure 2.2: Procedure of simulation (Shannon, 1998b).

As outlined by Shannon (1998c), the simulation process is subdivided into thirteen distinct steps. On the other hand, the VDI 3633 guideline from 2007 recommends the following eight steps: (1) Formulation of problems, (2) test of simulation, (3) formulation of targets, (4) data collection and data analysis, (5) modelling, (6) execution of simulation runs, (7) result in analysis and result interpretation, and (8) documentation. In order to differentiate a comparison and a better level of understanding of both strategies are compared in Table 2.1.

(Shannon, 1998d)	(VDI 3633, 2007)
1) Problem definition	1) Formulation of problems
Clearly identifying the objectives of the	-
study	
2) Project planning	2) Test of simulation worthiness
Ensure that have sufficient and suitable	
resources in terms of employees,	
management support, hardware and	
software resources in order to complete the	
task	
3) System definition	
Determining the limits and constraints that	
will be applied in the process of creating	
the system (or process), as well as	
conducting research into how the system	
operates.	
4) Conceptual Model Formulation	3) Formulation of targets
Creating a conceptual model of the system	
either graphically or using pseudo-code to	
specify the components, descriptive	
variables, and interactions (logic) that	
build up the system.	
5) Preliminary Experimental Design	
Selecting the effectiveness measurements	
to apply, the factors to manipulate, and the	
amounts of those factors to study	
6) Input Data Preparation	4) Data collection and data analysis
Identifying and collecting the model's input	اويوم سيى ي
data	10
7) Model Translation SITI TEKNIKAL	5) Modelling MELAKA
Creating a simulation model.	
8) Verification	
Confirming the model works as intended	
(debugging)	
9) Validation The model's extract metabolis the real	
The model's output matches the real	
systems.	
10) Final Experimental Design	
Designing an experiment that will provide	
appropriate data and determine now to	
11) Europimontation	() Execution of simulations mung
Simulating to create data and conduct	b) Execution of simulations runs
songitivity analysis	
12) A nolysis and Interpretation	7) Desult analysis and result
Simulation data inferences	interpretation
13) Implementation and Decompositation	8) Documontation
13) implementation and Documentation	o) Documentation

Table 2.1: Comparison of simulation procedure.

Reporting outcomes, analyzing results,	
recording findings, and documenting model	
use.	

2.2 Assembly System

An assembly system is a working arrangement that combines and joins individual components to form a unit that can be further integrated with other components to create a finished product. These individual components are combined and assembled to form a unit during the assembly process. An illustration of the many components that make up an assembly system is shown in Figure 2.3. The method of assembly that a product will undergo will be determined by such a specific product which is going to be manufactured, the dimensions of the product, and the number of components that will make up the product. Manual assembly systems, automated assembly systems, and hybrid assembly systems are the three primary categories. Manual assembly systems are the most common type of assembly system (Mikell P. Groove, 2008a).



Figure 2.3: Basic assembly system of representation (Butala, P. and Mpofu, 2015).

2.2.1 Classification of assembly system

Manual and automated assembly lines are the two primary categories used to classify assembly systems. In more recent years, hybrid assembly systems such as flexible assembly systems, reconfigurable assembly systems, adaptable assembly systems, and agile assembly systems have been created to deal with the variety of products available.

2.2.1.1 Manual assembly system

In this particular scenario, the assembly system is made up of some stations, each of which is handled by a worker responsible for completing a specific pre-assembly job. The worker has a high level of specialisation and after the worker accomplishes the task, the next person in line takes over and completes the previous worker's task. This continues until either a product with a semi-finished or finished assembly is produced (Hu *et al.*, 2011b).

2.2.1.2 Automated assembly system

In an automated assembly system, the individual components are moved from one station to the next by a material handling mechanism that is also automated. The assembly work is carried out by an automated machine consisting of a fixture and an assembly mechanism. Depending on the size of the final product, automated assembly systems may also take the shape of a single assembly station. This configuration brings all component pieces together at a single location. The following are more categories of automated assembly systems: The in-line assembly machine utilises primarily a synchronous or an asynchronous transfer mechanism to move foundational base parts from one workstation to the next in the assembly process (Mikell P. Groove, 2008b).

- The dial-type machine is circular, and the stations are placed around the circle's edge. Subassemblies and parts flow in a star-like pattern through the machine. The machine can function with synchronous or intermittent motion in its normal state.
- II) The carousel assembly is made up of a combination of in-line machines and dialtype machines.

III) The single-station assembly machine has a base part on which all of the operations of adding parts or subcomponents take place. The final part is the one that is moved outward from the station, while the rest of the parts are moved inward to the station.

2.2.1.3 Hybrid assembly system

A hybrid assembly system is a method aimed toward the product variation present in the market. This method uses both manual and automated assembly stations to complete the assembly process. One other component of hybrid systems is the interaction between humans and robots. Examples of these types of assemblies include flexible, agile, reconfigurable, and adaptive (Pulikottil *et al.*, 2021).

2.2.2 A hybrid assembly strategy

The traditional manual assembly method is based on conveyor lines that only handle one product at a time. This indicates that the strategy should require only a small number of modifications to the existing manual assembly lines while introducing new products. In addition, the ratio of manual stations compared to robot stations in the hybrid system needs to be kept at a relatively high level. The technique that has been described is designed so that, in most situations, there will only be one robot station. It can carry out the necessary operations while simultaneously providing decisions and various assembly jobs.

It is possible for the work cycle of a robot station to change depending on the workpiece being processed and it is assumed the station is sufficiently advanced. In this context, the robot can be considered an intelligent line operator because it can make quick decisions that are useful to identify the arriving workpiece, it's processing by the specified assembly plan, and returning it to the appropriate downstream line. The robot station is expected to have the required processing and part-handling equipment to service the required variety of workpieces (Wu *et al.*, 1996).

2.3 Reconfiguration

The idea of reconfiguration came into existence to achieve flexibility (Tolio, 2009a). It developed to achieve economic benefits by decreasing excess capacity or functionality and increasing reusability through the provision of customized flexibility on demand in a short time (El Maraghy, 2006). However, reconfiguration will need to be designed to successfully implement the changes, and there will be costs associated with installation and operation (Tolio, 2009b). Reconfiguration is characterized according to criteria such as scalability, convertibility, modularity, integrability, diagnosability, automatability, customization, and mobility (Koren *et al.*, 2003). Scalability refers to the ability to increase or decrease the size of a system. Reconfiguration refers to modifications made to the structure, hardware, and software to adjust capacity and functionality rapidly. Depending on the characteristics of the system's reconfiguration, it may need to adjust its structure and configuration. It can provide flexibility that is customized or focused.

2.3.1 Application of reconfiguration

Reconfigurations have been made in almost so many manufacturing companies. Over many years, research councils in various regions around the world have funded various projects that have brought a significant amount of attention to reconfigurable manufacturing. The applications of reconfigurations are discussed in the following subtopics (Bortolini *et al.*, 2018).

2.3.1.1 Reconfigurable manufacturing system

RMS and its components over time for various individualized products that are frequently required in small quantities and with a very short delivery lead time. Thus, it is necessary to design an effective quality measure to identify the capabilities of the production system and its other properties. When attempting to test the performance of RMS, it is important to consider the system's various characteristics, including its modularity, scalability, convertibility, and diagnosability (Gumasta *et al.*, 2011).

There has been a massive amount of effort put into modelling RMS. The primary objective of modelling the RMS strategy is to handle the system's changing requirements for functionality and capacity during the planning cycle, which takes more time horizons. Most RMS models consider a reduction in cost and the amount of effort required for reconfiguration to be a goal. Many researchers have approached the issue in two stages. During the first stage, solutions are recorded for each stage based on cost as the criterion. In the following stage, the best choices are selected from the previously recorded solution for each time horizon based on the aim to reduce the number of reconfigurations that are required at various phases (Deif and Elmaraghy, 2006).

A new paradigm in manufacturing is called RMS, which is developed to quickly adjust production capacity and functionality in response to new circumstances. This is achieved through the rearrangement or replacement of the system's components. These new systems deliver the same functionality when needed (Mehrabi *et al.*, 2000). Hence, an RMS is designed to be reconfigured so that it can process a family of parts, adapting to unexpected changes in the product design and the processing requirements. The process of creating product variations by combining common parts is referred to as configuration. Configuration allows for a large reduction in the number of different parts that need to be manufactured for a product family while still allowing for enough variety to be achieved through the combination of different configurations, as shown in Figure 2.4. Economies of scale, enhanced feasibility of product or component change, more product variety, and shorter lead time are some of the benefits of configurable products (Yigit and Allahverdi, 2003).



Figure 2.4: Machine configuration at different stages (Mittal and Jain, 2014)

2.3.1.2 Reconfigurable machine tools

The fundamental ideas behind machine tools are similar to those behind manufacturing systems. The attributes of being dedicated, flexible, and reconfigurable are all shared by machine tools. The specialized piece of equipment known as the dedicated machine tool contains various tool (Sethi, 2017). Because of this type of machine tool's suitability with low-variant products manufactured in huge volumes, the company can achieve a low cost per unit of the final product. A computer numerically controlled (CNC) machine with flexible functionality is one example of a flexible machine tool that can be used to produce a high number of variants with a low volume (Fowkes and Baber, 1984). CNCs are created before the exact machining process is specified, and it has very flexible functionality, even more than is required to cover the machining process that unexpectedly occurs. As a result of its high flexibility, CNCs are expensive and have limited throughput. The reconfigurable machine tool fills the gap between these two different categories of machine tools. Figure 2.5 indicates this type of machine can produce many variants at a high rate, allowing for cost-effective, speedy production. Reconfigurable Machine Tools (RMTs) are more cost-effective than CNCs because "the workers use exactly what's needed when it's needed" Also, it's adaptable to new product structures based on client demand, which is impossible for dedicated machine tools and expensive CNCs.







According to Figure 2.6, single-part high-volume production uses dedicated machine tools. This machine's structure is fixed, yet its throughput is high and economical at total capacity. Reconfigurable machine tools can be utilized for giant volumes of different products and have customizable structures.



Figure 2.6: Cost vs. production volume of different classes of machine tools (Aboufazeli, 2011b)

2.3.1.3 Reconfigurable conveyor system

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The engineer of a reconfigurable conveyor system can rearrange a wide variety of modules into a different layout with no additional cost and without changing the behaviours of the conveyor in the process. This eliminates the need to buy an entirely new conveyor. It is possible to rearrange its components on an ongoing basis (Jill Batka, 2011a). A genuinely reconfigurable conveyor is similar to LEGOs, enabling the highest possible level of reconfigurability. In practice, it is impossible to screw up the reconfigurable systems. Modifications to the configuration of a reconfigurable conveyor can be accomplished with relative ease by simply exchanging the modules, which requires just loosening a few bolts and nuts and snapping in or out of the modules (Jill Bakta, 2011b). A physical and logical conveyor unit is required for a finished reconfigurable conveyor system to be considered complete. The physical conveyor unit refers to the hardware of the conveyor, which includes things like the components of the conveyor, the different types of conveyors, and the design layout of the system. On the other hand, the logical conveyor unit refers to the controller that directs the movement of the transport item along the conveyor. A number of the actual conveyor units' physical counterparts belong to the logical conveyor unit (Martin Wentzel and Bengt Mueck, 2012).

In the manufacturing industry, a few configurations of conveyor systems are used. To cut down on the overall distance travelled, the total cost of material handling, and the system's cycle time, each manufacturing industry will create its unique system layout (Lasrado and Nazzal, 2011a). Various types of layouts will each have their own set of characteristics. The layout of a conveyor system can be one of several different forms, such as a single line pattern, an L-shape layout, a U-shape layout, or a closed-loop structure as shown in Figure 2.7. A single line arrangement refers to a linear transfer system with the flow in a straight line. The layout is a clearly defined processing sequence that is the same for all work units. The flow of work proceeds from left to right via identical workstations. The U-shape and the L-shape layouts are examples of opened loop layouts; the only difference is the shape. The product will move along the layout while adhering to its contours. After being unloaded at the last station in the series, the product can be recirculated back to the first station in the sequence due to a closed loop layout.



Figure 2.7: Example of assembly layouts (Lasrado and Nazzal, 2011b)

2.4 Tools

Tools are not merely just fixtures, jigs or materials. It brings various types of definitions. According to Oxford University Press (2022), a thing that facilitates the work or accomplishes a goal is a tool. There are many meanings for a tool. For example, sending out a newsletter by email can be a very efficient communication tool. Moreover, potential users in the industrial sector believe that DES is an expert tool that requires a significant amount of both time and cost to implement (Banks *et al.*, 2005). Despite these unfavourable attitudes, DES must be regarded as one of the most effective tools for making decisions because of its capacity to capture the dynamic complexity of creating a system. DES is also a versatile tool and the potential areas of application in the manufacturing business include various examples, such as operating planning assistance, system analysis, and system design.

2.5 Knowledge based method of reconfiguring tools in current industry

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It is not a simple work to design a product using the components of an assembly system, and even though there is a limited number of components and, as a result of this fact, a finite number of design solutions, there is a lack of advanced helping tools for a designer. The number of system components is extremely high, and there is a regular release of brand new components on the market. Despite this, designers are helped in the beginning by catalogues of ready-made parametric components and comprehensive guidelines for selecting certain components. These catalogues enhance design modelling in Computer-Aided Design (CAD) systems. The detailed guidelines on selecting particular complex components available in catalogues simplify the everyday tasks of the designing process. The wide use of such systems of fast assembly makes it possible to use more advanced computer design techniques to create products that are composed of such components. To accomplish this goal, methodologies founded on KBE (Knowledge-Based Engineering) have been proposed for developing products consisting of assembly system components. Although it is possible to use knowledge-based methods when designing an object, doing so is most profitable when applied to the design of repetitive products (Hopgood, 2001). This is because the formal identification of designing processes and knowledge space takes significant time. It is particularly helpful when Skarka (2010) the following conditions are met:

- I) Routine designing procedures are used
- II) The target form of a designer product is well known
- III) A given class of objects constitutes the subject of designing,
- IV) It is possible to identify and record knowledge concerning the designing process.

It is important to highlight the application of generative models as knowledge-based techniques since it makes it possible to use CAD environments and directly CAD models for integrating knowledge gained from the design process. As a result, a generative model is an extension of a parametric CAD model. Still, it also builds a knowledge base that relies on the building aspects represented by CAD model features. Towards this point, the designer has decided on the designed product features in the CAD model by drawing on his prior experience, which he gained from the outside as well as extra computer tools, such as computer-aided engineering (CAE). Nevertheless, with the generative model, this knowledge is integrated into the same CAD model, and it is this model independently maintains the design features. In contrast to a record of a single product instance, a generative model is a record of a certain class of product that was formed based on recognised knowledge space, also known as a generic model (Oldham et al., 1998). It is necessary to record these procedures formally, identify these relations and redefine the way of integration in the CAD model, basing it on given scenarios regarding the degree of advanced level and scope of generative model operation. This is necessary because the generative model reflects detailed relations between design features and functional features, which up until now have been identified based on designing procedures.

2.6 State-of-the-art research

The previous researches have done several studies on reconfigurations, subassembly identifications and development of virtual assembly using simulation. Table 2.2 shows the research studies that have been done by other researches related to this study.

Num	Title	Author/Year	Results
1.	Reconfigure	(Landers et al.,	In this study, the systematic design tools that have just
	Machine Tools	2001)	recently been developed for RMTs are analysed, and
	(RMT)		three different examples are given to illustrate how
			RMTs differ from more conventional types of machine
			tools. The objective of this study is to illustrate the
			characteristics of RMTs and the differences between
			RMTs and other types of machine tools. The authors
			had developed some method which are task matrix,
			graph theory and Homogeneous Transformation Matrix
			(HTM).
2.	Subassembly	(Wang and Liu,	In this study, the subassembly identification approach
	identification for	2013a)	is proposed and researched with the aim of simplifying
	assembly		the assembly sequence planning process for more
	sequence	2	complicated products. The objectives are to break down
	planning	Ş	a complicated assembly into a predetermined number of
	2		smaller subassemblies and to decrease the difficulty of
	-		assembly sequence planning of complex products. The
	50		researcher have developed some method which are
			graph theory, case-based reasoning and recursive.
3.	Development of	(Mohamad <i>et al.</i> ,	The paper presented the development of virtual
	virtual assembly	2012)	assembly layout model with modelling languages
	layout	- A alu	approach. This research also explores the flexibility of
	with modelling		the model configurations through the development
	languages		process of database for storing and representing the
	approach and	ITI TEKNIK/	virtual model. The objectives of the research are
	Simulation using		therefore to obtain a basic understanding on how these
	Delmia ¹ M		modelling languages are used to develop virtual model,
	QUESI®		OUEST® and to develop a database for share store and
			goes i to develop a database for share, store and
	A Pragmatic	(Lin at al 2018)	In this paper, the system has been successfully applied
т.	System to	(End <i>et al.</i> , 2010)	all of the methods to the virtual assembly for a certain
	Support Virtual		type of integrated transmission system of military
	Assembly		armored vehicle. The method used is method of graph
	for Military		theory The objective is to provide a prediction for the
	Armored Vehicle		two designs in design stage of integrated transmission
	Integrated		system, a pragmatic system to support virtual assembly
	Transmission		for military armored vehicle integrated transmission
	System in the		system.
	Virtual		
	Environment		
5.	Assembly	(Jiang et al.,	This paper formulates a concurrent optimization
	System	2019)	problem to design the assembly system configuration
	Configuration	,	by jointly determining the subassembly planning and
	Design for		task-station assignments considering uncertain product
	Reconfigurability		evolution. The author had developed some methods
	under Uncertain		which are assembly hierarchy and Evolutionary
	Production		Algorithm (EA). This study's aim to formulates a

Table 2.2: State of Art Research
	Evolution		concurrent optimization problem to design the assembly system configuration by jointly determining the subassembly planning and task-station assignments considering uncertain product evolution.
6.	Simulation as a support tool in assembly systems planning	(Václav <i>et al.</i> , 2017b)	This paper deals with assumption that simulation is the only reliable method for manufacturing and assembly systems profiling. In this article are mentioned theoretical base of topic and example as a case study. For case study was used software Tecnomatix plant simulation from company SIEMENS.



CHAPTER 3 METHODOLOGY

There are twelve steps in this process flow chart illustrated in figure 3.1. The overall flow chart consists of two sections which are developed and evaluated. These two sections will contribute to the discussion of methodology where a series of methods will be used to identify this study's needs.

- I) To develop a simulation aided reconfigure tool for hybrid assembly system.
- II) To evaluate the effectiveness of reconfigurable tools by minimizing the blocking percentage before the bottleneck process.

The activities are based on the simulation procedure approaches in subchapter two; thus, problem formulation (3.1) and project planning (3.2) contributed to the project's initialization. All other activities have been assigned to the objectives of this project. In order to develop a simulation model for the Production House at Teaching Factory, there has been a need for model conceptualization (3.3), part analysis (3.4), structural configuration (3.5) and development of tools (3.6). The objective II analysis has been conducted using the model translation (3.7), verification (3.8), validation (3.9), simulation run (3.10), evaluate the effectiveness of tools (3.11) and documentation and report (3.12). All activities are outlined explicitly and in chronological order according to the project flowchart in the following subchapters.



Figure 3.1: Process flow of project.

3.1 Define Problem

To compete in today's market, most manufacturing companies must offer many product variations with short lead times. Therefore RAS are getting more complex and facing more challenges. Components and subassemblies parts are assembled to make a unit of a product. Manual arrangement of equipment is mostly conducted by human operators who use their inherent talent, skill and judgment to assemble the components and subassemblies into a finished product. These assembly systems generally involve thousands of different pieces with various qualities. For example, employees must handle dimensions, weight, shape and frequency of use during assembly operations for every different piece to ensure that the system functions properly. In a manual assembly system, the quality of the parts has considerably impact worker performance, productivity. Currently, the hybrid assembly system in the Production House at Teaching Factory is used for packaging some products. Reconfigure tools appear to be a good choice to increase the worker performance and productivity required for product assembly which uses different types of tool configuration.

3.2 Project Planning

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This project has followed the final year project (FYP) guideline by University Technical Malaysia Melaka. In order to follow the requirements for the FYP, milestone planning was executed to organize the schedule for this project. Detailed Gantt charts for the overall project are illustrated in the Appendix A and B.

3.3 Model Conceptualization

The abstraction of a simulation model from the part of the real world it represents the real system is known as conceptual modelling. The need for a simplified representation of the real system in the simulation model is implied by abstraction. The key to successful conceptual modelling is to get the amount of simplification right or to abstract at the appropriate level. The hybrid assembly system in the production house is illustrated in the figure 3.2. There are six processes in the Production House at Teaching Factory which are base plate loading, plastic box loading, manual operator loading, plastic lid loading, pressing. The carriers will always be in the conveyor in order to carry the base plate and other components. The base plate will be placed on the carrier and moved to the next process which is the plastic box will be placed accurately on the base plate. Then, an operator loaded the product into the plastic box and moved to the next process which is the plastic lid will be placed accurately on the plastic lid to close the plastic box tightly. The conveyor acts as a transportation for the carrier to move from one process to another station.



Figure 3.2: Layout of assembly system at Teaching Factory

3.4 Part Analysis

According to the various contents of the part analysis descriptions, the assembly model information is separated into some categories which are geometry information, physics properties and management information, behaviour information including constraint information, hierarchical information assembly semantics and assembly process information and virtual environment information including assembly resources and scene information. There are eight products that are currently packaging in the Production House at Teaching Factory using the hybrid assembly system. All these products will undergo the same procedure to be packed and one example of the procedure is shown in the next subtopic. The products are as follows:



3.4.1 Packaging procedure for pink ball-headed AYSIA MELAKA

Process 1: Base plate loading

Figure 3.3 shows the base plate from the loader is gripped by the pneumatic actuator which is equipped with vacuum cups. Figure 3.4 indicates that the base plate is placed on the carrier which is on the conveyor.



Figure 3.3: Vacuum cups grip the base plate from the loader



Figure 3.4: Place the base plate on the carrier which is on the conveyor

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Process 2: Plastic box loading

Figure 3.5 shows the pneumatic actuator equipped with vacuum cups gripped the plastic box from the loader. Figure 3.6 indicates that the plastic box is placed accurately on the base plate which has the bottom part shape of the plastic box.



Figure 3.5: Vacuum cups grip the plastic box from the loader



Figure 3.6: Place the plastic box accurately on the base place

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Process 3: Manual operator loading

Figure 3.7 shows the products are loaded into the plastic box by an operator according to the requirements.



Figure 3.7: Loading the products into the box

Process 4: Plastic lid loading

Figure 3.8 shows the plastic lid from the loader is gripped by the pneumatic actuator which is equipped with vacuum cups. Figure 3.9 indicates that the plastic lid is placed accurately on the plastic box.



Figure 3.9: Place the plastic lid accurately on the plastic box

Process 5: Pressing

Figure 3.10 shows the presser pressed the plastic lid to close the plastic box tightly.



Figure 3.10: Pressing the plastic lid

3.4.2 Time study of the product's processing time

Table 3.1 shows the processing time for the manual operator when loading all the products that can be packed using a hybrid assembly system in the Production House. Processing Time for the manual operator when loading the products may change according to the product.

NO	PRODUCT	PROCESSING TIME (S)
1.	Pink ball-headed pin	37.0
2.	White ball-headed pin	37.0

Table 3.1: Processing time all the products



3.4.3 Time study of the process's processing time

Table 3.2 shows the processing time for each process in the production house. All the processing times are measured and recorded ten times in order to get the average time.

	MALI	YSIA									
	· ····	_	100 m								
		Ta	able 3.2: Pr	ocessing t	ime for eac	ch process		_			
Process 1:	Reading	1	2	3	4	5	6	7	8	9	10
Base Plate Loading	Process Start	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00
	Process Stop	0:17	0:19	0:20	0:24	0:22	0:20	0:18	0:19	0:22	0:19
	2	0:17	0:19	0:20	0:24	0:22	0:20	0:18	0:19	0:22	0:19
	ProcessingTime										
	0	Average: 21s									
	Malunda 15:53 in init										
Process 2:	ProcessStart	0:25	0:24	0:28	0:32	0:26	0:24	0:25	0:24	0:26	0:23
Plastic Box Loading	Process Stop	0:40	0:37	0:41	0:58	0:40	0:37	0:38	0:38	0:40	0:38
	UNIVER	0:15	0:13	0:13	0:26	0:14	0:13	0:13	0:14	0:14	0:15
	ProcessingTime	Average: 15s									





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3.4.4 Assembly liaison diagram



Figure 3.11: Example of an assembly liaison graph (Zhang et al., 2022)

The concept of showing the liaisons between pairs of pieces to describe the significant links between the various components of an assembly is known as a "liaison diagram." In the beginning, Bourjault (1988) comes up with the idea for this method, but De Fazio and Whitney (1987) are the ones who end up making it popular. A link or connection that has been formed between the components is known as a liaison. The formula for the liaison graph is LG = G(V,E), which stands for the graph of vertices and edges (connecting hyper arcs). Each vertex denotes an assembly part and each edge signifies a connection between other components. Figure 3.11 shows an example of an assembly liaison graph.

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3.4.5 Adjacency matrix

The adjacency matrix is figured out based on the information in liaison graph. This matrix is used to identify task dependencies between the nodes and arrows which represent the activities or processes. When there is an arrow from A to B, thus B is dependent on A before proceed to the other process and the value will be 1. If there is no arrow between nodes it means the process is not depending on anything so the value will be 0. An example of adjacency matrix is shown in Figure 3.12.

		Ending Points					
		A	В	С	D		
Starting Points	A	0	1	0	0)	
	в	0	0	1	1		
	С	0	0	0	0		
	D	1	0	0	0		
	(2				J	

Figure 3.12: Example of adjacency matrix (*Adjacency Matrix and Adjacency List | Graphs, Properties and Examples | Study.Com*, n.d.)

3.4.6 Precedence matrix

The precedence matrix is being used in order to explain the assembly precedence constrain relations that R_{ij} denotes. The elements' values represent the precedence constraints between the parts, and the row and column numbers correspond to the numbering for the components. In contrast, the values of the elements themselves represent the numbering for the associated precedence. That would be the same as applying ± 1 , where ± 1 represents the contact constraint, and represents the non-contact virtual constraint. An example of a precedence matrix is shown in Figure 3.13. If $R_{ij} = +1$ it means part *i* must be assembled before part *j*. If $R_{ij} = +1$ it means part *j* must be assembled after part *i*. If $R_{ij} = 0$ it means there is no assembly relation between part *i* and the part *j*.



Figure 3.13: Example of a precedence matrix (Wang and Liu, 2013b)

3.5 Structural Reconfiguration

The structural reconfiguration should be done in the simulation model and must consider the part analysis. Generate all of the possible sequences based on the assembly liaison diagram.

3.6 Development of Tools

All the user interfaces in terms of parts type, parts sequence, and structural configuration from the above methods are set to help users give input to come out with a reconfigure option. Thus, objective I will be achieved.

3.7 Model Translation

The results of the part analysis, structural configuration, and model conceptualization were merged throughout the model translation process, which resulted in the development of a simulation model. Within the context of this project, the simulation programme, which is Siemens Tecnomatix Plant Simulation, was used for DES. To develop a simulation model, it is necessary to make assumptions in order to simplify the production process.

3.8 Verification

Verification is an iterative procedure that aims to determine whether the product of each step in the construction of the simulation model satisfies all of the constraints imposed on it by the previous step and is internally complete, consistent, and correct enough to support the next phase.

3.9 Validation

Establish quantitative model validation standards. Represent the degree to each component and parameter of the model needs to be confirmed before continuing with the analysis. Validation of model elements based on a stochastic process is frequently accomplished through statistical tests to determine the degree to which the model's behaviour corresponds to that of the real system.

3.10 Simulation Run

The simulation model has been completed and is ready for simulation analysis now that the validation has been accomplished. The simulation run and tools included in Siemens Tecnomatix Plant Simulation have been implemented throughout this project.

3.11 Evaluate the Effectiveness of Tools

The evaluation process will be compared with the current layout and reconfigured layouts that minimise the blocking percentage before the bottleneck process.

3.12 Documentation and Report

This thesis has all the information for this final year project. The method has been described in detail so that the simulation trials can be understood and done again. So, this report has all the input data and simulation object parameters that are needed. The results have been categorized into two groups based on the project's objectives. After the simulation result for reconfiguring tools, a suitable reconfigured layout was discovered for each product and the last thing to do was to document and report.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Assembly Liaison Graph



Figure 4.1: Assembly liaison graph

The assembly liaison graph is constructed from the process flow which is discussed in the packaging procedure of using a hybrid assembly system (3.4.1). The nodes represent processes and the directed arrow represents the tasks or processes that are dependent on each other as shown in Figure 4.1. The processes are as follows:

- 1) Base plate loading
- 2) Plastic box loading
- 3) Manual operator loading
- 4) Plastic lid loading
- 5) Pressing

4.2 Adjacency Matrix

If there is a process dependency between two nodes, then the value of the corresponding elements in both the row and the column for those nodes will be one. On the other hand, the value of the element is zero. In other words, Aij value of 1 indicates process dependencies between nodes i and node j, but Aij value of 0 shows that it does not depend on any other processes. The matrix A shows that [2,1] is 1 because based on the liaison graph process 2 is dependent on process 1. In addition, [3,2] is 1 because process 3 is depends on process 2, [4,3] is 1 because process 4 is dependent on process 3 and [5,4] is 1 because process 5 is dependent on process 4. The others are 0 because the process is not depending on other processes.

Rows and columns represent the vertices from the row sum, which will get the degree of the vertex that the row represents. At the row sum of vertex 3, when summing up all will get 2 and the row sum shows that vertex has a degree of 2. Since columns also represent vertices the same is true for column sum. The column that represents vertex 3 will also get a degree of 2. Therefore, the adjacency matrix of the graph has all the same information contained in the graph.

4.3 Precedence Matrix

The following are the specific regulations that applied based on the liaison graph:

- i. If i = j, then the Rij = 0.
- ii. If Rij = +1, it indicates that part i must be assembled before the part j, and that this order must be followed.
- iii. In the case that Rij is equal to -1, it indicates that the part j must be assembled, after part i is assembled.
- iv. If Rij = 0, it indicates that there is no definite assembly relation between part i and part j.



The Table 3.3 illustrates that the R_{12} is 1 because part 1 is must be assemble before part 2, R_{21} is -1 because part 2 is assembled after part 1 is assembled, R_{23} is 1 because part 2 is must be assemble before part 3, R_{32} is -1 because part 3 is assembled after part 2 is assembled, R_{34} is 1 because part 3 is must be assemble before part 4, R_{43} is -1 because part 4 is assembled after part 3, R_{45} is 1 because part 4 is must be assemble before part 5 is assembled, R_{54} is -1 because part 5 is assembled after part 4 is assembled and the others 0 because there is no definite assemble relation.

4.4 Structural Reconfiguration



According to the sketch in the Figure 4.2, there are eight positions in the existing layout. The five processes need to fit into the eight positions by reconfiguring the positions. The process needs to be linked to one another whenever the reconfigurations happen. This is because the process which has relation need to allocate one another. Thus, the position of the process can be changed but cannot be switched. For example, it is possible to change the process 4 in the position from 5 to 6 and bring down the process 3 in the position 4 to 5 but cannot switch the process 1 in the position 1 to 2. The process with the longest processing time will lead to and be considered as a bottleneck process. So, the position of that process needs to be reconfigured correspondingly based on the matrix. Then, to achieve objective II the blocking percentage is taken from before the bottleneck process and compared the current and reconfigured layout.



4.5 Simulation Model for Current Layout (Mild Steel Pin)

Figure 4.3: Current layout for mild steel pin



Figure 4.4: Statistic of plastic lid loading process

As mentioned in (3.4.2), the processing time for manual operator loading may change according to the product and the other process's processing time remains the same. So, the processing time for pressing process is 29s which is higher than the others and leads to bottleneck. Based on Figure 4.3, the pressing process is in the 7th position and the plastic lid loading process is in the 5th position. Thus, the plastic lid loading process is blocked by the pressing process. Therefore, the blocking percentage in the plastic lid loading process which is before the bottleneck process is high as 2.64% and the working percentage is 94.13% as shown in Figure 4.4.



4.5.1 Simulation model for first reconfigured layout (mild steel pin)

Figure 4.6: Statistic of plastic lid loading process

Based on Figure 4.5, reconfiguration was done for the position of the manual operating loading process from position 4 to 3. The position of the pressing process and plastic lid loading process remained the same. Thus, the pressing process still blocked the plastic lid loading process. Therefore, the blocking percentage in the plastic lid loading process which is before the bottleneck process is the same as 2.64% and the working percentage decreased to 94.13% as shown in Figure 4.6.



4.5.2 Simulation model for second reconfigured layout (mild steel pin)

Figure 4.8: Statistic of plastic lid loading process

AssemblyStation1 Station

o

Figure 4.7 shows that the second reconfiguration was done for the position of the manual operator loading process from 4 to 3, the plastic lid loading process from position 5 to 4 and the pressing process from 7 to 8. Therefore, the blocking percentage in the plastic lid loading process which is before the bottleneck process is decreased to 0% and the working percentage is increased to 94.35%, as shown in Figure 4.8.

4.5.3 Comparison of statistics between working and blocking percentage for mild steel pin



Figure 4.9: Comparison of working and blocking percentage between current layout and reconfigured layouts for mild steel pin from plastic lid loading process (before bottleneck)

The bar chart in Figure 4.9 illustrates the comparison of working and blocking percentages between current layout and the other two reconfigured layouts for mild steel pin from plastic lid loading process which is before the bottleneck process. It can be seen that the blocking percentage in reconfigured layout 1 remained the same as in the current layout at 2.64%. However, the blocking percentage in reconfigured layout 2 dropped drastically to 0% compared to the others. The working percentage in reconfigured layout 1 is the lowest at 94.12% compared to the others. However, the working percentage in reconfigured layout 2 increased sharply to 94.35%. Therefore, reconfiguring the layout can minimize the blocking percentage before the bottleneck process and also can increase the working percentage. In addition, reconfigured layout 2 is the most suitable for mild steel pin when run at Teaching Factory.

4.5.4 Reconfiguration of position in matrix

$$B = \begin{array}{cccc} 1 & 2 & 3 & 4 \\ 1 & 1 & 1 & 1 \\ 2 & 1 & 0 & 0 \end{array}$$

For the second use case, the reconfiguration of positions for layout 2 is converted into a 2x4 matrix form as shown in matrix B. The two rows represent the conveyor and the four columns represent the positions. The above conveyor has four positions and the below has four positions, as shown in Figure 4.10. The matrix of [1,1], [1,2], [1,3], [1,4] and [2,1] is 1 because the positions are occupied with processes. The others are 0 because the position is not occupied with any process.



Figure 4.10: Suitable layout for mild steel pin



4.6 Simulation Model for Current Layout (Hard Steel Pin)

Figure 4.11: Current layout for hard steel pin



Figure 4.12: Statistics of plastic lid loading

Based on Figure 4.11, the processing time for the pressing process is the longest compared to the other processes which is leading to a bottleneck. In the current layout for hard steel pin, the pressing process is in the 7th position and the plastic lid loading process is in the 5th position. Thus, the plastic lid loading process is blocked by the pressing process. Therefore, the blocking percentage in the plastic lid loading process which is before the bottleneck process is high as 3.73% and the working percentage is 94.21% as shown in Figure 4.12.



4.6.1 Simulation model for first reconfigured layout (hard steel pin)

Figure 4.14: Statistic of plastic lid loading process

Based on Figure 4.13, reconfiguration was done for the position of the manual operating loading process from position 4 to 3. The position of the pressing process and plastic lid loading process remained the same. Thus, the pressing process still blocked the plastic lid loading process. Therefore, the blocking percentage in the plastic lid loading process which is before the bottleneck process is the same as 3.73% and the working percentage decreased to 94.20% as shown in Figure 4.14.



4.6.2 Simulation model for second reconfigured layout (hard steel pin)

Figure 4.15: Second reconfigured layout for hard steel pin



Figure 4.16: Statistic of plastic lid loading process

Figure 4.15 shows that the second reconfiguration was done for the position of the manual operator loading process from 4 to 3, the plastic lid loading process from position 5 to 4 and the pressing process from 7 to 8. Therefore, the blocking percentage in the plastic lid loading process which is before the bottleneck process is decreased to 0% and the working percentage is increased to 94.42%, as shown in Figure 4.16.





Figure 4.17: Comparison of Working and Blocking Percentage between Current Layout and Reconfigured Layouts for Hard Steel Pin from Plastic Lid Loading Process (before bottleneck)

The bar chart in Figure 4.17 illustrates the comparison of working and blocking percentages between the current layout and the other two reconfigured layouts for hard steel pin from the plastic lid loading process which is before the bottleneck process. It can be seen that the blocking percentage in reconfigured layout 1 remained the same as in the current layout at 3.73%. However, the blocking percentage in reconfigured layout 2 dropped drastically to 0% compared to the others. The working percentage in reconfigured layout 1 is the lowest at 94.20% compared to the others. However, the working percentage in reconfigured layout 2 increased sharply to 94.42%. Therefore, reconfiguring the layout can minimize the blocking percentage before the bottleneck process and also can increase the working percentage. In addition, reconfigured layout 2 is the most suitable for hard steel pin when run at Teaching Factory.

4.6.4 Reconfiguration of position in matrix

$$C = \begin{array}{cccc} 1 & 2 & 3 & 4 \\ 1 & 1 & 1 & 1 \\ 2 & 1 & 0 & 0 \end{array}$$

For the second use case, the reconfiguration of positions for layout 2 is converted into a 2x4 matrix form as shown in matrix C. The two rows represent the conveyor and the four columns represent the positions. The above conveyor has four positions and the below has four positions, as shown in Figure 4.18. The matrix of [1,1], [1,2], [1,3], [1,4] and [2,1] is 1 because the positions are occupied with processes. The others are 0 because the position is not occupied with any process.



Figure 4.18: Suitable layout for hard steel pin



4.7 Simulation Model for Current Layout (Ball-Headed Pin)

Figure 4.19: Current layout for ball-headed pin



Figure 4.20: Statistic of plastic box loading process

As mentioned in (3.4.2), the processing time for manual operator loading may change according to the product and the other process's processing time remains the same. So, the processing time for the manual operator loading process is 37s which is higher than the others and leads to a bottleneck. Based on Figure 4.19, the manual operator loading process is in the 4th position and the plastic box loading process is in the 2nd position. Thus, the manual operator loading process blocks the plastic box loading process. Therefore, the blocking percentage in the plastic box loading process which is before the bottleneck process is high at 56.21% and the working percentage is 42.14%, as shown in Figure 4.20.



4.7.1 Simulation model for first reconfigured layout (ball-headed pin)

Figure 4.22: Statistic of plastic box loading process

AssemblyStation Station

20 10 0

Based on Figure 4.21, reconfiguration was done for the position of the manual operating loading process from position 4 to 6, the plastic lid process from 5 to 7 and the pressing process from 7 to 8. There is no block in the plastic box loading process and the working percentage is 42.15% as shown in Figure 4.22.



4.7.2 Simulation model for second reconfigured layout (ball-headed pin)

Figure 4.24: Statistic of plastic box loading process

Based on Figure 4.23, reconfiguration was done for the position of the manual operating loading process from position 4 to 5, the plastic lid process from 5 to 7 and the pressing process from 7 to 8. There is no block in the plastic box loading process and the working percentage is 42.19% as shown in 4.24.



4.7.3 Comparison of statistics between working and blocking percentage for ballheaded pin

Figure 4.25: Comparison of Working and Blocking Percentage between Current Layout and Reconfigured Layout for Pink Ball-Headed Pin from Plastic Box Loading Process

The bar chart in Figure 4.25 illustrates the comparison of working and blocking percentages between the current layout and the other two reconfigured layouts for the ball-headed pin from the plastic box loading process, which is before the bottleneck process. It can be seen that the blocking percentage in reconfigured layout 1 dropped drastically to 0% same as in reconfigured layout 2. However, the working percentage in reconfigured layout 2 slightly increased to 42.19%. Therefore, reconfiguring the layout can minimize the blocking percentage before the bottleneck process and also can increase the working percentage. In addition, reconfigured layout 2 is the most suitable for ball-headed pin when run at Teaching Factory.
4.7.4 Reconfiguration of position in matrix

$$D = \begin{array}{ccccc} 1 & 2 & 3 & 4 \\ 1 \begin{bmatrix} 1 & 1 & 0 & 0 \\ 2 \begin{bmatrix} 1 & 1 & 0 & 1 \end{bmatrix}$$

For the second use case, the reconfiguration of positions for layout 2 is converted into a 2x4 matrix form as shown in matrix D. The two rows represent the conveyor and the four columns represent the positions. The above conveyor has four positions and the below has four positions, as shown in Figure 4.26. The matrix of [1,1], [1,2], [2,1], [2,2] and [2,4] is 1 because the positions are occupied with processes. The others are 0 because the position is not occupied with any process.



Figure 4.26: Suitable layout for ball-headed pin

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study's purpose was to study how effective tool reconfiguration is in a hybrid assembly system. According to this study's goal, simulation models were developed using Tecnomatix Plant Simulation which represents the real system virtually. Part analysis and time studies of product and process processing times were discovered to understand the assembly system components. Then, structural reconfiguration takes place with consideration of the analysis. The structural configuration was done using a simulation model by rearranging the possible sequences of processes. Finally, a suitable reconfigured layout was discovered for each product. The reconfigured layouts are chosen by considering the minimum blocking percentage before the bottleneck process and the highest working percentage.

5.1.1 First objective achievement

The first objective of this study is to develop a simulation aided reconfigure tool for hybrid assembly system. This objective was achieved when the general data collected from the hybrid assembly system and every existing process was transformed into a simulation model. The Teaching Factory's layout is used as the model's base.

5.1.2 Second objective achievement

The second objective of this study is to evaluate the effectiveness of reconfigurable tools by minimizing the blocking percentage before the bottleneck process. This objective was achieved based on the result by minimizing the blocking percentage before the bottleneck process using the reconfigurable tools.

5.2 **Recommendation for Future Work**

As a learning process, continuing a process into the future lets students learn more about a certain field. So, the recommendation is that more studies be done to confirm the results, which are:

- Course hours on Tecnomatix Plant Simulation software must be added in order for the learners to get more exposure to the software.
- II) Suggestion to research module selection is a hybrid assembly system.
- III) Suggestions to do more research on reconfigurable tools must be included for references
- IV) Studies on innovations in reconfigurable tools for manufacturing processes should be made and comparisons and transformation of existing manufacturing plants can be reduced.

5.3 **Project Limitations**

In the process of completing this study, numbers of limitations had been encountered:

- Lacking of proper and accurate research and studies regarding reconfigurable tools and implementation of them in industries.
- Inadequate exposure and manuals towards Tecnomatix software and methods to utilize it for the study.

III) Limitations in transforming existing hybrid assembly system in teaching factory by implementing reconfigurable tools via simulation.

5.4 **Project Sustainability**

Sustainability in industrial development is crucial. By implementing reconfigurable tools in industries, plenty of waste in terms of energy, time, resources and raw materials can be depleted. In order to achieve Sustainable Development Goals, industries in our country need to be more effective in implementing these reconfigurable tools in their manufacturing process and assembly system, as these reconfigurable tools and methods are imminent in the industrial revolution.

5.5 **Project Complexity**

The lack of methods, advanced studies and information regarding the software was the prime obstacle to completing this project. Moreover, proper guidance and techniques, especially in using Tecnomatix, made it harder to get a solution for the problem faced in implementing reconfigurable tools into an existing hybrid assembly system.

5.6 Lifelong Learning

The Industrial Revolution teaches us to periodically challenge our own business model and investigate the possibilities the new technological situation offers. By learning more about reconfigurable tools and methods to utilize them in industries opens up a new path towards innovations and creative approaches to building a better future in terms of sustainability and development towards better industrialization. Reconfigurable tools and methods to implement this technology are still pristine in Malaysia. More studies and research can be done in this particular field.

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APPENDICES



Appendix A

		Week													
Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Briefing about PSM 2 with Dr Shahir															
Overview of PSM 1	AL	AYSI	4												
	1		40												
Briefing the project with your supervisor			N N												
Preparation of the needed and information				2											
Conduct the methodologies		-						-			1				
Propose the development of tool used									_		1				
Thesis writing for Chapter 4	200-					-									
Thesis writing for enapter 1	- AND														
Thesis writing for Chapter 5			-	1/	-	1									
Slide preparation	ا ما	~~~	ah		-			10		"	بىي	91			
											10				
Presentation															
UNI	VEE	2SIT	T	EKN	IKA	L M	AL	AYS	IA I	AEL	AK	Δ.			
Submission of PSM 2 Report							and the Design								

Appendix B