DEVELOPMENT OF HOLONIC WORKFORCE ALLOCATION IN ELECTRONICS ASSEMBLY

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering (Hons) Industrial Engineering

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JANUARY 2017

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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Specially dedicated to
my beloved family

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude and special thanks to my supervisor, Dr.Joshua A/L Jaya Prakash for his guidance, advice and supervision throughout the progress of the whole Final Year Project. I am grateful that he always spends time to have discussion with regarding the project and gives prompt replies for my uncertainties.

Lastly, I would like to thank my peers and coursemates who have offered me a great support, both mentally and physically, upon completion of this Final Year Project.

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ABSTRACT

Workforce allocation is a vital chain in the shop floor management especially for job shop model because it is the key factor that will directly influence the end-to-end productivity of the production line. This research is based on a case study in a global electronics manufacturing company located in Batu Gajah, Perak. Company X specializes in manufacturing electronics components such as power inductor and electromagnetic interference (EMI) suppression filter. Electrical sorting and taping (EST) process which is one of the manufacturing processes of power inductor is focused in this study as it involves the most number of operators and machines where proactive improvement is needed to maximize the output of the manufacturing system. The work tasks and machine allocation in the current manufacturing process of EST were studied and analyzed to determine the limitations of the current EST manufacturing system. Machine interference problem is one of the common issues faced by the EST process that causes the reduction in machine efficiency due to restricted workforce flexibility. In the EST manufacturing line studied, machine interference is identified in two aspects, primarily shortstop interference and setup interference. Holonic Manufacturing System (HMS) was proposed in this study to improve the flexibility in workforce planning. By using the concept of HMS, four possible cases with distinct work tasks allocation between the operators and the water spider are proposed. The future model was constructed based on the best case that could result in highest machine efficiency and most effective in resolving machine interference problem. The average machine efficiency of the EST process and the ability of EST process to deal with production issues such as multiple machine breakdowns and absence of worker could be improved with the implementation of holonic workforce allocation.

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LIST OF SYMBOLS / ABBREVIATIONS

APP3	Appearance Checking Process
DOR	Daily Operator Record
EMI	Electromagnetic Interference
EST	Electrical Sorting and Taping
HMS	Holonic Manufacturing System
HWM	Holonic Workforce Allocation Model
IMS	Intelligent Manufacturing System
Inp T	Inspection of Tape
M1	Machine 1
M2	Machine 2
MIP	Machine Interference Problem
OA	Operator
OQC	Outgoing Quality Control
QC	Quality Checking
RC	Reconnect Tape
SOP	Standard Operating Procedure
WIP	Work-In-Process
WS	Water Spider

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter provides an overview of holonic manufacturing system in workforce allocation. It presents the concept of holonic workforce allocation as the potential improvement in a global electronics manufacturing company. Following this, the problem statements and objectives of the case study are outlined.

1.2 Holonic Manufacturing System

With rapid development of technology, customized products are in higher demand. A company that is able to respond rapidly to the ever changing market will ensure it will have an edge over its competitors. Yet, another challenge faced is to have the shortest processing time while delivering diverse products with high quality (Shiming Liu et al., 2000). In short, a company must have the ability to cope with dynamic production to be constantly competitive (Saadat et al., 2013). A possible way of achieving this is to instill the concept of "holonic" into the manufacturing system.

Aholonic manufacturing system was one of the cases studied under the Intelligent Manufacturing Systems (IMS) Feasibility Study Program in 1994. HMS was being established by considering the requirements of future manufacturing systems that possess a higher degree of control levels and decision space (Van Brussel et al., 1998). Instead of one single "brain" that monitors and schedules the entire production, multiple "brains" are installed at different production stages and hierarchy level to do the thinking and strategize plans (LeitÃo and Restivo, 2008). Nowadays, many manufacturing industries practice low-volume high variety production to provide better control over market changes. Ordinarily, HMS is applied in the manufacturing floor that practices job shop production. The high flexibility in a process-oriented manufacturing, from various machining processes, to material transfer routing, and to operators allocation, lead to the necessity to have a comprehensive production management strategy such as HMS (Ounnar and Pujo, 2009).

In a production line, there are several key elements that will directly or indirectly affect the productivity of the production line: operators, machines, work centers, resources, orders, etc. These elements are named as holons (Gou, Luh and Kyoya, 1998). A holon is an important element in HMS, as it can be depicted as the "brain" or "part of the brain" that is autonomous and capable of analyzing job task priorities sequencing throughout the manufacturing. It is beneficial for transforming, transporting, storing and/or validating information and physical objects. An information processing part and a physical part are two major components that make up a holon. Basically, there will be three types of basic holons: resource holon, order holon and product holon (Van Brussel et al., 1998). These three holons must communicate with each other from time to time for information exchange in order to achieve optimum outcomes from a holonic manufacturing system.

According to Van Brussel et al. (1998), resource holon acts as an information processing center that controls all the flows of resources and allocates the resources accordingly. It will carry the information to product holon on how certain processes could be carried out based on the types of resources and determine how much resources need to be allocated depending on the information from order holon. An order holon assigns tasks within the manufacturing system to ensure it meets the customer requirement and complete the order on time. It will provide the guidelines for the product holon in processes or task scheduling. A product holon is responsible for the manufacturing processes and quality of the products produced. It also controls the productivity and efficiency of the production line.

By introducing HMS in the production line, it also helps to achieve flexible workforce allocation. Workforce allocation is a vital chain in the shop floor management because it is the key factor that will directly influence the end-to-end productivity of the production line. Compared to complex machinery settings modification or relocation of bulky machinery, allocating workforce is more handy and practical. It enables the line leaders or production engineers to re-arrange workforce according to real-time needs as well as daily production goals. In holonic workforce allocation, holons are capable of responding quickly to the problems encountered in the manufacturing line such as machine interference. Machine interference occurs when there is a machine error that stops the machine from operating while the operators are engaged with other machines and the production continues only when the machine is attended by an operator (Hadad, Keren and Gurevich, 2013). Therefore, the level of machine interference is influenced by the operator allocation decision, whereby the degree of improvement is depending on the optimality of the operator staffing level (Yang, Fu and Yang, 2002).

1.3 Problem Statement

This research is based on a case study in a global electronics manufacturing company located in Batu Gajah, Perak. Company X specializes in manufacturing electronics components such as power inductor and electromagnetic interference (EMI) suppression filter. This research is aimed to study on the manufacturing environment of power inductor. Basically, the manufacturing processes of a power inductor include winding, coating or resin coating, drying and hardening, electrical sorting taping operation, human inspection, inductance checking and followed by electrical properties and dimension testing. Currently, company X utilizes process-oriented layout. This process layout is designed for the ease of company to fabricate various types of power inductors to fulfill different customer requirements.

This case study will focus on the electrical sorting taping (EST) process. In this process, there is a total of eight machines manufacturing two product types. Each operator is assigned to at least two machines manufacturing similar product types during the production. In such a case, each operator will be performing similar tasks and is required to execute every single operation task starting from the set-up of production lot to the transportation of finished goods which also include material replenishment and problem solving on the machinery. These operational tasks can be categorized into value-added activities and non-value-added activities. However, no specific rules are standardized on how the operators should perform their tasks when there are a few tasks such as machine set up, material replenishment, solving machine errors, etc. pending to be completed at the same time. At this stage, the only rule instructed to the operators is that they must complete the current task they are performing before they can proceed to the next task. In other words, preemption is prohibited to prevent incomplete tasks after interruption due to the forgetfulness of operator.

Another encountered issue is the unpredictability or uncertainties in occurrence of machine errors. These machine errors are usually shortstops that take place randomly and there are no specific technique that can be used to forecast or predict the errors. In EST, there are multiple machine errors that can be observed. If there is a malfunction in the production machines, the operator on the line will fill in a report regarding the machine breakdown through the main computer interface allocated in the production line to request for technicians to repair the machine. For minor machine errors, there are different types of solving methods for respective errors which can be performed by operators manually. Since an operator is assigned to at least two machines during the production, there might be situation where there is a parallel occurrence of machine errors. For instance, one of the machine, M1 experiences an unexpected shortstop. At the same time, before the assigned operator is about to solve the error at M1, there is an immediate shortstop arises at another machine, M2 such that the shortstop cannot be attended simultaneously by the operator. In such situation, the operator attends to the either M1 or M2 randomly because there is no standard operating procedure clarifying the priority sequence on machine shortstops.

Moreover, there are some unusual events where a few machines breakdown at the same time. This could happen because the machines in this manufacturing process are usually operating for 24 hours over days and nights. Machines breakdown in the production line will eventually affect the task allocation for the operators. Under usual operating conditions, the operator is commonly assigned to two machines, but if there is a breakdown in either one of the two machines, the operator will only need to take care of the another one machine which is functioning. However, if both of the machines are malfunction simultaneously, the operator will be instructed to support another operators in managing their machines and to attend randomly to shortstops. The only restriction is that the operator can only be assigned to the machines with similar product types. In the worst case scenario whereby most of the machines are under maintenance, on-shift operators tend to stay in idle state while awaiting for machine repairing from technicians or getting further instruction from line leaders.

Since machinery errors are unpredictable and unavoidable, the sole aspect that can be further improved is the workforce. Workforce allocation plays an important role in production planning. Through observation and analysis on the current manufacturing process, the operators are not characterized as holons, instead they are stationed based on Random Allocation Model. The current scheme practiced is that the operators will be randomly assigned to machine disregarding the individual skill rating and task urgency on machine. In other words, the selection will be on a free-for-all basis when every operator is engaged (Lim and Chin, 2011). Flexible manufacturing line can only be achieved with a proper workforce allocation that able to cope with any unforeseeable events or disturbances (Abdelhamied et al., 2015). To achieve this, holonic workforce could offer a better clarification in operator's task scheduling or sequencing.

Even though holonic workforce could improve the manufacturing process in term of flexibility and productivity, it also has some limitations in actual implementation in manufacturing lines. Holonic workforce allows a holon to have flexibility in the task execution. At the same time, the operators carry more responsibility as they are required to make judgments on which task to be carried out according to the production's priority. Thus, a holon must attain a higher level of expertise and knowledge with proper training provided by the management. In another point of view, it can be deduced that the decision making of a holon on job task priorities as well as intermediate production planning is subjective and solely dependent to previous experiences. The downside is that each individual operator is likely to develop dissimilar concept of sequencing job tasks priority based on personal point of view. In addition, in HMS, every holon has the rights to decide on their ways of conducting activities. Consequently, there is a possibility that those activities do not reflect the actual goal of the system as compared to the centralized control system with a controller that responsible in allocating all the tasks.

1.4 Objectives

The objectives of the research are:

1. To study the work tasks and machine allocation in the current manufacturing process of electrical sorting and taping (EST).
2. To developand verify the priority rules to make the operator more holonic in facing machine interference problem due to the occurrence of either parallel tasks or parallel machine errors, and at the same time to equip them with cross training.
3. To validate the proposed solution.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter outlines the pertinent topics and theories which are significant to the thesis on the study of workforce planning in real shop floor environment. Following this, a list of reviews covering different strategies proposed for workforce allocation with respect to different manufacturing circumstances as shown in table 2.1.

2.2 Workforce Planning

Workforce planning is an essential process to minimize the labor cost as well as maximize the profitability. It can ensure the smooth flow of production line while maintaining the maximum desirable production capacity as well as system throughput by allocating optimum work labour to achieve target demand.

Master production scheduling (MPS) is a mixed-integer program that has been widely used for workforce allocation in the manufacturing environment. Techawiboonwong et al. (2006) revised the traditional MPS model by including temporary workers in model formulation and thus a new model named MPS-T is proposed. In the formulation of MPS-T model, the workers are classified according to two important aspects: permanent or temporary, and skilled or unskilled. The workers are assigned to workstations according to their skills level such that the workstations with significant operational complexity can only be operated by skillful workers while there is also a minimum ratio of permanent to temporary workers for each workstation. MPS-T is validated by carrying out an experimental study in a factory which has high demand variance and relatively short lead time for the orders.

The objective of the authors' study is to minimize the labor costs by determining the type and number of workers to hire or layoff in each period, the optimal operator-machine assignment and the overtime hours needed to fulfill the customer orders. There are a total of four different products being produced in which one of the products is processed on Line-1 whereas the remaining three types of products are processed on Line-2. In order to insure the quality of products, three skilled workers are required for Line-1 and two skilled workers are required for Line-2. In the authors' study, all the permanent workers are considered to be skilled workers and the temporary workers can be either skilled or unskilled. The authors found out that the optimum ratio of permanent workers to temporary workers should be kept at 0.63. Having a large number of permanent workforces, in which the ratio is more than 0.63, is not preferable for factory with high variance in product demand as it deems to be profligate use of resources.

Hytonen et al. (2008) proposed the use of discrete event simulation to develop a simple and efficient workforce allocation in a job shop production line. The empirical experimentation is carried out with a discrete event simulator on an assembly consists of four serial workstations and forty-eight operators. Every product has the similar process flow. In each station, the line efficiency is highly dependent on the productivity and work rate of the manual operators. From the authors' research, it is observed that operators ought to be experienced and highly-skilled as work tasks in a job shop production possess greater complexity than production lines with other types of layout. Additionally, there is no buffer located in between the stations as the product can only be transferred to the next station when the next station is not occupied. This lowers the worker utilization when there is a bottleneck in one of the stations whereby the operator requires longer processing times. In this case, cross-training for a small group of operators on every work tasks is essential to overcome the bottlenecks. These trained workers are allocated in the stations as mobile workers whereby they could assist other workers when their designated task is accomplished. The number of workers in each station is determined by the workload or the total processing time of the station. In this study, gamma distribution is adapted to determine the work content of each station for different products and calculate the optimum number of workers needed by each station and their respective processing times. From the authors' research, it can be concluded that adding cross-trained moving workers to the production line successfully increases the efficiency only when there is a large product variation. Higher interaction between workers will lead to low capacity as the numbers of workers needed are higher.

The proposed methodology by Azadeh et al. (2014) utilizes the integrated analytic hierarchy process (AHP) and genetic algorithm (GA) for the optimization of operator allocation in cellular manufacturing systems with weighted variables. A five-step operator allocation process is illustrated in a cellular manufacturing system equipped with eight machines. Firstly, the limitations of the existing system are observed. In this cell, each operator is assigned to multiple machines and will only attend to each machine once per cycle. The cycle time in this case is defined as the total time taken for an operator to start an operation at the first designated machine and re-attend to it to process the subsequent workpart. The cycle time covers all required waiting times, processing times, and attending time for the operator to move from one machine to another. At the second stage, a computer simulation model is built to structure the actual manufacturing environment with different scenarios and the output of the simulation model are lead-time of demands, waiting time of demands, operator and machine utilization and annual number of completed parts. Next, the twelve scenarios with all the possible operators' layouts in three shifts are considered in formulating the solutions. Thus, there are a total of 36 alternatives for the optimal workforce allocation. Following that, AHP is utilized to provide the overview of the relationships between the outputs of the simulation model and then evaluate their relative weights in operator allocation problem. Lastly, a fitness function is formulated with all the relative weights identified in the previous stage. GA is then implemented to determine the feasible solutions for the operator allocation problem. In short, the results of AHP-GA-CS proved that the proposed methodology in this study is competent in strategizing the optimal operator allocation in the cellular manufacturing system.

2.3 Strategies for Workforce Planning

To achieve effective workforce allocation, several strategies for workforce planning are proposed by different researchers to fit different manufacturing environments. In this section, workforce planning strategies such as holonic workforce allocation, workforce allocation by enhancing the standard operating procedure and workforce allocation via workforce training are discussed. These strategies are utilized to achieve different objectives and one of these is to reduce the impact of machine interference problem on manufacturing line.

2.3.1 Holonic Workforce Allocation

Holonic Workforce Allocation Model (HWM) is introduced by Lim and Chin (2011) as an effective model to mitigate the impacts of worker absenteeism and turnover in performing operator assignment. Operator assignment is commonly defined as a multi-objective decision-making problem where the optimal solution should achieve the objective with the highest weightage. In order to verify the effectiveness of HWM, a case study is carried out on a local cartoon manufacturer that practices job shop production. Basically, there are five major tasks that the operators should perform on the seven machines for each process cycle. WITNESS simulation model is adopted to determine the outcome of HWM. There are three basic elements in the simulation which are machine, part and labor. In this case, there are a total of seven parts which include the five tasks and two disturbances: absenteeism and turnover. In the simulation model, HWM is compared with three other operator allocation models: Random Allocation (RND), Skilled and Available Allocation (SAA) and Stationed for Total Specialisation (STS). Each model has distinct rule in the process of allocating operators to the machines. The comparison is carried out under three different scenarios: All typical, High demand and High disturbance. The four performance measures of this study are task’s overdue rate, operators’ average skill level, and operators’ interpersonal and intrapersonal skill deviations. HWM proved to be the most effective operator allocation model as it owns the highest performance rating for the two most important measures for the company: overdue rate and average skill level.

Lim (2011) presented a job-shop workforce sizing method based on the concept of Holonic Manufacturing System (HMS). A holonic model namely Workforce Sizing Plan (WOZIP) is developed to compute the optimum number of workers to maximize the productivity of the manufacturing line. The varying parameters such as the variation in machine utilization due to fluctuating product demand and unexpected disturbance in production line are taken into consideration in the WOZIP model. From the management's perspective, minimal usage of workers for daily operations is always desirable as it could help to lower the overhead cost (Lim et al. 2008). In the authors' study, mathematical models are used to calculate the varying parameters such as the utilization rate of machines, frequency and intensity of the production disturbance. The idling rate of the workers is also computed to examine the utilization rate of workers based on the data obtained from the production floor. Furthermore, exponential smoothing which is a forecasting technique is implied to predict these varying parameters in the production line with ten machines for the upcoming 24 months. Results obtained from the mock-up analysis showed that WOZIP is applicable and practical with respect to the variation in machine utilization and worker idling rates as well as different levels of disturbance.

In the manufacturing control system, there are two primary functions, such that they can be categorized into process related functions (process planning) and resource allocation related functions. Leitão et al. (2003) studied about the importance of introducing a flexible and intelligent manufacturing system that is able to response swiftly to the variation in product variety and unexpected disturbance while maintaining the manufacturing's productivity. Two modeling tools are applied to model a clearer visible structure of the manufacturing system. A unified Modeling language (UML) class diagram is utilized for static aspects while the Petri Nets (PN) is employed for dynamic behaviour of manufacturing system. Four classes of holon, product, task, operational and supervisor holons are formed using the ADACOR architecture, with further aid of the generalization concept of the object-oriented paradigm (Leitão, Colombo and Restivo, 2003). In fact, the product, task and operational holons are likewise the product, order and resource holons extended at the PROSA architecture (Ashbacher, 2004). Unlike the behaviour of staff holons defined in PROSA, the supervisor holon stimulates the implication of coordination and global optimization in decentralized control methods. Under normal circumstances, the supervisor holon synchronizes the activity of the holons under its domain whereas they need to be self-regulating and capable of tackling disturbances without referring to the supervisor holon.

2.3.2 Allocation using Standard Operating Procedure (SOP)

For all the manufacturing lines, the operators are required to perform tasks according to the standard operating procedure (SOP) set by the engineers or production officers. SOP acts as a guideline to standardize all the operating requirements in order to assure the quality of services and products for the customer’s benefits and simultaneously prevent vague instructions from individual supervisor.

Bucket brigades is an effective model in performing workforce allocation in a production or assembly line in which the number of operators is always less than the number of machines. (Bartholdi and Eisenstein, 1996) defined this way of organizing manpower as “TSS protocol”, from the Toyota Sewn Products Management System. Basically, there are two TSS rules that must be fulfilled to achieve bucket brigades. The operators are placed in line from the slowest to the fastest to prevent blockage or idle workers. TSS forward rule states that each operator must process only one single item at one time on subsequent stations. The last operator who has completed the work task should then follow the TSS backward rule. TSS backward rule requires the last operator to move upstream and take over the task in the previous station once the task in current station is completed. In such situation, the process is reset where the first operator will need to start processing a new item and follows the TSS forward rule.

De et al. (2013) introduced the concept of bucket brigades into a manual packing line for leather bags to achieve the best balance of workloads. The assembly line consists of four different product models and each model possesses a distinct processing sequence. In the existing packing line, operators are assigned to a fixed station whereby each operator is only trained for that particular task issued by a foreman. This arrangement will result to unbalanced line that affects the line productivity as the operators are not trained to deal with unusual and unexpected situations. Another drawback of this production arrangement is that the foreman is required to re-distribute the job to every operator with respect to each product change. From the experimental study, it showed that the bucket brigades has successfully improved the overall line performance with a reduction in cycle time of a product and throughput time of the line. At the same time, bucket brigades model helps to reduce the amount of work-in-process (WIP) and eliminate the bottlenecks in the production line as the work tasks are carried out continuously by flexible operators.

Bartholdi and Eisenstein (2005) implemented bucket brigades in TUG and successfully helped the company to transform from craft manufacturing to assembly lines. TUGis an industrial tractor assembly company that supplies more than 10 different tractor models in the market, which include those typically used at major airports as luggage tractor. As there was no proper production line at the beginning stage of transformation, bucket brigades is a suitable concept to be implemented. This is because bucket brigades allows the assembly line to balance itself and thus it does not require specific task allocation to the operators. The advantage of having bucket brigades for a newly set up production line is that it would help to train up the workforce easily as the operators are trained to balance the production line by themselves. In the authors' study, the bucket brigade model is revised by introducing several rules to the workers. For bucket brigade model, the slowest worker will be assigned to the first workstation while the fastest worker to the last workstation. Therefore, during the production, only the first worker has the right to start a new process cycle and only the last worker could initiate a walk-back. Walk-backs and hand-offs of several workstations simultaneously is prohibited. Secondly, passing is allowed in the revised bucket brigade model as the self-balancing behavior and proper sequence of slowest to fastest are maintained. Furthermore, the bucket brigade assembly lines at TUG are proved to be feasible as they substantially fulfilled the idealized circumstances in normative model.

2.3.3 Allocation under Machine Interference Problem

Machine breakdown is often an important factor that inhibits the productivity of the manufacturing line. With proper operator-machine assignment, most of the impacts of machine interference problem (MIP) can be lessen such that parallel error occurrences can be attended by workers at the shortest possible time. In other words, it can significantly reduce the respond time and hence decreases the machine stoppage time.

Samat et al. (2013) established an improved maintenance system that would provide better workforce allocation with shorter operator response time to the machine. The new maintenance system is implemented in a semiconductor company in Malaysia which has four clusters with 160 machines and seven technicians assigned to the machine maintenance. The study focuses only on one cluster consisting 12 machines and 24 operators. An 6-phase improvement plan is constructed to implement new maintenance system. At the initial phase, the current system is revised to figure out the average operator response time to machine breakdown by outlining the detailed sequential maintenance procedures. Second phase is to determine the problems that lead to long response time to machine breakdown. This process is done by identifying the Ohno's seven wastes: overproduction, waiting, transportation, overprocessing, inventory, motion and defects by analyzing the chronology developed in the previous phase. In this case, three manufacturing wastes: waiting, transportation and motion are emphasized and studied. In phase 3, Value Stream Mapping (VSM) method is applied for further problems verification. VSM is a powerful lean tool that illustrates the detailed process and material flows in the manufacturing line while identifying value-added and non-value-added activities. Clarification of goal is then done to set the target. In this case study, the company targeted to reduce the response time by 30 percent within one month. Following that, phase 5 of the improvement plan is to identify the ideal solution to achieve the goal using brainstorming to generate and evaluate the feasibility of all possible alternatives. Lastly, the proposed solution in phase 5 is executed in real manufacturing line and determines the outcome of the implementation. In practical, the implementation of proposed improvement model is simple and convenient. Equipment failure can interrupt company production, eventually leading to productivity loss (Alsyouf, 2007). Hence, proper equipment maintenance through an effective maintenance system is vital and plays as the decisive factor in establishing a cost-efficient production environment (Tan and Raghavan, 2007).

Hadad et al. (2013) proposed a multinomial model that is used to determine the optimum number of operators and qualified technicians for each machine failure type in order to reduce the machine interference problem (MIP). The purpose of this model is to propose optimal workforce allocation for minimizing the manufacturing cost and simultaneously maximize the profit. A case study for this proposed model is based on a factory that manufactures a plastic irrigation product equipped with 13 identical machines in the production line. In this case, the machine will only request for two types of services where the first service is to be performed by the operator while the second service will be carried out by qualified technician. Multinomial distribution is used to calculate the expected machine interference or waiting time for each service type. Each type of machine failure is assumed to occur randomly and stochastically. Firstly, the theoretical cycle time to produce one product unit without machine interference is calculated. Next, the expected adjusted cycle time with all the possible assignment of operators and technicians to the machines is computed. In this case, there are a total of 169 possible combinations for 13 machines. Since the objective of this model is to minimize the manufacturing cost and maximize the profit, the cost per unit and hourly profit for each possible combination are determined. By comparison, the optimal assignment for machine failure is four operators with two qualified technicians. The advantage of this proposed model is that it is simple to be applied to any manufacturing line with multiple identical machines. Besides that, this model requires only little data inputs obtainable from work measurements such as runtime of the machine, the average service time for each machine failure, the number of identical machines and number of workers.

Gurevich et al. (2015) recommended the use of binomial probability function in determining the economic number of operators in solving the machine interference problem. This method is applicable to the manufacturing line equipped with several identical machines that are designated to manufacture the same product and independent of each other. A case study is conducted in a factory that produces plastic irrigation product. There are a total of three groups of machines that are operated by five operators. Each group of machines consists of different number of machines, such that five machines in group A, four machines in group B and six machines in group C. In the authors' study, the binomial probability function is used to compute the machine interference proportion. When there is machine interference in the production line, the operators are required to attend to the group of machines with highest priority. In such a case, the factory adopts the rule in which the machines that belong to that particular group with the shortest processing time and average service time is granted the service priority. Therefore, machines in group B has the highest priority, followed by machines in group A and group C. On the other hand, the formulation of the economic number of operators required to deal with the machine interference problem is based on the objective functions. The two objective functions are to maximize the hourly yield and minimize the total cost per unit produced. In conclusion, the optimal number of operator differs as different objective function is considered.

Yang et al. (2007) proposed the multiple attribute decision-making (MADM) method to find a solution to a dynamic operator allocation problem for an integrated circuit (IC) molding workstation. The operator allocation problem is defined as dynamic because the production planning is carried out weekly with respect to the actual production status. This study focuses only on the molding workstation because it is where the bottleneck occurs due to long setup time and frequent machine interference problem. The molding workstation consists of nine molding machines and each operator is assigned to at least two machines. Previously, Yang et al.(2002) did implement a simulation-based model that considers only the cycle time and service level for the dynamic operator assignment which may neglect other importance measures in the production line. To further enhance the practical pertinence of the simulation model, additional four system performances measures are studied in the process of multiple objectives decision making, namely: staffing level, system throughput, tool utilization and flow time. Besides that, AHP is used to compute the weightage of each measure according to the objective of study and figure out all the alternatives for operator assignment. Lastly, two MADM methods: a technique for The Order Preference by Similarity to Ideal Solution (TOPSIS) and fuzzy-based model were applied to figure out the feasible solution for workforce allocation with reference to the relative performance ratings computed using AHP. Both methods contribute to similar outcome with the achievement of all predefined objectives in the study.

Chien et al. (2013) employed an effective methodology to improve the system performance of a semiconductor company in Taiwan by solving the machine interference problem. This is achieved by identifying the optimal operator-machine assignment (Stafford 1988; Haque and Armstrong 2007) through a hybrid approach of simulation model and optimization model. An empirical study with real-time data collection in the company's testing facility is carried out to verify the feasibility of the proposed approach. A simulation model is developed to examine and analyze the real manufacturing process where the movement of the operators and the machine operating conditions are focused. In the testing facility, there are a total of 66 machines with three distinct types. Besides that, there are five operators with two operators in each group, whereby the two operators are assigned to attend the same machine in turn. Moreover, the manufacturing aspects such as product mix, operation details, and operations with different priorities are considered in the simulation model. The output of the simulation model is the frequency of machine errors which address frequency of machine interference. After that, (Chien, Zheng and Lin, 2013) came out with two algorithms: Heuristic Assignment Model with Mixture Experiment (HAM-ME) and Assignment Genetic Algorithm (AGA) to enhance the operator-machine assignment aiming to reduce the machine interference time. Three main factors that contribute to the machine interference time were addressed, which are the number of machines assigned to an operator, different product cycle time due to product variety and the priority of machine operation. A polynomial function is formulated in HAM-ME by utilizing the design of mixture experiment together with the response surface method (RSM). For AGA, global search is conducted with the use of genetic algorithms without involving much mathematical operations. In their study, they proved that both algorithms are suitable in determining the operator-machine assignment while the AGA is found out to be more effective than HAM-ME.

2.3.4 Allocation via Workforce Training

In the manufacturing line, operators play a key role in running an efficient production. Therefore, operator training is essential as the operators equipped with higher level of skills can perform tasks more effectively in the sense of shorter processing time.

For the production floor with manual assembly, the line productivity and the product cycle time are usually influenced by the worker's efficiency. With fixed-worker, the station with the slowest worker will have longest processing time, thus becoming the bottleneck of the assembly line. To improve this, previous research did by (Mileham et al. 2000) is to assign buffers between the stations. However, this solution is only effective to the production line with constant demand and it restricts the flexibility of production line. Therefore, Wang et al. (2007) introduced the concept of flexibility into a local small and medium enterprise (SME) by having walking-worker instead of fixed-worker in the assembly lines. In linear walking-worker assembly lines, the workers are cross-trained so that they are familiar with all the end-to-end process work tasks. In this study, the relationship between the number of workstations and the number of walking workers are investigated by using a WITNESS simulation model to determine the optimal operator-machine assignment. The company set up three parallel assembly lines for three product families (A, B and C series). All the product families share a 'prepare-zone' line for raw materials preparation before proceeding to the production line. From the simulation result, a few conclusions can be drawn. Firstly, as the number of walking workers and workstations increases, the overall line output will increase until the maximum output where the number of walking workers is equivalent to the number of workstations. Secondly, utilization of linear walking-worker assembly lines offers the flexibility in adjusting the number of walking workers corresponds to the daily production demand. The proposed method is applicable as the addition of extra workstations in the production line will not increase the overall cycle time but help to reduce the processing time at other workstations. Wang et al. (2007) concluded that linear walking-workers assembly line offers higher adaptability and proficiency in terms of workforce allocation and line output compared to liner fixed-worker assembly line under similar operating conditions.

Mccreery and Krajewski (1999) promoted workforce flexibility to enhance the performance of an assembly environment with the presence of learning and forgetting effects. The nature of the task assigned to the operators will determine the rate of worker learning and forgetting. For simple task, operators tend to learn faster and the knowledge acquired is comparatively long-lasting. Contrary, operators find it difficult in learning complex task and there is a higher probability of forgetting. Moreover, the rate of learning and forgetting of workers increases as the product variety increases. Therefore, in order to demonstrate the learning and forgetting effects, two manufacturing variables are defined: product variety and task complexity. Discrete-event simulation is utilized to simulate four different manufacturing environments with respect to these two variables. A case study is conducted on a discrete-parts manufacturing line. There are a total of twelve distinct processes assigning to twelve operators for each product. The assembly line is arranged in U-shaped to facilitate the movement of workers between workstations and allow the workers to assist each other in case of unbalanced line. In this study, the importance of workers' cross-training is emphasized and the level of cross training required is mainly based on the manufacturing condition. For low product variety and task complexity, the optimum solution is to have moderate level of cross training and high flexibility in allocating workers to designated tasks. For high product variety and task complexity, it is suitable to have high level of cross training with restricted workforce flexibility. In addition, simple task with high product variety requires high level of cross training with high workforce flexibility. While complex task with low product variety only requires minimal cross training with restricted workforce flexibility. In short, this study highlighted the importance of cross training of workers and their flexibility in dealing with different manufacturing conditions to improve the line performance.

Hopp et al. (2004) suggested two types of cross-training strategies: cherry picking and skill-chaining for optimal workforce allocation in serial production line. From their study, they found out that the skill-chaining strategy is relatively more effective as it offers higher flexibility in workforce coordination. In practice, cross-training is vital for all the manufacturing industries in the effort to eliminate the bottleneck and work-in-process (WIP) inventories where possible. For a serial production line without cross-training of workers, the maximum capacity of the line is restrained by the bottleneck station. To counter this, it is feasible to increase the capacity by diverting the excess capacity from low-utilization stations to the high-utilization stations with the assistance from cross-training manpower. Ruud Lighting, Inc. of Kenosha, Wisconsin with high level of product variety is one of the companies that employed the skill-chaining strategies in their production lines. There are two parallel and identical lines such that each consists of five workstations that are utilized to produce industrial and security lighting products. Each production line is responsible for three product families with a total of more than 1000 different product models. A simulation model is being set up with a constant work-in-process of 12 units in the production line to determine the system throughput for each possible cross-training pattern. The simulation results showed that partial training in both the production line is not effective to maximize the system throughput. Therefore, complete chaining is proposed with different types of manufacturing layouts and validated by using the simulation model. U-shaped production line is tested and it was found to have the highest system throughput. In spite of that, U-shaped production line could not be implemented due to difficulties in material-handling. The optimum solution in this case is to include additional two moving workers to assist the ends of both production lines. As a result, this case study proved that complete skill chaining is applicable and capable of maximizing system throughput without altering workforce capacity.

Table 2.1: Workforce allocation strategies

Source	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]
Year of Publication	2006	2008	2014	2011	2011	2003	1996	2013	2005	2013	2013	2015	2007	2013	2007	1999	2004
Workforce allocation strategies																	
Bucket Brigades							√	√	√								
Cross-training				√	√	√									√	√	√
Holonic Workforce Model (HWM)				√	√	√											
Workforce Flexibility		√		√	√	√	√	√	√						√	√	
Modelling tool	√		√							√	√	√	√	√			
Water-spider																	
Rules Setting							√	√	√			√					

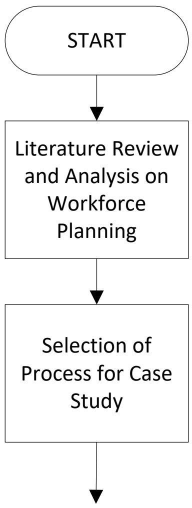
Table 2.1 shows a list of strategies proposed by different researchers for effective workforce allocation. All workers optimization is initiated with dissection and improvement of individual task times, followed by optimizing work contents of workers. Mathematical modelling tool is widely used to solve various workforce allocation problems due to its simplicity to be applied to situations involving multiple manufacturing attributes. However, mathematical modelling restricts the flexibility of workforce allocation when there is an unexpected disturbance in manufacturing environment. To respond to different disturbances, multi-skilled workers are required. By referring to the table 2.1, only a handful of papers talk about workers with different skills for a given task, rest papers assume same skills for a given task. The self-determination of HWM allows the workers to deal with real-time disturbances and thus introduces the flexibility of workforce allocation into the manufacturing system. Therefore, HWM is selected as the primary strategy in this study. Additionally, to further enhance the adaptability of HWM in manufacturing system, the concept of water-spider with predetermined tasks is integrated. In this study, the water-spider does not restricted to replenishment tasks only but also responsible for the regular tasks that do not have to be carried out in every cycle. Water-spider is utilized to assist the operators in the main process flow on maximizing the system productivity and keep the flows of manufacturing system smooth.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methodology of the research. Figure 3.1 shows the flow chart that illustrates the chronological order of the research.



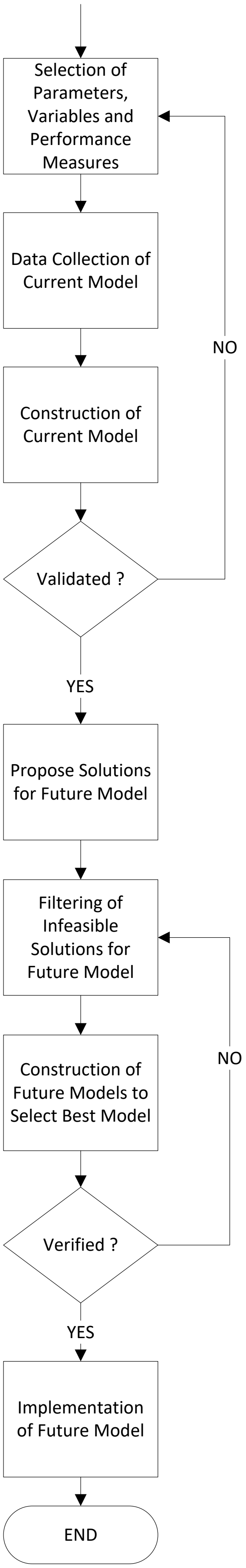


Figure 3.1: Flow Chart

3.2 Methodology

At the early stage of the research, literature review is to be done by reading through articles and filtering them based on the relevant topics about the study. The case study focuses on the workforce allocation in a semiconductor manufacturing that adopts job shop. Detail reading is performed to summarize and analyze various strategies of workforce allocation proposed by different researchers under different manufacturing circumstances. As such, the articles are categorized into four main workforce allocation sections: Holonic Workforce Allocation Model (HWM), workforce allocation via standard operating procedures (SOP), workforce allocation to solve machine interference problem and workforce training. HWM is one of the strategies proposed by the researchers in which the operators are characterized as holons who are autonomous and with high flexibility relative to production changes. Workforce allocation can also be done by altering the SOP for the operators to perform work. SOP is important to ensure high quality of the products manufactured and also consistent and flexible line productivity. Several reviews stated that the objective of having effective workforce allocation is mainly to minimize the impact of machine interference problem by reducing the response time of the operator to the machine stoppage. Effective workforce allocation can also be achieved with the assistance of proper workforce training for the operator. The reviews are summarized into table 2.1 in page 21 and analyzed to determine strategies most commonly utilized in workforce allocation.

A comprehensive understanding on the operating conditions of the selected production is required in order to propose a novel and feasible strategy for manufacturing processes improvement. A case study is carried out in a global electronics manufacturing company that manufactures electronic components such as power inductor and electromagnetic interference (EMI) suppression filter. Manufacturing of power inductors involves a few processes. The scope of the case study is narrowed down to focus on one of the manufacturing processes of the power inductor, namely electrical sorting and taping (EST) process. At current stage, there is no standard rule instructed to the operators on how they should carry out their tasks according to the priority of the tasks. In EST process, the workforce allocation is not flexible enough to deal with uncertainties and unexpected events in the manufacturing environment. Therefore, the objective of this study is to improve the manufacturing process in term of workforce flexibility with proper workforce allocation.

The number of workstations, number of machines, cycle time of the production line, cycle time of each individual task carried out by the operators, machine stoppage time, response time of operators to each shortstop and also the solving time are used for the construction of current model. The performance measures which include the worker productivity, total machine stoppage time, total machine setup time, machine efficiency are the indicators of the performance of the production and reflect the effectiveness of the future model compared to the current model. Data collection is carried out specifically on the EST line on a twice-a-week basis for six weeks, with each individual data collection lasting for two hours. The study is narrowed down to observing all eight machines and the operators assigned to respective machines. Time study is adopted to observe the operating behaviour in two perspectives: operator-bound and machine-bound. For operator bound, the focus is placed on determining job tasks sequencing as well as the cycle time of each individual tasks. For the machine bound, the details gathered are about the types of shortstops, response time of operator to each shortstop, and the duration required for solving. The data collected is constructed using machine-worker activity chart to obtain the operator-machine interaction over time.

A worker-machine activity chart is a multiple activity chart that is used to demonstrate the relationship between the operator and the machines on which the operator works, and is evaluated in parallel with the timeline. A series of the job tasks performed by the operator is plotted against a time scale. By analyzing this chart, the utilization of both worker and machine times could be interpreted. Worker-machine activity chart is comprised of two parts: operator and machine. For operator, the cycle time for each individual task, operator’s idle time and walking time are included based on the data collected. For machine, duration of each machine shortstops, machine breakdown, machine setup and machine interference were included.

In this study, manual simulation is performed instead of the application of simulation software because the job tasks performed by the operator do not follow an exact sequence. The job tasks sequencing is solely dependent on the machine conditions. Furthermore, there are certain uncontrolled variables that are infeasible to be used as input in software simulation. After obtaining the performance measures of the EST production line on the machine efficiency and human labour productivity, a validation is done to check the reliability of data collected to ensure the feasibility of current model. Any significant deviation will indicate inaccurate model and thus the parameters need to be re-selected for another data collection before proceeding to the subsequent step which is the development of future model. In order to depict and reflect the actual operating conditions with the constructed model, the performance measures obtained from the current model, such as the machine uptime and the operator utilization are validated with the data provided by the company and must fall within the acceptable range.

After the pre-analysis on the operating conditions of EST process, HWM is selected as the primary strategy for workforce allocation to improve the flexibility of the manufacturing line and also minimize the machine interference problem. HWM is implemented with additional of one operator into the manufacturing system as water spider to facilitate the workforce allocation. Thus, there are three operators with one water spider who are responsible for eight machines. Four possible solutions with different job tasks allocation between operators and water spider are proposed for the construction of future model.

The main objective of this study is to minimize the machine interference problem by reducing the machine stoppage time. As machine errors are random and unpredictable, operator must be ready to deal with machine shortstops by assigning some tasks to water spider. The similarity between the four cases is that the machine solving tasks are assigned to the operators instead of water spider. This is because there is only one water spider who needs to take care of eight machines and could not respond quickly to all the machine shortstops that occur frequently.

Manual simulation is then performed to investigate the outcome for two final cases for the construction of future model. At this stage, performance measures such as work ratio, total machine interference time and machine efficiency are evaluated from the results of manual simulation as they act as the clinchers to justify which case yields a better performance. For verification purpose, several test runs are carried out in the EST process with the job tasks allocation proposed in the two final cases. In scenario where there is a high deviation between the test run results and the simulation results, it has to return to the previous stage to check the feasibility of the two proposed cases or propose alternative feasible solutions. Implementation of future model can only be carried out once the verification process is completed.

At the initial stage of the implementation, the process layout and the footwork which illustrate the movement of the operators and water spider within the manufacturing system are drawn. The SOP of the water spider is established and a little amendment is done to the SOP of the operator in the current model. Workforce training is then provided to the operators and the water spider by production according to the SOP. During the implementation, the movements of the operators and water spider are observed and issues encountered by the manufacturing system are recorded. Once the manufacturing system achieves its stability, data collection is carried out to evaluate the performance measures which reflect the effectiveness of the future model as compared to the current model.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter divided into 10 sections and each stage of the research is discussed in detail in each section. Section 4.2 describes the selection of the case study. Section 4.3 outlines the selected parameters, variables and performance measures that required to construct and evaluate the current and future models. Section 4.4 describes the execution of data collection to gather the necessary information required for the construction of current model. In section 4.5, the current model of EST process is constructed with the data collected. The validation procedures are discussed in section 4.6. In section 4.7, several feasible solutions are proposed to optimize the productivity of the EST process. The infeasible solutions are then filtered out in section 4.8. Section 4.9 outlines the simulation model that is performed to elect the optimal solution that obeys the objectives of the case study. In section 4.10, verification of constructed future model is presented. With verified future model, the implementation of future model is described in section 4.11. In the last section, the result of the implementation is compared with the simulated model in section 4.9.

4.2 Selection of Process for Case Study

The case study is carried out on the EST process. Among the manufacturing processes of the power inductor, EST process involves the most number of operators and machines where proactive improvement on the EST process is needed to maximize the output of the manufacturing system. The current process flow and the work tasks carried out by the operators are observed and studied before the data collection can be carried out. The input to the process is the inductor cores while the output of the process is a complete reel of inductors. Figure 4.1 shows the process flow of the EST process.

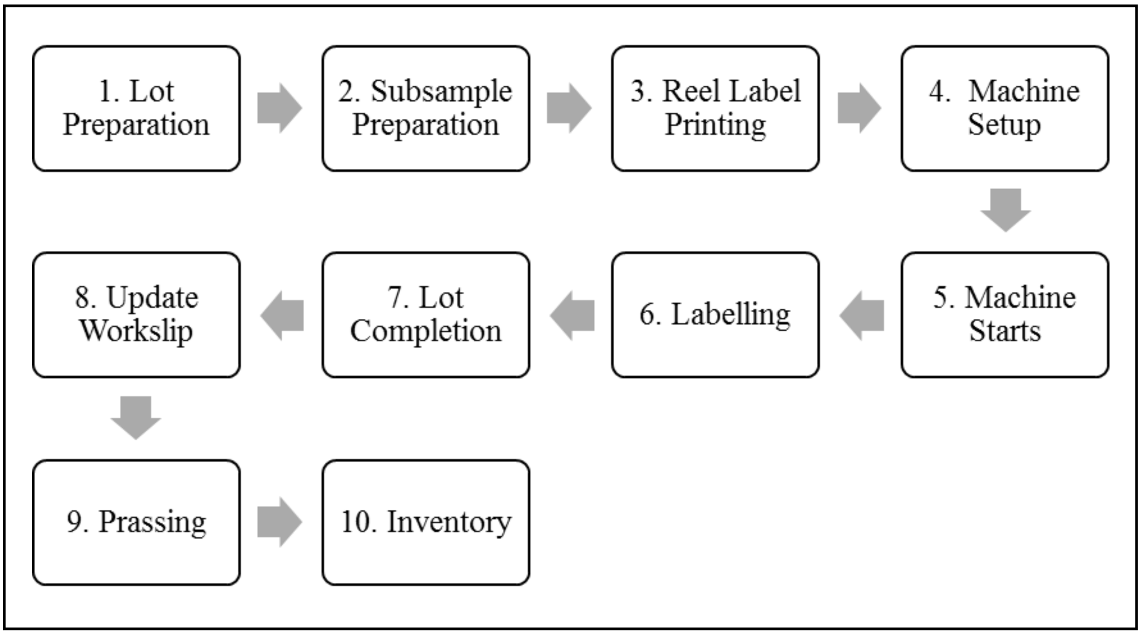


Figure 4.1: Electrical Sorting and Taping (EST) Process Flow

Figure 4.2 shows the layout of the EST process. The movement of operator while carrying out tasks throughout the process is indicated in the layout. Before the production starts, lot preparation by operator is required. The operator is required to bring along a tray from the respective machine workstation and proceed to the EST material rack to collect the raw materials which are the inductor cores stored inside a container. Details written on the container are checked to be identical with those stated on the workslip before transferring back to the machine workstation. After that, the operator will proceed to subsample preparation at outgoing quality control (OQC) station where the cores are calibrated and inspected before they go into production. The calibration result is updated to the system by using main computer located near the OQC station. Reel label printing is then carried out by using the main computer located near the raw materials rack. 22 labels are printed as a complete lot consists of 22 reels of power inductors. After lot preparation, machine setup is performed. The work tasks performed by the operator during machine setup include closing of the previous lot, machine cleaning, machine calibrating, manual input of lot details into the machine, workslip updating and sample checking. The machine will start operation after the machine setup is accomplished. During the process, the labelling task is carried out by the operator once for every 5 reels manufactured. The labelled reels are then packed into box after 5 reels. After the completion of lot, the workslip is updated with the production details such as the lot starting and ending time. Prassing is performed at the main computer where the production details are updated into the system. At the last stage of the EST process, the boxes with the inductor reels are transferred to the rack to be further processed such as box label printing and appearance checking.

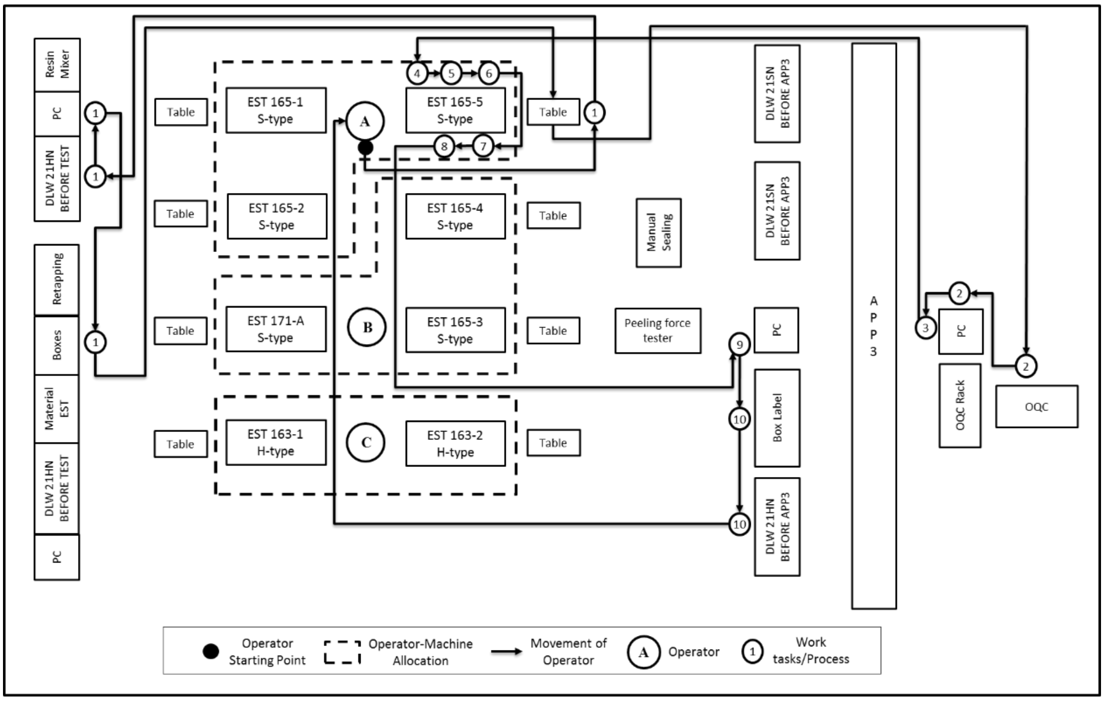


Figure 4.2: Layout of Electrical Sorting and Taping (EST) Process

EST job shop model consists of eight machines operated to produce two main types of power inductors, namely H-type and S-type. Among the eight machines, six machines are used for S-type products while two machines are used to manufacture H-type products. As shown in figure 4.2, there is a total of three operators involved in EST process. The three dashed line boxes indicate the operator allocation to the machines. For S-type machines, one operator is assigned to three machines while for H-type machines, one operator is assigned to two machines.

By referring to the current layout of EST process, the main computers that are used for prassing, the material replenishment racks and the inventory racks are located at the two sides of the eight machines. Therefore, except for solving machine shortstops and updating workslip, the operators need to travel out from the machine areas to perform the other work tasks. Principally, machine interference problems are encountered when the operators could not attend to the machines immediately to solve the machine errors. Machine efficiency decreases as the machine stops operating.

4.3 Selection of Parameters, Variables and Performance Measures

The main objective of the case study is to improve the productivity of the manufacturing system in terms of machine efficiency. In order to achieve this, optimal workforce allocation is targeted. Operators play an important role in deciding the machine efficiency. The shorter time that they use to solve the machine shortstops, the higher the machine efficiency. In current manufacturing system, the operators are assigned with similar and fixed tasks that provide no flexibility to the manufacturing line and hence inevitably lengthen the operator's machine solving time. Therefore, Holonic Manufacturing System (HMS) is introduced as it allows flexibility in operator's work tasks allocation. HMS is one of the intelligent manufacturing systems in which the decision making process is carried out at each manufacturing stages and hierarchy levels by the workers that are trained to become the holon workers. With the improvement in decision making process, the effectiveness of information transfer within the manufacturing system could be improved as well. The operator's work tasks allocation could be adjusted depending on the condition of the manufacturing line. Water spider is mainly responsible for the non-value added activities within the manufacturing system such as material replenishment. The concept of water spider is implemented together with HMS so that the operator can shorten the machine solving time with the assistance of water spider. Water spider in this case is an example of holon worker where he must be a well-trained worker as the work task sequence must be determined wisely to ensure a smooth flow of production.

The number of workstations and machines are observed from the manufacturing system while the cycle time of the EST process, the cycle time of each individual task carried out by the operators, the machine stoppage time, the response time of operators to each shortstops and also the solving time are recorded during the data collection. The collected data is used to compute the performance measures such as worker productivity, total machine stoppage time, total machine setup time and machine efficiency. The worker productivity and machine efficiency are the main performance measures to evaluate the effectiveness of the future model.

$$\text{Worker Productivity} = \frac{\text{Total time operator is occupied}}{\text{Total available time}} \qquad ------- (1)$$

Worker productivity is determined by dividing the total time whereby the operator is performing tasks, with the total available working time.

$$\text{Machine Efficiency} = \frac{\text{Total machine running time}}{\text{Total available time}} \qquad ------- (2)$$

Machine efficiency is computed by dividing the total time whereby the machine is running, with the total available time.

In this study, the available working time is defined as the duration of data collection. Increase in machine efficiency with appropriate level of worker productivity is targeted in proposing feasible solutions for the construction of future model.

4.4 Data Collection of Current Model

Time study is performed on the EST process using stopwatch for data collection. The time study focuses on two aspects which are operators and machines. For each interval of data collection, one operator and the assigned machines are observed. The movement of the operator and the time taken for the operator to perform the work tasks are observed and recorded. The six general tasks performed by the operator are raw materials replenishment, machine setup, machine solving, workslip update, prassing and inventory regulating. At the same time, the machines are monitored to identify the types and time-point of machine shortstops occurred throughout the entire inductor reels production. The response time of the operator to attend to the respective machine shortstops and the solving time are recorded as well. Two data collectors participate in the data collection where one data collector observes the movement of the operators while another data collector observes the operating conditions of the operator’s assigned machines. Different operator and machines are observed for each data collection in order to have a complete overview on the EST process, such that the required data about the three operators and the eight machines are gathered.

4.5 Construction of Current Model

With the collected data, worker-machine activity chart is plotted to analyze the interaction between the operator and the machines. Figure 4.3 shows one of the worker-machine activity charts plotted that illustrates the operator’s activity and the three S-type machines conditions in parallel. The first row of the chart represents the time frame for data tabulation. There is a total of 749 columns with each column scaled to 15 seconds duration. For better visual presentation and tabulation of the operator work tasks, colours are used for highlighting the six distinct general task categories as well as the other non-value-added activities which include off positioning, idling, and moving or walking of the operator. These work tasks categories are listed on the left column of the table. By referring to table 4.1, the operator’s work tasks legends are defined to ease the data representation. For machine part, the machine conditions for the three S-type machines, on which the operator works on, are listed with different cell colours on the left columns as well.

Table 4.2 shows the legends for the machine's condition. As the operator is required to work on at least two machines and most of the work tasks involving walking and material transportation, it takes a longer respond time for the operator to attend to each machine shortstop. The machine interference problem could be observed with ease by referring to the black coloured cells. The black coloured cells could also reflect the response time of the operator to the machine shortstops.

Table 4.1: Work Tasks Allocation between Operator and Water Spider for Four Cases

Operator's tasks		
Machine Solving	5S 1	Machine Solving (Core stuck) - Use vacuum or air gun
	Add	Machine Solving (Core missing / Empty pocket - use tweezer add core)
	Adj	Solving Tape Problem (Adjust tape)
	Cut E	Machine Solving (Cut Tape due to machine error)
	TW	Machine solving (Core stuck- Use tweezer)
	Refill	Machine Solving (Insufficient cores in the machine – pour the cores into the feeder)
Setup	5S 2	5S (Routine) - Use air gun ** Machine cleaning after every 2nd and 4th lot
	Cal	Calibration (Set up) Use the standby sample - pour the cores inside the container to the machine
	Cut S	Cut Tape (Stick on workslip, act as standby cores for machine error solving)
	Key	Data Key In (Machine)
	Rej	Setup (Remove rejected cores from machine and pour into plastic)
	Rec	Record - Workslip (Quantity produced)
	Replenishment	Replenishment (Core - place the core container to the machine)
	Refill	Refill - Core (Pour cores inside the container to the machine)
	Label	Label the last few reels after inspection
	RC	Reconnect the tape
Replenishment		Replenishment - from the Material Replenishment Rack - Embossed tape - Cover tape - Adhesive tape

		- Plastic reel
Refill		Refill - Core (Pour cores inside the container to the machine) - Tape (Install Embossed/cover/adhesive tape into the machine) - Plastic Reel (Put plastic reel into the machine)
Record		Record - Workslip - Daily Operator Record (DOR) - Label plastics used to keep rejected cores from machines - Machine breakdown record (logbook)
Others	Main PC	Issue Machine Breakdown/ Prassing / Confirmation of standby lot
	PC QC	Key in core details after subsample preparation and also print label
	SP	Setup (Subsample preparation - Calibration)
	N Clean	Non-routine cleaning on machine (Use cotton bud and liquid - IPA)
	Inp	Inspection on final product (reel) before labelling - every 5 reels
	Label	Labelling after inspection
	R Confirm	Reel Confirmation - Take 1 complete reel to QC (ON-line Checking)
	RC	Reconnect Cut Tape
	Inv	Transfer Finished Goods
	RT	Re-taping (Removes the reusable cores from the tape and put into container)
	Throw	Clean trash (Tape) inside the bins located at machine
	Inp T	Checking (Make sure the position of cores in tape within the specification)
	Cut QC	Cut Tape (Inpection / Embross carrier tape peeling force testing)
	Cut S	Cut Tape (Stick on workslip, act as standby cores for machine error solving)
	Key	Data key in
	Cal	Calibration of machine using standby cores
Off Position		Operator is out of working area
IDLE		Operator is not performing task
Walking		Operator travel from one wokstation to another workstation

Table 4.2: Machine's Conditions Legends

Machine's Conditions	
Operation	Machine is operating
Non-operation	Non-operation of machine (Machine breakdown/Machine setup)
Shortstop	Machine shortstops
Interference stop	Machine interference (Operator is busy with other tasks while the machine shortstop occurs or during machine setup)

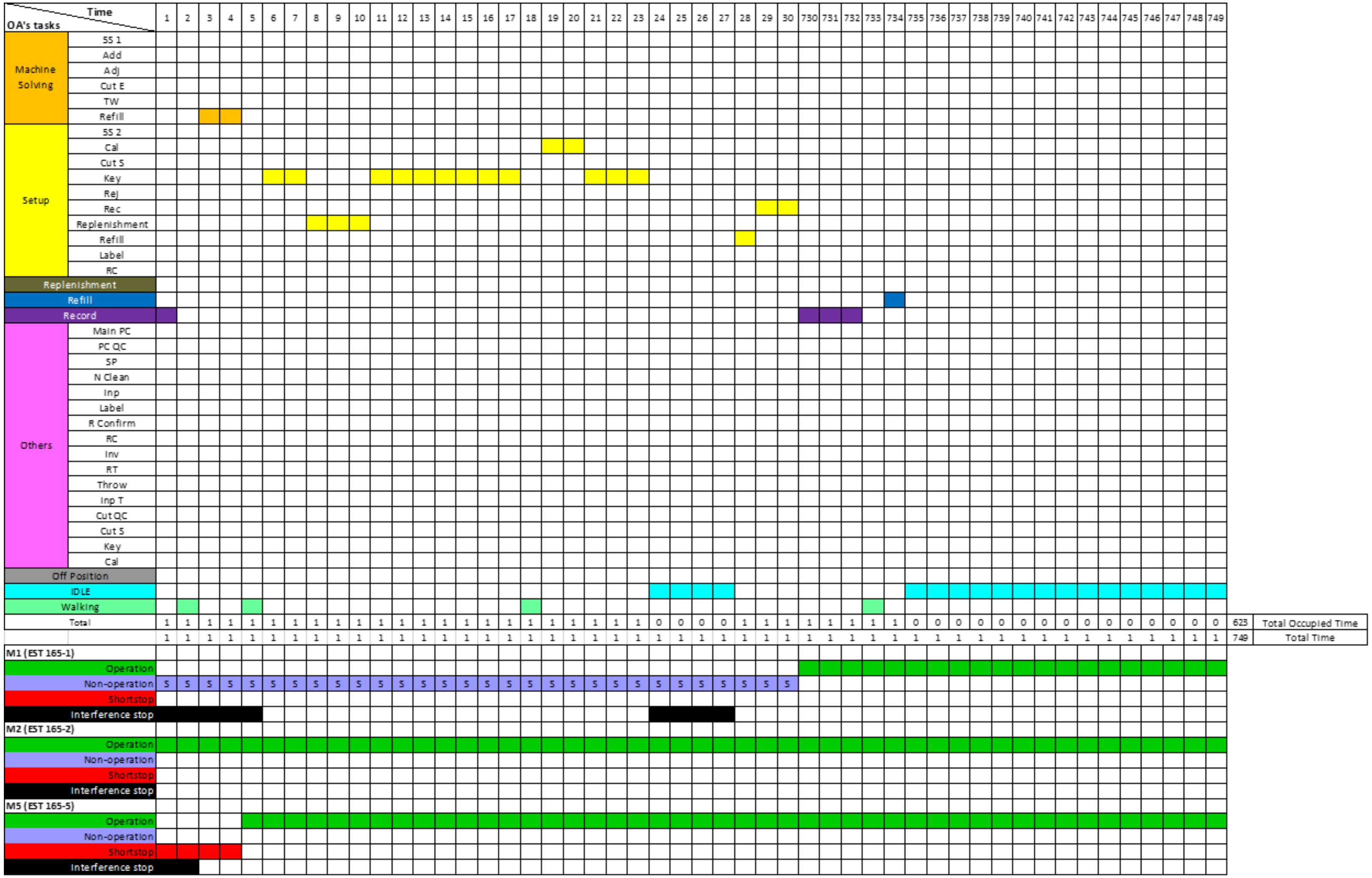


Figure 4.3: Worker-Machine Activity Chart

Based on the plotted worker-machine activity chart, a preliminary analysis is performed to evaluate the essential performance measures such as the machine efficiency and worker productivity. Four worker-machine activity charts averaged the eight machines and three operators are interpreted to determine the operating conditions and to provide an overview of the current EST model. Table 4.3 shows the performance measures computed that could reflect the operating conditions of the EST process.

Table 4.3: Operating Conditions of EST Process

<table>
<tr><th colspan="2">Machine</th><th colspan="2">Current</th></tr>
<tr><td colspan="2">Average Machine Efficiency</td><td colspan="2">72.6%</td></tr>
<tr><td colspan="2">Average Machine Breakdown Time</td><td colspan="2">7.1%</td></tr>
<tr><td rowspan="2">Average Setup Time</td><td>Interference</td><td>3.5%</td><td rowspan="2">9.8%</td></tr>
<tr><td>Actual</td><td>6.3%</td></tr>
<tr><td rowspan="2">Average Machine Shortstops Time</td><td>Interference</td><td>3.5%</td><td rowspan="2">10.5%</td></tr>
<tr><td>Actual</td><td>7.0%</td></tr>
<tr><td colspan="2">TOTAL</td><td colspan="2">100.0%</td></tr>
</table>

Worker	Current
Average Worker Productivity	76.4%

The average machine efficiency of the current model is 72.6% where the remaining 27.4% of time, the machines are not operating due to machine breakdown, machine shortstops and also machine setup. In this study, the main concern is to reduce the machine interference time for machine setup and machine shortstop which will help to improve the machine efficiency. For machine setup, it weighs 9.8% of the total machine operating time. Out of the 9.8% of machine setup time, 6.3% is the actual machine setup while the remaining 3.5% of time, setup interference occurs. Besides that, for the 10.5% out of the total machine operating time, the machines experience shortstops which is the decisive factor leading to the reduction in machine efficiency. Out of 10.5% of machine shortstops time, the actual shortstops time is only 7.0% while the remaining 3.5% of time, the operators could not attend to the machine immediately after the shortstops occur. The operator's performance is evaluated in term of worker productivity with the average of 76.4% for the current model.

4.6 Data Validation

The collected data is verified with the data provided by the company. Table 4.4 shows that the constructed EST model reflects the actual operating conditions of the EST process as the variations are small which stay between 0.2% to 1.4%. This indicates that the complete cycle of EST process could be observed with 2 hours of data collection over four data sets.

Table 4.4: Comparison between Collected Data and Company's Data

	Collected Data	Company's Data	% Deviation
Average Machine Efficiency	72.6%	71.2%	1.4%
Average Machine Breakdown Time	7.1%	7.3%	0.2%
Average Setup Time	9.8%	11.7%	1.9%
Average Machine Shortstops Time	10.5%	9.8%	0.7%

4.7 Propose Solutions for Future Model

In order to deal with machine interference problem, optimal job tasks allocation within the operators is the main target. Workforce flexibility is essential for job shop manufacturing system. Holonic Workforce Model (HWM) is proposed for EST process. As the work tasks for the operators in EST process involve a lot of transportation within the working area, the concept of water spider is recommended to incorporate with the HWM. Addition of one operator is proposed to be trained to become the water spider in EST process. Therefore, the workforce level of EST process is increased to 4 operators. The water spider is mainly responsible for the transportation and replenishment tasks for all themachines in the EST process. The water spider has to assist another 3 operators by taking up some of the work tasks to reduce the occurrence of machine interference problem during machine setup and machine shortstops. The water spider is an important element in HMS as he acts like a holon where he must be familiar with the EST process and capable of analyzing the job task priorities sequencing throughout the manufacturing system.

Four possible cases with distinct work tasks allocation between the operators and the water spider with the concept of holonic are proposed. Table 4.5 shows the work tasks allocation between the operator and the water spider for the four cases proposed. Priority rule is developed to make the operators and water spider more holonic where they are required to identify their optimum work task sequences according to the work tasks' priority. Work tasks that would directly affect the machine operation such as machine solving are given higher priority as compared to other non-value added activities such as workslip update. Preemption is only allowed when there is a machine shortstop occurs while the operator is performing a work task with lower priority, and the less-prioritized task is to be continued subsequently. For water spider, work tasks such as material replenishment that would indirectly affect the machine setup or machine operation are given higher priority as compared to other work tasks such as clean trash and re-taping that do not contribute to machine operation.

Apart from that, a little amendment is suggested to the current layout of EST process. In the current layout, all the workstations are located near to the EST machines except the outgoing quality control (OQC) station. Thus, it is more convenient to the operator if another OQC station is located near to the EST machines which could help to shorten the distance travelled by the operator.

Table 4.5: Work tasks allocation between operator and water spider for four cases

Work tasks (√ - Operator, X – Water Spider)		Case 1	Case 2	Case 3	Case 4
Machine Solving	5S 1	√	√	√	√
	Add	√	√	√	√
	Adj	√	√	√	√
	Cut E	√	√	√	√
	TW	√	√	√	√

	Refill	√	√	√	√
Setup	5S 2	X	X	√	√
	Cal	X	X	√	√
	Cut S	X	X	√	√
	Key	X	X	√	√
	Rej	X	X	√	√
	Rec	X	X	√	√
	Replenishment	X	X	√	X
	Refill	X	X	√	√
	Label	X	X	√	√
	RC	X	X	√	√
Replenishment		X	X	X	X
Refill		√	√	X	√
Record		√	√	X	√
Others	Main PC	X	X	X	X
	PC QC	X	X	X	X
	SP	X	X	X	X
	N Clean	√	√	√	√
	Inp	√	√	X	√
	Label	√	√	X	√
	R Confirm	X	X	X	X
	RC	X	√	X	√
	Inv	X	X	X	X
	RT	X	X	X	X
	Throw	X	X	X	X
	Inp T	X	√	X	√
	Cut QC	√	√	X	√
	Cut S	√	√	X	√
	Key	√	√	√	√
	Cal	√	√	√	√

For case 1, machine setup and all the tasks that involve material transportation which is one of the manufacturing wastes are assigned to the water spider. Basically, the operator is responsible for the work tasks that could be carried out within the machine area which include machine solving, materials refill, workslip record and labelling. The operators in this case could stay within the operator working area and always available for solving machine errors and thus reduce the machine stoppage time. In this case, although machine setup is performed within the machine area, machine setup is assigned to water spider. Since the water spider is responsible for machine setup, two machine-based tasks which are RC and Inp T are assigned to water spider as well. For case 2, the overall job tasks allocation and the movement of operator and water spider is similar to case 1 with minimal changes by shifting the two machine-based tasks which are RC and Inp T from water spider to operator. Figure 4.4 shows the work tasks allocation and the movement of operator and water spider for case 1 and case 2.

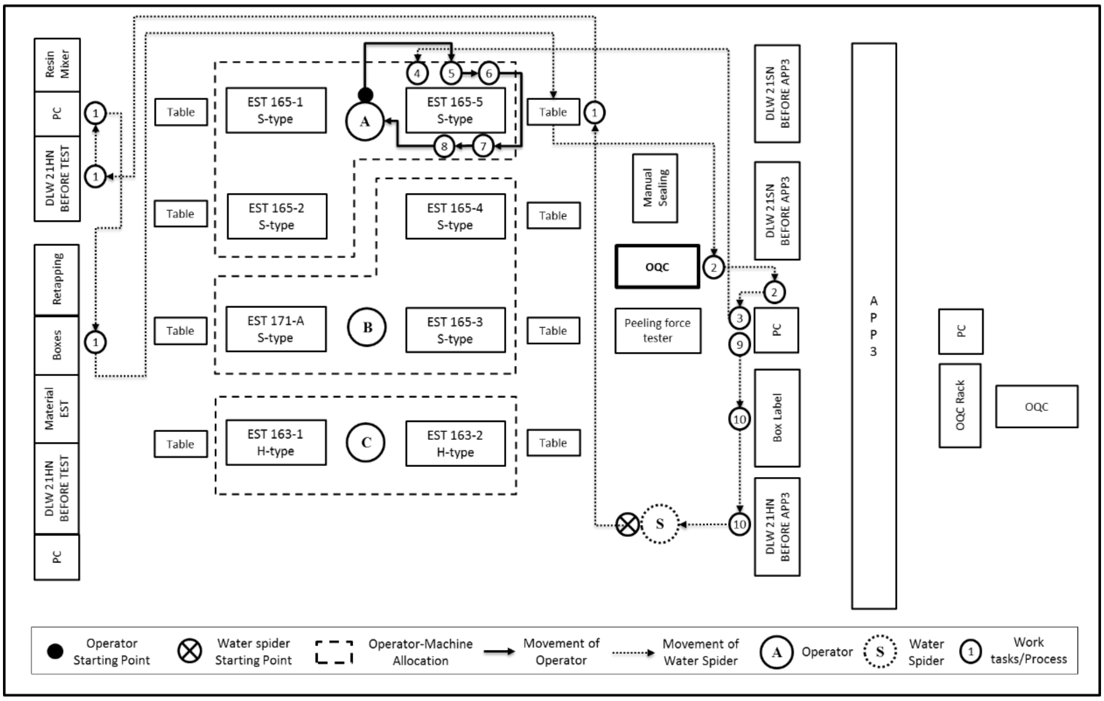


Figure 4.4: Work Tasks Allocation and Movement of Operator and Water Spider (Case 1 and 2)

For case 3, the job tasks allocation is mainly based on inner and outer work tasks. Inner work tasks are the non-value added activities whereby the machine is not running during the task execution. Outer work tasks do not affect the productivity of the manufacturing system whereby the operator performs the tasks while the machine is running. In order to improve on the system productivity, the inner work tasks are carried out by the respective operator while the water spider is responsible for the outer work tasks for all the eight machines. Figure 4.5 shows the work tasks allocation and the movement of operator and water spider for case 3.

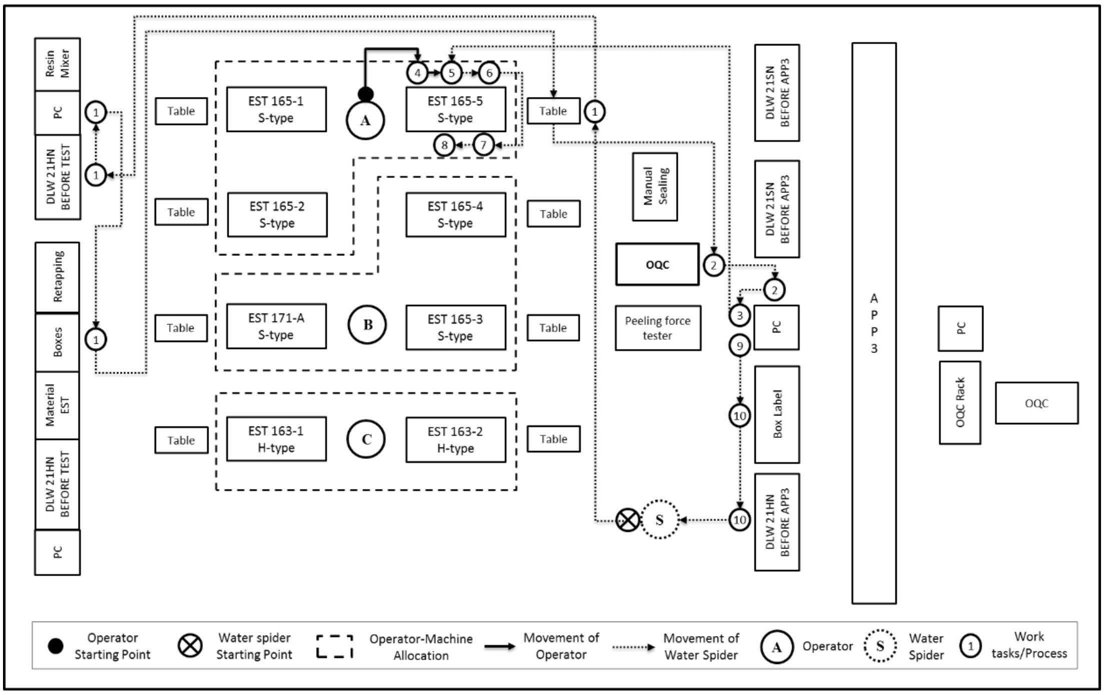


Figure 4.5: Work Tasks Allocation and Movement of Operator and Water Spider (Case 3)

For case 4, the job tasks are categorized into online tasks and offline tasks. Online tasks are defined as the work tasks that are executed by the operator within the operator working area while offline tasks are the work tasks that need to be carried out by the operator outside the operator working area. Transportation is considered as one of the offline tasks. In this case, the online tasks are assigned to the operator while the offline tasks are assigned to the water spider. Machine setup which consists of online and offline setup tasks is performed by both operator and water spider respectively. Figure 4.6 shows the work tasks allocation and the movement of operator and water spider for case 4.

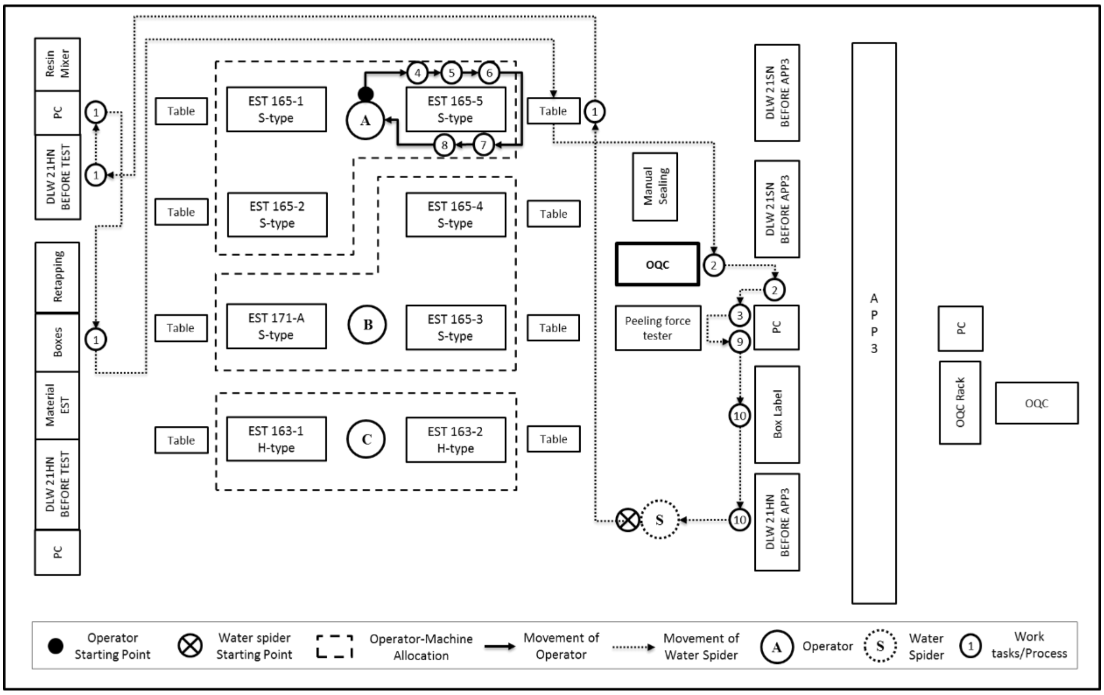


Figure 4.6: Work Tasks Allocation and Movement of Operator and Water Spider (Case 4)

4.8 Filtering of Infeasible Solutions for Future Model

The four cases proposed are analyzed to filter the feasible solutions that could trigger a distinct improvement on the machine efficiency and at the same time maintain the suitable level of worker productivity. This is done to simplify the analysis by reducing the unnecessary effort in evaluating non-feasible solutions.

Among the four cases, the machine setup job is categorized into three distinct scenarios. For the first and second cases, the entire setup process is performed by the water spider. The operator is responsible for machine setup job in the third case. Whereas in the fourth case, the setup tasks are shared between them such that operator deals with on-spot setup job tasks while setup tasks that must be done outside working area are handled by water spider. For case 1 and case 2, the water spider is solely responsible for the machine setup as it has long task time and to avoid preemption during machine setup. By comparing case 1 and case 2, the only difference is the allocation of the two machine-based tasks between the operator and water spider. The two machine-based tasks are assigned to water spider in case 1 to maintain the process flow of the production as these two tasks are performed after the machine setup. In case 2, except for machine setup, the water spider is responsible for all the work tasks that need to be performed outside the machine area. Therefore, the two machine-based tasks are performed by the operator instead of water spider. Case 2 is preferable with the consideration that the two machine-based tasks could only be performed after the machine starts operating for a period time. The operator who always stays within the machine area could perform these tasks more conveniently while the water spider could proceed to other work tasks right after the machine setup.

By comparing case 3 and case 4 in term of operator's availability to machine shortstops, operators in case 4 can always attend to machine shortstops quickly as the operators only perform their work tasks within the working area. Besides that, in case 3, the water spider is responsible for the inner tasks of all the eight machines. Since the machines are running at most of the time, it can be anticipated that there are much more outer tasks than inner tasks hence resulting in overloading workload of the water spider in contrast to the workload of the operators. From the perspective of conducting workforce training and to deliver clear and straightforward instructions within the manufacturing system, job tasks allocation in case 4 is desirable as there is no overlapping working area between the operator and water spider. Therefore, among the four proposed solutions, case 2 and case 4 are the feasible solutions proposed for the future model.

4.9 Construction of Future Models to Select Best Model

Manual simulation is performed to illustrate the system performance of EST process with the job tasks allocation stated in case 2 and case 4. In order to ensure the validity of the simulation results, several assumptions are made during the manual simulation. Firstly, the time where the machine errors occur in the current model is remained in the simulation for the construction of future model. Principally, when the machine error time is maintained in the simulation, the probability and stochasticity of errors are well-retained, yet simultaneously any significant change in worker response time after the implementation can be observed clearly and compared in analytical phase. Secondly, the machine breakdown time is remained constant as machine breakdown is attended by the technicians and the operators do not responsible for solving machine breakdown.

At current stage, the manual simulation is performed with the workforce level improved to four operators as an additional operator is added to the EST process to be trained as water spider. The simulation involves eight machines which consists of six S-type machines and two H-type machines. In the simulation, the three operators are assumed to be identical with same level of skills and abilities. Besides that, the operator that trained to become the water spider is assumed to be an experienced or senior operator that familiar with all the work tasks in EST process.

Future models are constructed with the proposed feasible solutions with different task allocation between operators and water spider by using the concept of HMS. The best model is selected based on the effectiveness of the model in solving machine interference problem in EST process. Table 4.6 shows the comparison between the performance measures of case 2 and case 4.

Table 4.6: Comparison between the performance measures of Case 2 and Case 4

<table>
<tr><th colspan="2">Machine</th><th colspan="2">Current</th><th colspan="2">Case 2</th><th colspan="2">Case 4</th></tr>
<tr><td colspan="2">Average Machine Efficiency</td><td colspan="2">72.6%</td><td colspan="2">77.6%</td><td colspan="2">78.2%</td></tr>
<tr><td colspan="2">Average Machine Breakdown Time</td><td colspan="2">7.1%</td><td colspan="2">7.1%</td><td colspan="2">6.4%</td></tr>
<tr><td rowspan="2">Average Setup Time</td><td>Interference</td><td>3.5%</td><td rowspan="2">9.8%</td><td>0.2%</td><td rowspan="2">6.7%</td><td>0.6%</td><td rowspan="2">7.8%</td></tr>
<tr><td>Actual</td><td>6.3%</td><td>6.5%</td><td>7.2%</td></tr>
<tr><td rowspan="2">Average Machine Shortstops Time</td><td>Interference</td><td>3.5%</td><td rowspan="2">10.5%</td><td>1.9%</td><td rowspan="2">8.6%</td><td>1.5%</td><td rowspan="2">7.6%</td></tr>
<tr><td>Actual</td><td>7.0%</td><td>6.7%</td><td>6.1%</td></tr>
<tr><td colspan="2">TOTAL</td><td colspan="2">100.0%</td><td colspan="2">100.0%</td><td colspan="2">100.0%</td></tr>
</table>

Worker	**Current**	**Case 2**	**Case 4**
Average Operator Utilization	-	52.4%	60.7%
Water Spider Utilization	-	85.8%	58.0%
Average Worker Utilization	76.4%	60.8%	60.1%

Standard Deviation	Current	Case 2	Case 4
Machine Efficiency	0.1655	0.1914	0.1901
Worker Utilization	0.0800	0.2007	0.0622

By referring to table 4.6, it could be concluded that both case 2 and case 4 show feasibility in improving the average machine efficiency whereby the average machine efficiency is improved from 72.6% to 77.6% and 78.2% respectively. Case 4 has the highest increased percentage in machine efficiency of 5.6%. The average machine breakdown time remained almost constant during the simulation with a small deviation of 0.7% in case 4 as the operators do not responsible in solving machine breakdown. Principally, the average machine efficiency is improved by reducing the average setup time and machine shortstop time. From the table, it is shown that the average setup time in case 2 and case 4 is reduced as compared to the current model from 9.8% to 6.7% and 7.8% respectively. The average machine shortstops time of the current model is 10.5% and it could be reduced to 8.6% in case 2 and 7.6% in case 4. The focus of this study is to minimize the machine interference problem during machine setup and machine shortstops. In term of machine setup, case 2 is preferable as the average interference machine setup time is reduced from 3.5% to 0.2% with a total reduction of 3.3%. For case 4, the total reduction in average interference machine setup time is only 2.9% which is from 3.5% to 0.6%. In term of machine shortstops, case 4 is preferable as the average interference machine shortstops time is reduced from 3.5% to 1.5% with a total reduction of 2.0%. For case 2, the total reduction in average interference machine shortstops time is only 1.6% which is from 3.5% to 1.9%.

In the current model, all the operators are performing the similar work tasks on their respective machines in EST process. The overall worker utilization is 76.4%. For both proposed feasible cases, water spider is introduced into the EST process. Water spider has a distinct work tasks allocation from the ordinary operators. Hence, in order to better monitor the utilization of all the labors and ensure workload balancing between the operators and the water spider, the utilization rate of both operator and water spider are computed individually. The average worker utilization rate is reduced from 76.4% to 60.8% in case 2 and 60.1% in case 4. Both case 2 and case 4 have the similar average worker utilization rate with a minimal difference of

0.7% as the overall work tasks allocation in both cases is almost identical. In case 2, the average operator utilization is 52.4% and the water spider utilization is 85.8%. Whereas in case 4, the average operator utilization is 60.7% and the water spider utilization is 58.0%.

In this study, the standard deviation is calculated to determine the variability for the average machine efficiency and the average worker utilization in case 2 and case 4. The standard deviation value for both cases are slightly higher than the current model. This is because there are only a few machines encountered machine breakdown during data collection where the machine breakdown time is assumed to be a constant variable in the simulation model. The implementation of holonic workforce allocation does not improve on the machine breakdown time. Machines encountered machine breakdown during the data collection tend to have lower machine efficiency as compared to other machines that operate normally during data collection. The value of standard deviation for average machine efficiency is 0.1914 for case 2 and 0.1901 for case 4 with a slight difference of 0.0013.

The value of standard deviation for average worker utilization is 0.2007 for case 2 and 0.0622 for case 4 with a difference of 0.1385. This is because in case 2, the machine setup is fully assigned to water spider while in case 4, the machine setup tasks are assigned to both operator and water spider. Machine setup consumes the longest time compared to the other tasks as it consists of a series of work tasks and thus results in higher variation in the worker utilization of each operator in case 2. As compared to the current model, case 4 with lower standard deviation is preferable as the workload for all the workers is more equitable with the proposed workforce and work tasks allocation.

Based on the objective of this study, better workforce and work tasks allocation are targeted to improve on EST system output and machine efficiency. Overall, the improvement on the machine efficiency of EST process could be achieved with the reduction of interference machine shortstops and machine setup. Through the study and analysis on the EST process, the occurrence of machine shortstops is more frequent as compared to the machine setup and thus the shortstops interference reduction is highly valued in contrast to setup interference reduction.

Therefore, case 4 with greater significant reduction in machine interference shortstops time is selected. Besides that, in case 4, the operators are responsible for the online tasks within the machine area while the offline tasks that need to be carried out outside the machine area are assigned to the water spider. There is no overlapping of working area for the water spider and the water spider in performing their respective work tasks. With the workforce and work tasks allocation proposed in case 4, workforce training is more effective and easier to be conducted without confusion in work tasks allocation between the operators and the water spider. Apart from that, case 4 is selected as the best model with its lower standard deviation values for both machine efficiency and worker utilization. Theoretically, lower standard deviation is preferable as it indicates that the variation in performance between the machines or the workers is smaller and hence the result is more reliable. For the application in real industry environment, case 4 illustrates better workforce planning by allocating similar workload among all the workers in EST process.

Table 4.7: Simulation Analysis (Case 2)

<table>
<tr><th colspan="2">Machine</th><th colspan="2">Current</th><th colspan="2">Case 2</th><th colspan="2">Difference</th></tr>
<tr><td colspan="2">Average Machine Efficiency</td><td colspan="2">72.6%</td><td colspan="2">77.6%</td><td colspan="2">+5.0%</td></tr>
<tr><td colspan="2">Average Machine Breakdown Time</td><td colspan="2">7.1%</td><td colspan="2">7.1%</td><td colspan="2">0.0%</td></tr>
<tr><td rowspan="2">Average Setup Time</td><td>Interference</td><td>3.5%</td><td rowspan="2">9.8%</td><td>0.2%</td><td rowspan="2">6.7%</td><td>-3.3%</td><td rowspan="2">-3.1%</td></tr>
<tr><td>Actual</td><td>6.3%</td><td>6.5%</td><td>+0.2%</td></tr>
<tr><td rowspan="2">Average Machine Shortstops Time</td><td>Interference</td><td>3.5%</td><td rowspan="2">10.5%</td><td>1.9%</td><td rowspan="2">8.6%</td><td>-1.6%</td><td rowspan="2">-1.9%</td></tr>
<tr><td>Actual</td><td>7.0%</td><td>6.7%</td><td>-0.3%</td></tr>
<tr><td colspan="2">TOTAL</td><td colspan="2">100.0%</td><td colspan="2">100.0%</td><td colspan="2">-</td></tr>
</table>

Worker	Current	Case 2	Difference
Average Operator Utilization	-	52.4%	-
Water Spider Utilization	-	85.8%	-
Average Worker Utilization	76.4%	60.8%	-15.6%

Table 4.7 shows the analysis of the simulation results for case 2. The average machine efficiency is increased from 72.6% to 77.6% with the difference of 5.0%. The average machine breakdown time is a constant between the current model and

case 2. For machine setup, the average setup time is reduced from 9.8% to 6.7% with a difference of 3.1%. Currently, each machine setup in EST process consumes about 12 minutes of time but with the improvement suggested in case 2, the machine setup time could be reduced to about 8 minutes. In current model, the machine setup is preemptive as the machine shortstop has a higher priority than machine setup and therefore setup interference occurs. In case 2, the machine setup tasks are assigned to the water spider and thus the setup interference time is reduced as the machine setup is carried out by the water spider and not affected by any arisen machine shortstops. The average setup interference time is reduced from 3.5% to 0.2% with a difference of 3.3% which is about 4 minutes in time. The setup interference in this case is due to the water spider is performing other tasks outside the machine area and as a result the setup might be delayed. By comparing the average machine shortstops time in case 2, it has been reduced from 10.5% to 8.6% with the total reduction of 1.9% as compared to the current model. This is because the operator can always focus on solving machine shortstops as all the machine setup tasks and the work tasks that involve transportation such as material replenishment are assigned to water spider. This also leads to the reduction of average interference shortstops time from 3.5% to 1.9% with a difference of 1.6%. However, the average worker utilization rate decreases from 76.4% to 60.8% due to the fact that water spider and the operators have different workloads.

Table 4.8: Simulation Analysis (Case 4)

<table>
<tr><th colspan="2">Machine</th><th colspan="2">Current</th><th colspan="2">Case 4</th><th colspan="2">Difference</th></tr>
<tr><td colspan="2">Average Machine Efficiency</td><td colspan="2">72.6%</td><td colspan="2">78.2%</td><td colspan="2">+5.6%</td></tr>
<tr><td colspan="2">Average Machine Breakdown Time</td><td colspan="2">7.1%</td><td colspan="2">6.4%</td><td colspan="2">+0.7%</td></tr>
<tr><td rowspan="2">Average Setup Time</td><td>Interference</td><td>3.5%</td><td rowspan="2">9.8%</td><td>0.6%</td><td rowspan="2">7.8%</td><td>-2.9</td><td rowspan="2">-2.0%</td></tr>
<tr><td>Actual</td><td>6.3%</td><td>7.2%</td><td>+0.9</td></tr>
<tr><td rowspan="2">Average Machine Shortstops Time</td><td>Interference</td><td>3.5%</td><td rowspan="2">10.5%</td><td>1.5%</td><td rowspan="2">7.6%</td><td>-2.0</td><td rowspan="2">-2.9%</td></tr>
<tr><td>Actual</td><td>7.0%</td><td>6.1%</td><td>+0.9</td></tr>
<tr><td colspan="2">TOTAL</td><td colspan="2">100.0%</td><td colspan="2">100.0%</td><td colspan="2">-</td></tr>
</table>

Worker	Current	Case 4	Difference
Average Operator Utilization	-	60.7%	-
Water Spider Utilization	-	58.0%	-
Average Worker Utilization	76.4%	60.1%	-16.3%

Table 4.8 shows the analysis of the simulation results for Case 4. With the operators and work tasks allocation proposed in case 4, the average machine efficiency could be improved from 72.6% in current model to 78.2% with a difference of 5.6%. The average machine breakdown time is remained almost constant with only a minimal difference of 0.7% between the current model and case 4. The average machine setup time is reduced from 9.8% to 7.8% with a total reduction of 2.0% which is about 2 minutes in time. The average interference setup time reduced is 2.9%, which is about 4 minute in time. The average interference setup time is reduced from 3.5% to 0.6%. The reduction of average machine setup time is smaller as compared to case 2. This is because the machine setup in case 4 is carried out by both the operator and the water spider and thus the some of the setup tasks that are assigned to the operator might be interfered by the occurrence of machine shortstops. For case 4, the operator is responsible for all the online tasks which could be carried out within the machine area whereas the water spider is responsible for the remaining offline tasks which require him to travel out from the machine areas. In addition, the machine shortstop has the highest priority among the assigned tasks to the operator as most of the online tasks are preemptive. As a result, the average interference machine shortstops time could be reduced from 3.5% to 1.5%, a total reduction of 2.0%. This leads to the reduction of average machine shortstops time of 2.9%, which is from 10.5% to 7.6%. The average worker utilization for case 4 is 60.1%, which is lower than the current model of 76.4%. This is due to the water spider and the operators are now having slightly different workload as compared to the current model where all the workers are having equal work tasks and workload.

4.10 Implementation of Future Model

4.10.1 Workforce Training

First of all, the workforce training has to be done before the actual implementation could be carried out in the EST process. The senior or experienced operators are trained to function as the water spider. In order to ensure smooth production flow and high process output, the company had decided to recruit one extra operator to assist the EST process. As such, the workforce level of EST process is increased to 4 workers which consist of 3 operators and 1 water spider. Through the analysis, the unusual events that commonly faced by the company are the absence of workers and breakdown of multiple machines at the same time. With holonic workforce allocation, the workers are trained to be more holonic and the decision making process on the EST process could be carried out more efficiently. In the event of multiple machine breakdowns, one of the operators could be shifted to perform the water spider's job tasks. For example, there will be a combination of 2 WS + 2 OA instead of 1 WS + 3 OA under normal operation. Besides that, as all the operators are cross-trained in which they are trained to take care of both S-type and H-type machines, the idle operator could be assigned to take care of any machines when there are multiple machines breakdown at the same time. Whereas in the event of absenteeism of worker, the trained water spider is reverted back to an ordinary operator, whereby no distinct work tasks allocation among the workers. The workforce in EST will then contain with ordinary operators only, which is synonymous to current model. Cross-training is introduced in workforce training in order to improve the flexibility of workforce planning and the ability of EST process to deal with unusual events. All the workers are trained to perform job tasks under two distinct operating situations: with and without water spider. Among the 4 workers, 3 senior workers are cross-trained to ensure they could shift between ordinary operators and water spider under unusual events. The training of operators took about 3 weeks time.

4.10.2 Layout Modification

Minor changes were applied to the current layout of EST process to facilitate the movement of workers while performing their work tasks. In order to shorten the travelling distance of the water spider, one additional outgoing quality control (OQC) station is placed near to the machine area as shown in Figure 4.8. In the proposed model, the coverage of the work area for water spider is larger compared to the ordinary operators as the water spider is responsible for all the offline tasks that involve abundant of movement outside the machine area. Indicator lights are newly installed next to each machine in order to alert the water spider about pending work tasks. For example, as soon as the operator on-line completed the machine setup, the operator would actuate the indicator light so that the water spider could move to the station and proceed with the next work task such as prassing for the particular machine. Besides that, water spider is equipped with a trolley to eliminate the redundant movement while performing work-in-process (WIP) transportation. For example, the water spider could perform material replenishment at the raw material racks for multiple machines simultaneously because a trolley can accommodate the required raw materials for more than one machine at once.

4.10.3 Test Run

Several test runs are conducted to determine the outcome of the proposed model and to ensure all the workers are familiar with their new job scope. EST process consists of 2 working shifts with a daily production time of 1305 minutes. Day shift covers 675 minutes whilst night shift comprises 630 minutes. In this study, data collection on EST process was performed during the day shift and thus the test run is initiated on the day shift. The test run involves all the 8 EST machines as an additional worker is added to assist in the EST process. There are 4 workers which are 3 operators and 1 water spider participated in the test run. Since proper cross-training requires relatively lengthy and detailed planning for effective implementation, thus, for the test running purpose, a normal operator instead of senior operator is assigned to conduct the work tasks of a water spider. This is because the proposed work tasks for the water spider do not require specific skills in machine handling. During the test run, the movement of the workers and the difficulties faced by the workers especially for the water spider while performing their tasks are observed. The simulated results together with the implementation are detailed planned and discussed with the production and industrial engineering department of the company. Based on the evaluation, the test run performed can reflect near to the actual operating conditions in post-implementation phase. Hence, the test run results are highly reliable and feasible.

4.11 Suggestions for Future Implementation

4.11.1 Workforce Planning

Through the test run, the company found out that the water spider utilization could be further improved by allocating extra work tasks from the appearance checking process (APP3). The workstations of APP3 are located next to the EST process. Figure 4.7 shows the work tasks that need to be performed by the operators and water spider in both the EST and APP3 processes. The newly assigned tasks to the water spider are the material replenishment and inventory tasks in APP3. Figure 4.8 shows the movement of the operators and the water spider.

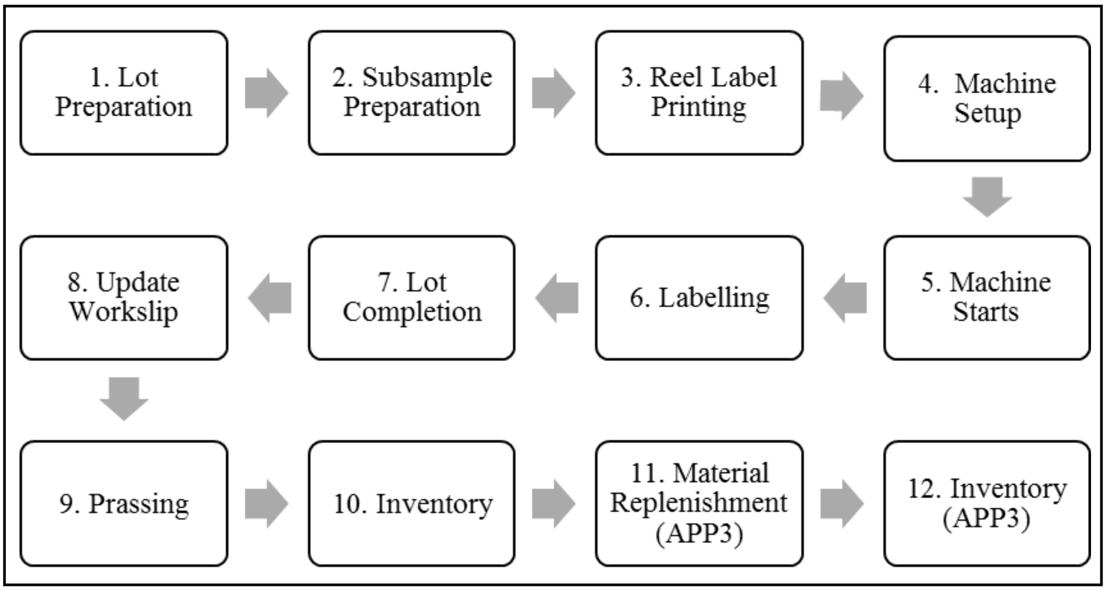


Figure 4.7: Operators and Water Spider's Work Tasks Execution Flow

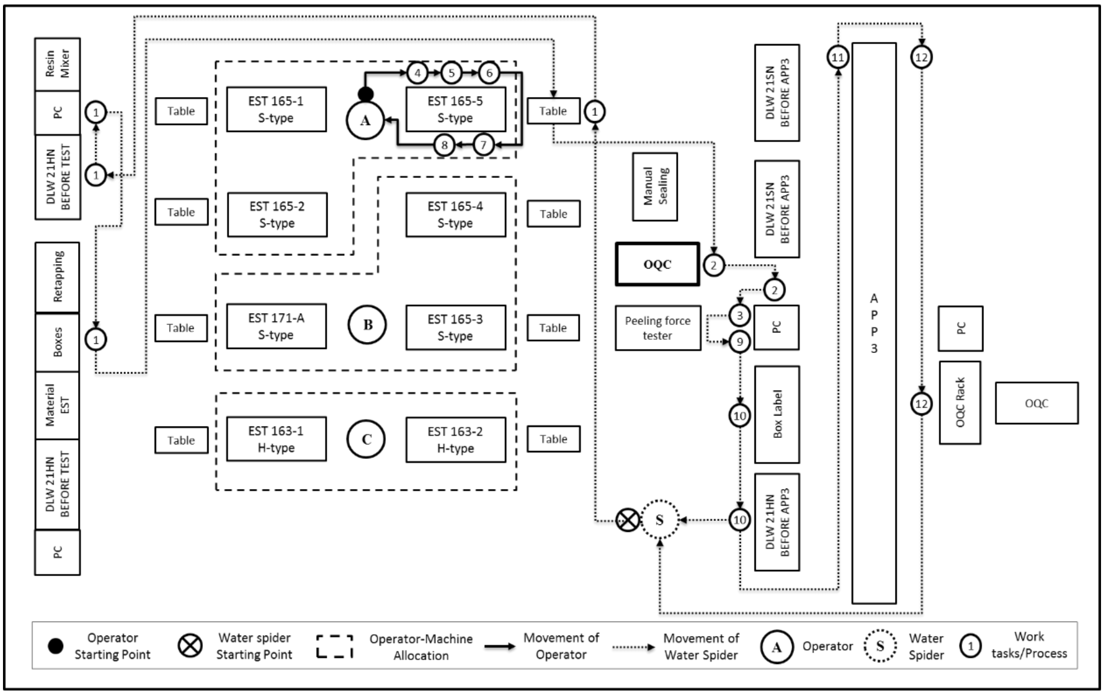


Figure 4.8: Work Tasks Allocation and Movement of Operator and Water Spider

In addition, the flexibility of the EST process could be further improved by promoting cross training among all 4 workers in EST process. All the workers should be trained to work as operator and water spider for the ease of workforce allocation during unusual situation. Unlike in most manufacturing line, step-by-step instructions are given by the line leaders to the operators for roles or job tasks switching. In this case, all the workers are characterized more towards holons where every worker is autonomous and capable of analyzing job task priorities sequencing. For example, during unusual scenario such as multiple machine breakdowns and whereby all available workers are cross-trained, they can easily switch between the role of normal operator and water spider with highest flexibility. A holonic manufacturing system would allow EST process to deal with dynamic production.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Continuous improvement on the manufacturing system by improving the manufacturing productivity and product quality is a crucial factor for a company to uphold its market position and maintain the competitive edge among the competitors. In this study, a research is conducted based on a case study in a global electronic company that manufactures and supplies electronic components. Process-oriented layout is adopted in the manufacturing system so that the company could provide a wide range of product varieties in order to satisfy different customers' demand. Electrical sorting and taping (EST) process which is one of the manufacturing processes of reel inductors is chosen for the case study. The objective of this study is to improve the productivity of the manufacturing system by introducing better worker-machine allocation and also work tasks allocation among the workers in EST process.

The reduction in average machine efficiency in EST process is mainly caused by the machine interference problem. Machine interference problem occurs when there are two or more work tasks pending to be completed by the operators at the same time. Currently, there is no any specific rule that acts as the guideline for the operators to deal with the machine interference problems. They only follow one rule that is set by the company whereby they must complete the work tasks on hand before they can perform the following tasks as preemption is prohibited in EST process. Therefore, the machine interference problem recurs as machine shortstop occurs frequently in EST process and it is unpredictable. Besides that, in the current manufacturing system, all the operators in EST process are assigned with similar and fixed tasks. The flexibility in workforce and work tasks allocations are restricted especially when there are some unusual events such as multiple machines breakdown simultaneously.

Holonic Manufacturing System (HMS) is proposed for EST process to improve the average machine efficiency with flexible workforce and work tasks allocations. It also helps to reduce the occurrence of machine interference problem. By introducing holonic workforce allocation, the operators are trained to be more holonic where they are able to identify the optimum work task sequence by considering the work tasks' priority. Work tasks that directly affect the machine operation such as machine shortstop have higher priority as compared to other non-value added activities such as workslip update. Preemption is only allowed when there is a machine shortstop occurs while the operator is performing a work task with lower priority, and the less-prioritized task is to be continued subsequently. By doing this, the machine stoppage time could be effectively reduced so as to increase the average machine efficiency of EST process. Besides that, water spider is introduced to facilitate the holonic workforce allocation. Water spider is solely responsible for non-machine based work tasks to increase the availability of the operators on-line for solving machine shortstops. The senior and experienced workers are trained as water spider. This is because the water spider has to behave like a holon where he is able to take care of the whole EST process by identifying the work tasks priority based on his own skills and experience. Apart from that, cross training is promoted among the operators to encounter the unusual event such as absence of worker. The operators are trained to deal with two different scenarios which are with water spider and without water spider.

In this study, data collection is performed on EST process and worker-machine activity chart is utilized to illustrate the interaction between the operators and their assigned machines. Manual simulation is carried out to demonstrate the actual operating condition of the current EST process and the simulation result is validated with the actual data provided by the company to determine the effectiveness of the manual simulation model. Four different cases of work tasks allocation between the operator and water spider are proposed to reduce the machine interference problem in EST process. One similarity among the four cases is that the operators are fully responsible on the machine solving tasks for their respective machines. The significant difference between the four cases is the allocation of the machine setup tasks between the operator and the water spider.

For case 1 and case 2, the machine setup tasks are fully performed by the water spider while in case 3 the machine setup is fully performed by the operator. In case 4, the machine setup is performed by the operator with the aid from water spider. Case 1 and case 2 have similar work tasks allocation between the operators and the water spider. The only difference between these two cases is that the two machine-based activities that are assigned to the water spider in case 1 are instead conducted by the operators in case 2. Case 2 is preferable as the machine interference time could be kept at minimal if the two machine-based activities are allocated to the operators who stay at the machine area for most of the time and to avoid confusion.

For case 3 and case 4, the machine setup tasks are conducted by the operators. A slight difference in case 4 as compared to case 3 is that the water spider assists the operators in conducting the setup tasks that need to be done outside the working area such as material replenishment. In case 3, the operators are responsible for all the inner tasks where the machine stops operating until these tasks are completed. The water spider is responsible for all the outer tasks in which the machine continues to operate while these tasks are ongoing. In case 4, the operators are assigned with online tasks which keep them to stay within the working area during their execution of tasks while the water spider is responsible for the offline tasks that need to be done outside the working area. Therefore, case 4 is preferable as the operator could focus on the machine setup and machine solving without the need of travelling outside the working area. As a result, case 2 and case 4 are selected as the feasible cases which could help in achieving greater improvement on the average machine efficiency.

For the two feasible cases, simulations using chosen parameters are carried out for constructing the future models in order to obtain the respective performance measures. The feasible model that could result in larger machine interference time reduction is chosen for implementation. For case 2, the resulting average machine efficiency is 77.6% with an increase of 5.0% as compared to the current model of

EST process. According to the simulation results, the average interference setup time in case 2 is 0.2% and the total average machine setup time is effectively reduced to 6.7% of the total machine operating time. Besides that, the average machine shortstops time is also reduced to 8.6% due to the reduction in the average interference machine shortstops time to 1.9% of the total machine operating time.

For case 4, the average machine efficiency obtained from the simulation results is 78.2% which is higher than case 2 and with an increment of 5.6% as compared to the current model of EST process. In term of average machine setup time, case 4 has slightly higher percentage of 7.8% than case 2 with only 6.7%. The average interference machine setup time in case 4 is also higher as compared to case 2 with a total percentage of 0.6%. However, case 4 has a more significant improvement on the average machine shortstops than in case 2. The average machine shortstops time is reduced to 7.6% as compared to case 2 with the shortstops time of 8.6%. This is also indicates that case 4 has greater reduction in average interference machine shortstops time to 1.5% than case 2 with the interference time of 1.9%.

By comparing case 2 and case 4 using the simulation results, case 4 is preferable as it could result in greater improvement in the average machine efficiency, which is 78.2%. Based on the evaluation on machine efficiency improvement, case 2 excels in terms of reducing the interference machine setup time whereas case 4 tops in terms of shortening the interference machine shortstops time. Case 4 is conclusively chosen. This is because the occurrence of machine shortstops in EST process is more frequent as compared to the machine setup and thus the improvement on machine shortstops is more significant than machine setup. The work tasks allocation in case 2 and case 4 are similar where the operators stay within the operator working area at all time and are always standby for attending machine shortstops. The difference between the two cases is the task allocation for machine setup. Machine setup in case 2 is fully performed by water spider while both the operators and the water spider are involved in machine setup in case 4. In actual implementation, the workforce and work tasks allocations in case 4 is more desirable as there is no overlapping of working area between the operators and the water spider that helps to avoid confusion in task allocation and thus the training of operator could be done effectively. Most importantly, case 4 achieves the main objective of this study in resulting higher average machine efficiency than case 2.

In this study, manual simulation is utilized for the construction of current model to reflect the actual operating situation of the EST process. Manual simulations are also performed to compare the feasibility of the future models constructed based on the workforce and work tasks allocation proposed in case 2 and case 4. However, manual simulation has its limitations whereby it can only include a few parameters such as the work tasks completion time, machine shortstops time, machine breakdown time and machine setup time.

Besides that, the results of implementation could not be obtained immediately as proper operator training is necessary for the operators to be more holonic before the real implementation can take place in EST process. This is because the cross training into implementation takes time to achieve significant improvement, whereby depending on uncontrollable factors such as learning curve of operators and water spider. The outcome of the operator training differs for individual operators depending on their personal experiences and skills.

5.2 Recommendations for Future Studies

There are several recommendations for future studies in order to achieve more significant improvement:

- A more reliable simulation model such as simulation software could be used to replace manual simulation in order to incorporate more essential parameters into the simulation model such as desired daily production, takt rate, operator's working shift, operator's daily working hour and etc.
- Cross training performed only on experienced operators which attain high level of skills instead of inexperienced operators or trainees for implementation. A steep learning curve with a substantial time-effective learning process can be acquired due to the familiarization of experienced operators with existing work tasks.
- Replicate for other labor intensive process to verify findings.

- Restructuring of layout to facilitate water spider-operator movement.
- Raw material better replenishment activities to improve efficiency of process.

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APPENDICES

Appendix A : Simulation Results

The simulation data in this study is tabulated by using the worker-machine activity chart. Performance measures such as average machine efficiency, average machine breakdown time, average setup time, average interference machine shortstops time, average interference machine setup time and average worker utilization could be computed from the machine-worker activity chart.

Table 1: Operating Conditions of M1 (Current)

M1 (EST 165-1)			**Count**	**Ratio**
Operation			636	84.9%
Non-operation	Repair		0	0.0%
	Setup	Interference	39	5.2%
		Actual	43	5.7%
Shortstop		Interference	17	2.3%
		Actual	14	1.9%
TOTAL			749	100.0%

Table 2: Operating Conditions of M2 (Current)

M2 (EST 165-2)			**Count**	**Ratio**
Operation			686	91.6%
Non-operation	Repair		0	0.0%
	Setup	Interference	0	0.0%
		Actual	0	0.0%
Shortstop		Interference	51	6.8%
		Actual	12	1.6%
TOTAL			749	100.0%

Table 3: Operating Conditions of M5 (Current)

M5 (EST 165-5)			**Count**	**Ratio**
Operation			601	80.2%
Non-operation	Repair		0	0.0%
	Setup	Interference	12	1.6%
		Actual	60	8.0%
Shortstop		Interference	8	1.1%
		Actual	68	9.1%
TOTAL			749	100.0%

Table 4: Operating Conditions of M3 (Current)

M3 (EST 171-A)			**Count**	**Ratio**
Operation			633	84.5%
Non-operation	Repair		0	0.0%
	Setup	Interference	0	0.0%
		Actual	0	0.0%
Shortstop		Interference	64	8.5%
		Actual	52	7.0%
TOTAL			749	100.0%

Table 5: Operating Conditions of M6 (Current)

M6 (EST 165-4)			Count	Ratio
Operation			313	41.8%
Non-operation	Repair		270	36.0%
	Setup	Interference	59	7.9%
		Actual	79	10.5%
Shortstop		Interference	8	1.1%
		Actual	20	2.7%
TOTAL			749	100.0%

Table 6: Operating Conditions of M7 (Current)

M7 (EST 165-3)			Count	Ratio
Operation			436	58.2%
Non-operation	Repair		158	21.1%
	Setup	Interference	16	2.1%
		Actual	38	5.1%
Shortstop		Interference	24	3.2%
		Actual	77	10.3%
TOTAL			749	100.0%

Table 7: Operating Conditions of M4 (Current)

M4 (EST 163-1)			Count	Ratio
Operation			492	65.7%
Non-operation	Repair		0	0.0%
	Setup	Interference	14	1.9%
		Actual	78	10.4%
Shortstop		Interference	33	4.4%
		Actual	132	17.6%
TOTAL			749	100.0%

Table 8: Operating Conditions of M8 (Current)

M8 (EST 163-2)			Count	Ratio
Operation			551	73.6%
Non-operation	Repair		0	0.0%
	Setup	Interference	71	9.5%
		Actual	76	10.1%
Shortstop		Interference	6	0.8%
		Actual	45	6.0%
TOTAL			749	100.0%

Table 9: Operating Conditions of M1 (Case 2)

<table>
<tr><th colspan="3">M1 (EST 165-1)</th><th>Count</th><th>Ratio</th></tr>
<tr><td colspan="3">Operation</td><td>632</td><td>91.9%</td></tr>
<tr><td rowspan="3">Non-operation</td><td colspan="2">Repair</td><td>0</td><td>0.0%</td></tr>
<tr><td rowspan="2">Setup</td><td>Interference</td><td>1</td><td>0.1%</td></tr>
<tr><td>Actual</td><td>26</td><td>3.8%</td></tr>
<tr><td colspan="2" rowspan="2">Shortstop</td><td>Interference</td><td>10</td><td>1.4%</td></tr>
<tr><td>Actual</td><td>19</td><td>2.8%</td></tr>
<tr><td colspan="3">TOTAL</td><td>688</td><td>100.0%</td></tr>
</table>

Table 10: Operating Conditions of M2 (Case 2)

<table>
<tr><th colspan="3">M2 (EST 165-2)</th><th>Count</th><th>Ratio</th></tr>
<tr><td colspan="3">Operation</td><td>666</td><td>96.8%</td></tr>
<tr><td rowspan="3">Non-operation</td><td colspan="2">Repair</td><td>0</td><td>0.0%</td></tr>
<tr><td rowspan="2">Setup</td><td>Interference</td><td>0</td><td>0.0%</td></tr>
<tr><td>Actual</td><td>0</td><td>0.0%</td></tr>
<tr><td colspan="2" rowspan="2">Shortstop</td><td>Interference</td><td>6</td><td>0.9%</td></tr>
<tr><td>Actual</td><td>16</td><td>2.3%</td></tr>
<tr><td colspan="3">TOTAL</td><td>688</td><td>100.0%</td></tr>
</table>

Table 11: Operating Conditions of M5 (Case 2)

<table>
<tr><th colspan="3">M5 (EST 165-5)</th><th>Count</th><th>Ratio</th></tr>
<tr><td colspan="3">Operation</td><td>582</td><td>84.6%</td></tr>
<tr><td rowspan="3">Non-operation</td><td colspan="2">Repair</td><td>0</td><td>0.0%</td></tr>
<tr><td rowspan="2">Setup</td><td>Interference</td><td>0</td><td>0.0%</td></tr>
<tr><td>Actual</td><td>41</td><td>6.0%</td></tr>
<tr><td colspan="2" rowspan="2">Shortstop</td><td>Interference</td><td>7</td><td>1.0%</td></tr>
<tr><td>Actual</td><td>58</td><td>8.4%</td></tr>
<tr><td colspan="3">TOTAL</td><td>688</td><td>100.0%</td></tr>
</table>

Table 12: Operating Conditions of M3 (Case 2)

<table>
<tr><th colspan="3">M3 (EST 171-A)</th><th>Count</th><th>Ratio</th></tr>
<tr><td colspan="3">Operation</td><td>611</td><td>88.8%</td></tr>
<tr><td rowspan="3">Non-operation</td><td colspan="2">Repair</td><td>0</td><td>0.0%</td></tr>
<tr><td rowspan="2">Setup</td><td>Interference</td><td>0</td><td>0.0%</td></tr>
<tr><td>Actual</td><td>0</td><td>0.0%</td></tr>
<tr><td colspan="2" rowspan="2">Shortstop</td><td>Interference</td><td>32</td><td>4.7%</td></tr>
<tr><td>Actual</td><td>45</td><td>6.5%</td></tr>
<tr><td colspan="3">TOTAL</td><td>688</td><td>100.0%</td></tr>
</table>

Table 13: Operating Conditions of M6 (Case 2)

M6 (EST 165-4)			Count	Ratio
Operation			272	39.6%
Non-operation	Repair		242	35.2%
	Setup	Interference	0	0.0%
		Actual	157	22.8%
Shortstop		Interference	3	0.4%
		Actual	14	2.0%
TOTAL			688	100.0%

Table 14: Operating Conditions of M7 (Case 2)

M7 (EST 165-3)			Count	Ratio
Operation			417	60.6%
Non-operation	Repair		149	21.7%
	Setup	Interference	5	0.7%
		Actual	25	3.6%
Shortstop		Interference	13	1.9%
		Actual	79	11.5%
TOTAL			688	100.0%

Table 15: Operating Conditions of M4 (Case 2)

M4 (EST 163-1)			Count	Ratio
Operation			504	73.2%
Non-operation	Repair		0	0.0%
	Setup	Interference	2	0.3%
		Actual	68	9.9%
Shortstop		Interference	20	2.9%
		Actual	94	13.7%
TOTAL			688	100.0%

Table 16: Operating Conditions of M8 (Case 2)

M8 (EST 163-2)			Count	Ratio
Operation			589	85.6%
Non-operation	Repair		0	0.0%
	Setup	Interference	2	0.3%
		Actual	40	5.8%
Shortstop		Interference	11	1.6%
		Actual	46	6.7%
TOTAL			688	100.0%

Table 17: Operating Conditions of M1 (Case 4)

M1 (EST 165-1)			**Count**	**Ratio**
Operation			635	93.3%
Non-operation	Repair		0	0.0%
	Setup	Interference	0	0.0%
		Actual	20	2.9%
Shortstop		Interference	9	1.3%
		Actual	17	2.5%
TOTAL			681	100.0%

Table 18: Operating Conditions of M2 (Case 4)

M2 (EST 165-2)			**Count**	**Ratio**
Operation			657	96.5%
Non-operation	Repair		0	0.0%
	Setup	Interference	0	0.0%
		Actual	0	0.0%
Shortstop		Interference	6	0.9%
		Actual	18	2.6%
TOTAL			681	100.0%

Table 19: Operating Conditions of M5 (Case 4)

M5 (EST 165-5)			**Count**	**Ratio**
Operation			577	84.7%
Non-operation	Repair		0	0.0%
	Setup	Interference	1	0.1%
		Actual	53	7.8%
Shortstop		Interference	6	0.9%
		Actual	44	6.5%
TOTAL			681	100.0%

Table 20: Operating Conditions of M5 (Case 4)

M3 (EST 171-A)			**Count**	**Ratio**
Operation			612	89.9%
Non-operation	Repair		0	0.0%
	Setup	Interference	0	0.0%
		Actual	0	0.0%
Shortstop		Interference	26	3.8%
		Actual	43	6.3%
TOTAL			681	100.0%

Table 21: Operating Conditions of M6 (Case 4)

M6 (EST 165-4)			**Count**	**Ratio**
Operation			270	39.7%
Non-operation	Repair		209	30.7%
	Setup	Interference	0	0.0%
		Actual	182	26.7%
Shortstop		Interference	3	0.4%
		Actual	17	2.5%
TOTAL			681	100.0%

Table 22: Operating Conditions of M7 (Case 4)

M7 (EST 165-3)			**Count**	**Ratio**
Operation			425	62.4%
Non-operation	Repair		139	20.4%
	Setup	Interference	3	0.4%
		Actual	28	4.1%
Shortstop		Interference	14	2.1%
		Actual	72	10.6%
TOTAL			681	100.0%

Table 23: Operating Conditions of M4 (Case 4)

M4 (EST 163-1)			**Count**	**Ratio**
Operation			509	74.7%
Non-operation	Repair		0	0.0%
	Setup	Interference	6	0.9%
		Actual	78	11.5%
Shortstop		Interference	11	1.6%
		Actual	77	11.3%
TOTAL			681	100.0%

Table 24: Operating Conditions of M8 (Case 4)

M8 (EST 163-2)			**Count**	**Ratio**
Operation			577	84.7%
Non-operation	Repair		0	0.0%
	Setup	Interference	21	3.1%
		Actual	31	4.5%
Shortstop		Interference	6	0.9%
		Actual	46	6.8%
TOTAL			681	100.0%

Table 25: Operator 1's Activity (Current)

Operator's tasks	Count	Ratio
Machine solving	80	10.7%
Setup	100	13.4%
Replenishment	42	5.6%
Refill	22	2.9%
Record	86	11.5%
Others	239	31.9%
Off Position	0	0.0%
Idle	126	16.8%
Walking	54	7.2%
TOTAL	749	100.0%

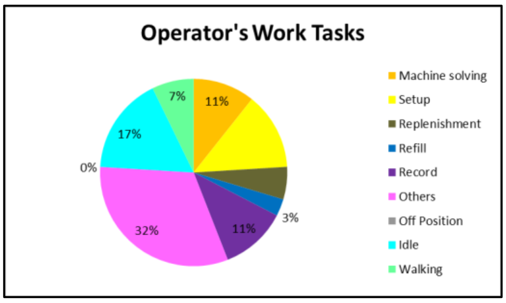

Figure 1: Analysis of Operator 1's Activity

Table 26: Operator 2's Activity (Current)

Operator's tasks	Count	Ratio
Machine solving	120	16.0%
Setup	123	16.4%
Replenishment	17	2.3%
Refill	16	2.1%
Record	91	12.1%
Others	117	15.6%
Off Position	0	0.0%
Idle	162	21.6%
Walking	103	13.9%
TOTAL	749	100.0%

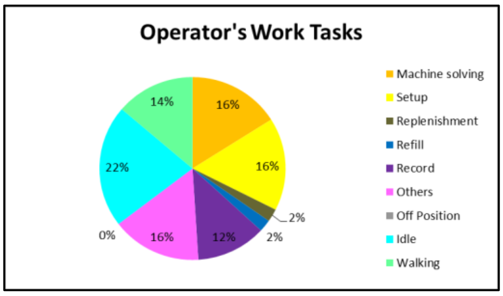

Figure 2: Analysis of Operator 2's Activity

Table 27: Operator 3's Activity (Current)

Operator's tasks	Count	Ratio
Machine solving	140	18.7%
Setup	167	22.3%
Replenishment	19	2.5%
Refill	8	1.1%
Record	29	3.9%
Others	116	15.5%
Off Position	0	0.0%
Idle	243	32.4%
Walking	27	3.6%
TOTAL	749	100.0%

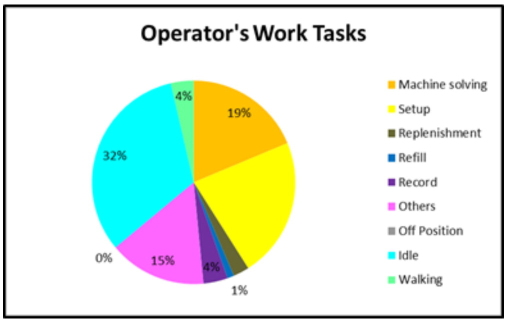

Figure 3: Analysis of Operator 3's Activity

Table 28: Water Spider's Activity (Case 2)

Operator's tasks	Count	Ratio
Machine solving	0	0.0%
Setup	204	29.7%
Replenishment	67	9.7%
Refill	0	0.0%
Record	0	0.0%
Others	210	30.5%
Off Position	0	0.0%
Idle	98	14.2%
Walking	109	15.9%
TOTAL	688	100.0%

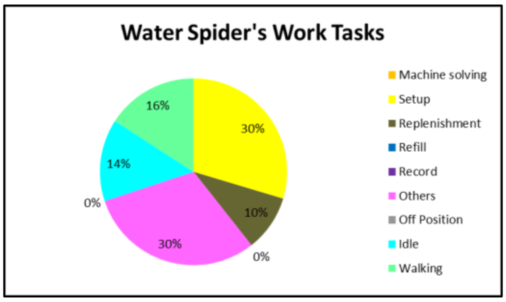

Figure 4: Analysis of Water Spider's Activity

Table 29: Operator 1's Activity (Case 2)

Operator's tasks	Count	Ratio
Machine solving	85	12.4%
Setup	0	0.0%
Replenishment	0	0.0%
Refill	19	2.8%
Record	111	16.1%
Others	105	15.2%
Off Position	0	0.0%
Idle	320	46.5%
Walking	48	7.0%
TOTAL	688	100.0%

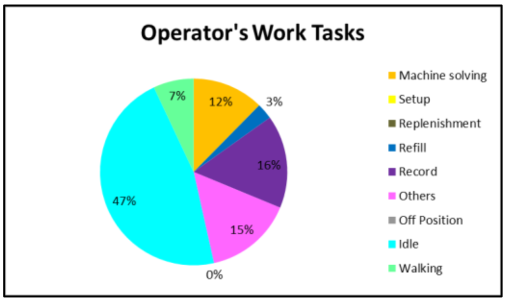

Figure 5: Analysis of Operator 1's Activity

Table 30: Operator 2's Activity (Case 2)

Operator's tasks	Count	Ratio
Machine solving	109	15.8%
Setup	64	9.3%
Replenishment	0	0.0%
Refill	13	1.9%
Record	116	16.9%
Others	69	10.0%
Off Position	0	0.0%
Idle	237	34.5%
Walking	80	11.6%
TOTAL	688	100.0%

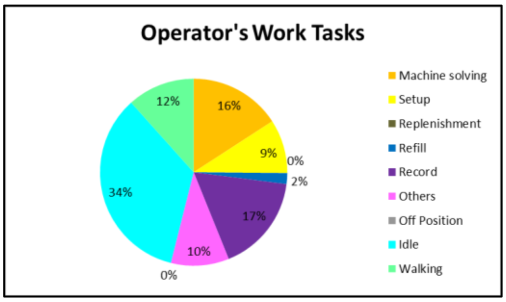

Figure 6: Analysis of Operator 2's Activity

Table 31: Operator 3's Activity (Case 2)

Operator's tasks	Count	Ratio
Machine solving	106	15.4%
Setup	6	0.9%
Replenishment	0	0.0%
Refill	10	1.4%
Record	53	7.7%
Others	62	9.0%
Off Position	0	0.0%
Idle	425	61.8%
Walking	26	3.8%
TOTAL	688	100.0%

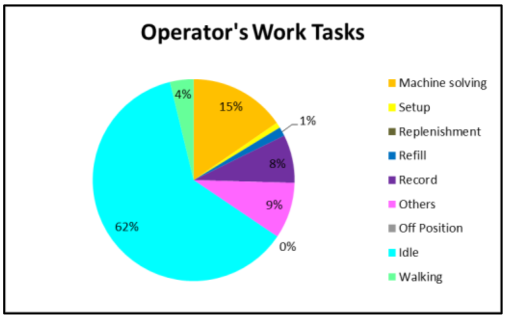

Figure 7: Analysis of Operator 3's Activity (Case 2)

Table 32: Water Spider's Activity (Case 4)

Operator's tasks	Count	Ratio
Machine solving	0	0.0%
Setup	0	0.0%
Replenishment	83	12.2%
Refill	0	0.0%
Record	0	0.0%
Others	208	30.5%
Off Position	0	0.0%
Idle	286	42.0%
Walking	104	15.3%
TOTAL	681	100.0%

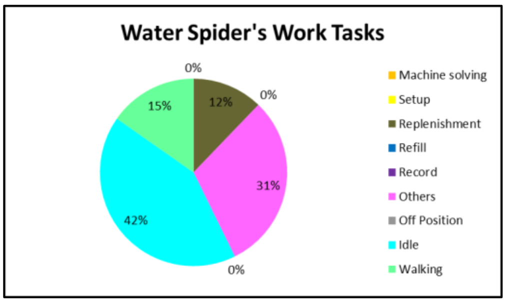

Figure 8: Analysis of Water Spider's Activity (Case 4)

Table 33: Operator 1's Activity (Case 4)

Operator's tasks	Count	Ratio
Machine solving	80	11.8%
Setup	83	12.2%
Replenishment	2	0.3%
Refill	28	4.1%
Record	84	12.3%
Others	94	13.8%
Off Position	0	0.0%
Idle	255	37.4%
Walking	55	8.1%
TOTAL	681	100.0%

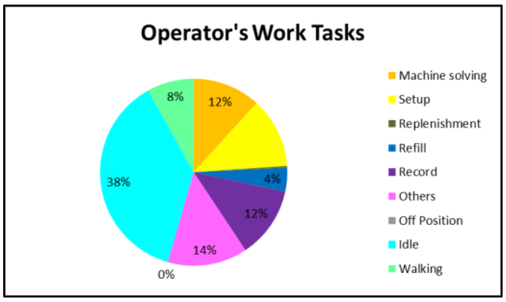

Figure 9: Analysis of Operator 1's Activity (Case 4)

Table 34: Operator 2's Activity (Case 4)

Operator's tasks	Count	Ratio
Machine solving	103	15.1%
Setup	84	12.3%
Replenishment	0	0.0%
Refill	16	2.4%
Record	105	15.4%
Others	71	10.4%
Off Position	0	0.0%
Idle	224	32.9%
Walking	78	11.5%
TOTAL	681	100.0%

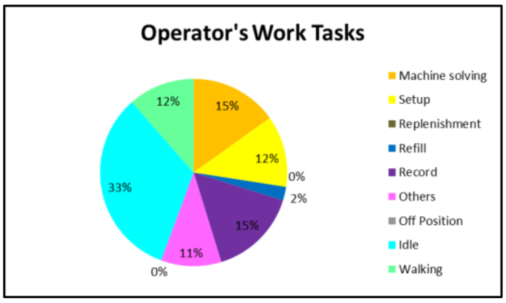

Figure 10: Analysis of Operator 2's Activity (Case 4)

Table 35: Operator 3's Activity (Case 4)

Operator's tasks	Count	Ratio
Machine solving	102	15.0%
Setup	119	17.5%
Replenishment	0	0.0%
Refill	9	1.3%
Record	48	7.0%
Others	48	7.0%
Off Position	0	0.0%
Idle	323	47.5%
Walking	32	4.7%
TOTAL	681	100.0%

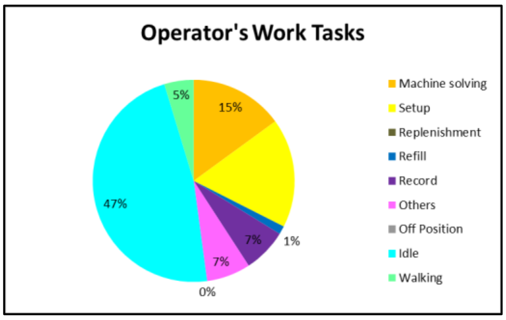

Figure 11: Analysis of Operator 3's Activity (Case 4)

FACULTY OF ENGINEERING AND GREEN TECHNOLOGY
UNIVERSITI TUNKU ABDUL RAHMAN

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It is hereby certified that **LEE ZI WEI** (ID No: **12AGB03241**) has completed this final year project / ~~dissertation / thesis~~* entitled "DEVELOPMENT OF HOLONIC WORKFORCE ALLOCATION IN ELECTRONICS ASSEMBLY" under the supervision of Dr. Joshua A/L Jaya Prakash (Supervisor) from the Department of Industrial Engineering, Faculty of Engineering and Green Technology.

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20**CHAPTER 1** 1 **INTRODUCTION 1.1 Introduction This chapter provides an overview of**

holonic manufacturing system in workforce allocation. It presents the concept of holonic workforce allocation as the potential improvement in a global electronics manufacturing company. Following this, the problem statements and objectives of the case study are outlined. 1.2 Holonic Manufacturing System With rapid development of technology, customized products are in higher demand. A company that is able to respond rapidly to the ever changing market will ensure it will have an edge over its competitors. Yet, another challenge faced is to have the shortest processing time while delivering diverse products with high quality (Shiming Liu et al., 2000). In short, a company must have the ability to cope with dynamic production to be constantly competitive (Saadat et al., 2013). A possible way of achieving this is to instill the concept of "holonic" into the manufacturing system. A holonic manufacturing system was one of the cases studied under the Intelligent Manufacturing Systems (IMS) Feasibility Study Program in 1994. HMS was being established by considering the requirements of future manufacturing systems that possess a higher degree of control levels and decision space (Van Brussel et al., 1998). Instead of one single "brain" that monitors and schedules the entire production, multiple "brains" are installed at different production stages and hierarchy level to do the thinking and strategize plans (LeitÃo and Restivo, 2008). Nowadays, many manufacturing industries practice low-volume high variety production to provide better control over market changes. Ordinarily, HMS is applied in the manufacturing floor that practices job shop production. The high flexibility in a process-oriented manufacturing, from various machining processes, to material transfer routing, and to operators allocation, lead to the necessity to have a comprehensive production management strategy such as HMS (Ounnar and Pujo, 2009). In a production line, there are several key elements that will directly or indirectly affect the productivity of the production line: operators, machines, work centers, resources, orders, etc. These elements are named as holons (Gou, Luh and Kyoya, 1998). A holon is an important element in HMS, as it can be depicted as the "brain" or "part of the brain" that is autonomous and capable of analyzing job task priorities sequencing throughout the manufacturing. It is beneficial

13**for transforming, transporting, storing and/or validating information and physical objects. An information processing part and a physical part**

are two major components that make up a holon. Basically, there will be

24**three types of basic holons:** resource **holon,** order **holon and** product **holon**

17**(Van Brussel et al., 1998).** These **three holons**

must communicate with each other from time to time for information exchange in order to achieve optimum outcomes from a holonic manufacturing system. According to (Van Brussel et al., 1998), resource holon acts as an information processing center that controls all the flows of resources and allocates the resources accordingly. It will carry the information to product holon on how certain processes could be carried out based on the types of resources and determine how much resources need to be allocated depending on the information from order holon. An order holon assigns tasks within the manufacturing system to ensure it meets the customer requirement and complete the order on time. It will provide the guidelines for the product holon in processes or task scheduling. A product holon is responsible for the manufacturing processes and quality of the products produced. It also controls the productivity and efficiency of the production line. By introducing HMS in the production line, it also helps to achieve flexible workforce allocation. Workforce allocation is a vital chain in the shop floor management because it is the key factor that will directly influence the end-to-end productivity of the production line. Compared to complex machinery settings modification or relocation of bulky machinery, allocating workforce is more handy and practical. It enables the line leaders or production engineers to re-arrange workforce according to real-time needs as well as daily production goals. In holonic workforce allocation, holons are capable of responding quickly to the problems encountered in the manufacturing line such as machine interference. Machine interference occurs when there is a machine error that stops the machine from operating while the operators are engaged with other machines and the production continues only when the machine is attended by an operator (Hadad, Keren and Gurevich, 2013). Therefore, the level of machine interference is influenced by the operator allocation decision, whereby the degree of improvement is depending on the optimality of the operator staffing level (Yang, Fu and Yang, 2002). 1.3 Problem Statement This research is based on a case study in a global electronics manufacturing company located in Batu Gajah, Perak. Company X

9**specializes in manufacturing electronics components such as power** inductor **and EMI suppression filter.**

This research is aimed to study on the manufacturing environment of power inductor. Basically, the manufacturing processes of a power inductor include winding, coating or resin coating, drying and hardening, electrical sorting taping operation, human inspection, inductance checking and followed by electrical properties and dimension testing. Currently, company X utilizes process-oriented layout. This process layout is designed

9**for the ease of company to fabricate various types of power inductors to fulfill different customer requirements.**

This case study will focus on the electrical sorting taping (EST) process. In this process, there is a total of ten machines manufacturing four product types. Each operator is assigned to at least two machines manufacturing similar product types during the production. In such a case, each operator will be performing similar tasks and is required to execute every single operation task starting from the set-up of production lot to the transportation of finished goods which also include material replenishment and problem solving on the machinery. These operational tasks can be categorized into value-added activities and non-value-added activities. However, no specific rules are standardized on how the operators should perform their tasks when there are a few tasks such as machine set up, material replenishment, solving machine errors, etc. pending to be completed at the same time. At this stage, the only rule instructed to the operators is that they must complete the current task they are performing before they can proceed to the next task. In other words, preemption is prohibited to prevent incomplete tasks after interruption due to the forgetfulness of operator. Another encountered issue is the unpredictability or uncertainties in occurrence of machine errors. These machine errors are usually shortstops that take place randomly and there are no specific technique that can be used to forecast or predict the errors. In EST, there are multiple machine errors that can be observed. If there is a malfunction in the production machines, the operator on the line will fill in a report regarding the machine breakdown through the main computer interface allocated in the production line to request for technicians to repair the machine. For minor machine errors, there are different types of solving methods for respective errors which can be performed by operators manually. Since an operator is assigned to at least two machines during the production, there might be situation where there is a parallel occurrence of machine errors. For instance, one of the machine, M1 experiences an unexpected shortstop. At the same time, before the assigned operator is about to solve the error at M1, there is an immediate shortstop arises at another machine, M2 such that the shortstop cannot be attended simultaneously by the operator. In such situation, the operator attends to the either M1 or M2 randomly because there is no standard operating procedure clarifying the priority sequence on machine shortstops. Moreover, there are some unusual events where a few machines breakdown at the same time. This could happen because the machines in this manufacturing process are usually operating for 24 hours over days and nights. Machines breakdown in the production line will eventually affect the task allocation for the operators. Under usual operating conditions, the operator is commonly assigned to two machines, but if there is a breakdown in either one of the two machines, the operator will only need to take care of the another one machine which is functioning. However, if both of the machines are malfunction simultaneously, the operator will be instructed to support another operators in managing their machines and to attend randomly to shortstops. The only restriction is that the operator can only be assigned to the machines with similar product types. In the worst case scenario whereby most of the machines are under maintenance, on-shift operators tend to stay in idle state while awaiting for machine repairing from technicians or getting further instruction from line leaders. Since machinery errors are unpredictable and unavoidable, the sole aspect that can be further improved is the workforce. Workforce allocation plays an important role in production planning. Through observation and analysis on the current manufacturing process, the operators are not characterized as holons, instead they are stationed based on Random Allocation Model. The current scheme practiced is that the operators will be randomly assigned to machine disregarding the individual skill rating and task urgency on machine. In other words, the selection will be on a free-for-all basis when every operator is engaged (Lim and Chin, 2011). Flexible manufacturing line can only be achieved with a proper workforce allocation that able to cope with any unforeseeable events or disturbances (Abdelhamied et al., 2015). To achieve this, holonic workforce could offer a better clarification in operator's task scheduling or sequencing. Even though holonic workforce could improve the manufacturing process in term of flexibility and productivity, it also has some limitations in actual implementation in manufacturing lines. Holonic workforce allows a holon to have flexibility in the task execution. At the same time, the operators carry more responsibility as they are required to make judgments on which task to be carried out according to the production's priority. Thus, a holon must attain

17**a higher level of** expertise **and knowledge** with proper **training provided**

by the management. In another point of view, it can be deduced that the decision making of a holon on job task priorities as well as intermediate production planning is subjective and solely dependent to previous experiences. The downside is that each individual operator is likely to develop dissimilar concept of sequencing job tasks priority based on personal point of view. In addition, in HMS, every holon has the

rights to decide on their ways of conducting activities. Consequently, there is a possibility that those activities do not reflect the actual goal of the system as compared to the centralized control system with a controller that responsible in allocating all the tasks. 1.4 Objectives The objectives of the research are: 1. To study the work tasks and machine allocation in the current manufacturing process of electrical sorting and taping (EST). 2. To develop and verify the priority rules to make the operator more holonic in facing machine interference problem due to the occurrence of either parallel tasks or parallel machine errors, and at the same time to equip them with cross training. 3. To validate the proposed solution.

23**CHAPTER 2** 2LITERATURE **REVIEW 2.1 Introduction This chapter** outlines **the**

pertinent topics and theories which are significant to the thesis on the study of workforce planning in real shop floor environment. Following this, a list of reviews covering different strategies proposed for workforce allocation with respect to different manufacturing circumstances. 2.2 Workforce Planning Workforce planning is an essential process to minimize the labor cost as well as maximize the profitability. It can ensure the smooth flow of production line while maintaining the maximum desirable production capacity as well as system throughput by allocating optimum work labour to achieve target demand. Master production scheduling (MPS) is a mixed-integer program that has been widely used for workforce allocation in the manufacturing environment. Techawiboonwong et al. (2006) revised the traditional MPS model by including temporary workers in model formulation and thus a new model named MPS-T is proposed. In the formulation of MPS-T model, the workers are classified according to two important aspects: permanent or temporary, and skilled or unskilled. The workers are assigned to workstations according to their skills level such that the workstations with significant operational complexity can only be operated by skillful workers while there is also a minimum ratio of permanent to temporary workers for each workstation. MPS-T is validated by carrying out an experimental study in a factory which has high demand variance and relatively short lead time for the orders. The objective of the authors' study is to minimize the labor costs by determining the type and number of workers to hire or layoff in each period, the optimal operator- machine assignment and the overtime hours needed to fulfill the customer orders. There are a total of four different products being produced in which one of the products is processed on Line-1 whereas the remaining three types of products are processed on Line-2. In order to insure the quality of products, three skilled workers are required for Line-1 and two skilled workers are required for Line-2. In the authors' study, all the permanent workers are considered to be skilled workers and the temporary workers can be either skilled or unskilled. The authors found out that the optimum ratio of permanent workers to temporary workers should be kept at 0.63. Having a large number of permanent workforces, in which the ratio is more than 0.63, is not preferable for factory with high variance in product demand as it deems to be profligate use of resources. Hytonen et al. (2008) proposed the use of discrete event simulation to

15**develop a simple and efficient workforce allocation in a**

job shop production line. The empirical experimentation is carried out with a discrete event simulator on an assembly consists of four serial workstations and forty-eight operators. Every product has the similar process flow. In each station, the line efficiency is highly dependent on the productivity and work rate of the manual operators. From the authors' research, it is observed that operators ought to be experienced and highly- skilled as work tasks in a job shop production possess greater complexity than production lines with other types of layout. Additionally, there is no buffer located in between the stations as the product can only be transferred to the next station when the next station is not occupied. This lowers the worker utilization when there is a bottleneck in one of the stations whereby the operator requires longer processing times. In this case, cross-training for a small group of operators on every work tasks is essential to overcome the bottlenecks. These trained workers are allocated in the stations as mobile workers whereby they could assist other workers when their designated task is accomplished. The number of workers in each station is

15**determined by the workload** or **the** total **processing** time **of**

the station. In this study, gamma distribution is adapted to determine the work content of each station for different products and calculate the optimum number of workers needed by each station and their respective processing times. From the authors' research, it can be concluded that adding cross-trained moving workers to the production line successfully increases the efficiency only when there is a large product variation. Higher interaction between workers will lead to low capacity as the numbers of workers needed are higher. The proposed methodology by Azadeh et al. (2014) utilizes the

14**integrated analytic hierarchy process (AHP) and** genetic algorithm (GA) **for** the optimization **of operator allocation in cellular manufacturing systems with weighted variables. A**

five-step operator allocation process is illustrated in a cellular manufacturing system equipped with eight machines. Firstly, the limitations of the existing system are observed. In this cell, each operator is assigned to multiple machines and will only attend to each machine once per cycle. The cycle time

30**in this case is defined as the** total **time**

taken for an operator to start an operation at the first designated machine and re-attend to it to process the subsequent workpart. The cycle time covers all required waiting times, processing times, and attending time for the operator to move from one machine to another. At the second stage, a computer simulation model is built to structure the actual manufacturing environment with different scenarios and the output of the

12**simulation model are lead-time of demands, waiting time of demands, operator and machine utilization and annual number of completed parts.**

Next, the twelve scenarios with all the possible operators' layouts in three shifts are considered in formulating the solutions. Thus, there are a total of 36 alternatives for the optimal workforce allocation. Following that, AHP is utilized to provide the overview of the relationships between the outputs of the simulation model and then evaluate their relative weights in operator allocation problem. Lastly, a fitness function is formulated with all the relative weights identified in the previous stage. GA is then implemented to determine the feasible solutions for the operator allocation problem. In short, the results of AHP-GA-CS proved that the proposed methodology in this study is competent in strategizing the optimal operator allocation in the cellular manufacturing system. 2.3 Strategies for Workforce Planning To achieve effective workforce allocation, several strategies for workforce planning are proposed by different researchers to fit different manufacturing environments. In this section, workforce planning strategies such as holonic workforce allocation, workforce allocation by enhancing the standard operating procedure and workforce allocation via workforce training are discussed. These strategies are utilized to achieve different objectives and one of these is to reduce the impact of machine interference problem on manufacturing line. 2.3.1 Holonic Workforce Allocation Holonic Workforce Allocation Model (HWM) is introduced by Lim and Chin (2011) as an effective model to mitigate the impacts of worker absenteeism and turnover in performing operator assignment. Operator assignment is commonly defined as a multi-objective decision-making problem where the optimal solution should achieve the objective with the highest weightage. In order to verify the effectiveness of HWM, a case study is carried out on a local cartoon manufacturer that practices job shop production. Basically, there are five major tasks that the operators should perform on the seven machines for each process cycle. WITNESS simulation model is adopted to determine the outcome of HWM. There are three basic elements in the simulation which are machine, part and labor. In this case, there are a total of seven parts which include the five tasks and two disturbances: absenteeism and turnover. In the simulation model, HWM is compared with three other operator allocation models: Random Allocation (RND), Skilled and Available Allocation (SAA) and Stationed for Total Specialisation (STS). Each model has distinct rule in the process of allocating operators to the machines. The comparison is carried out under three different scenarios: All typical, High demand and High disturbance. The four performance measures of this study are task's overdue rate, operators' average skill level, and operators' interpersonal and intrapersonal skill deviations. HWM proved to be the most effective operator allocation model as it owns the highest performance rating for the two most important measures for the company: overdue rate and average skill level. Lim (2011) presented a job-shop workforce sizing method based on the concept of Holonic Manufacturing System (HMS). A holonic model namely Workforce Sizing Plan (WOZIP) is developed to compute the optimum number of workers to maximize the productivity of the manufacturing line. The varying parameters such as the variation in machine utilization due to fluctuating product demand and unexpected disturbance in production line are taken into consideration in the WOZIP model. From the management's perspective, minimal usage of workers for daily operations is always desirable as it could help to lower the overhead cost (Lim et al. 2008). In the authors' study, mathematical models are used to calculate the varying parameters such as the utilization rate of machines, frequency and intensity of the production disturbance. The idling rate of the workers is also computed to examine the utilization rate of workers based on the data obtained from the production floor. Furthermore, exponential smoothing which is a forecasting technique is implied to predict these varying parameters in the production line with ten machines for the upcoming 24 months. Results obtained from the mock-up analysis showed that WOZIP is applicable and practical with respect to the variation in machine utilization and worker idling rates as well as different levels of disturbance. In the manufacturing control system, there are two primary functions, such that they

6**can be** categorized **into process related functions (process planning) and resource allocation related functions.**

Leitão et al. (2003) studied about the importance of introducing a flexible and intelligent manufacturing system that is able to response swiftly to the variation in product variety and unexpected disturbance while

maintaining the manufacturing's productivity. Two modeling tools are applied to model a clearer visible structure of the manufacturing system. A unified Modeling language (UML) class diagram is utilized for static aspects while the Petri Nets (PN) is employed for dynamic behaviour of manufacturing system. Four classes of holon,

6**product, task, operational and supervisor holons**

are formed using the ADACOR architecture, with further aid of the

10**generalization concept of the object-oriented paradigm**

(Leitão, Colombo and Restivo, 2003). In fact, the

10**product, task and operational holons are** likewise **the product, order and resource holons** extended **at the PROSA architecture** (Ashbacher, 2004). Unlike **the**

behaviour of staff holons defined in PROSA, the supervisor holon stimulates the implication of

16**coordination and global optimization in decentralized control**

methods. Under normal circumstances, the

6**supervisor holon** synchronizes **the activity of the holons under its domain**

whereas they need to be self-regulating and capable of tackling disturbances without referring to the supervisor holon. 2.3.2 Allocation using Standard Operating Procedure (SOP) For all the manufacturing lines, the operators are required to perform tasks according to the standard operating procedure (SOP) set by the engineers or production officers. SOP acts as a guideline to standardize all the operating requirements in order to assure the quality of services and products for the customer's benefits and simultaneously prevent vague instructions from individual supervisor. Bucket brigades is an effective model in performing workforce allocation in a production or assembly line in which the

1**number of operators is** always **less than the number of machines.**

(Bartholdi and Eisenstein, 1996) defined this way of organizing manpower as "TSS protocol", from the Toyota Sewn Products Management System. Basically, there are two TSS rules that must be fulfilled to achieve bucket brigades. The operators are placed in line from the slowest to the fastest to prevent blockage or idle workers. TSS forward rule states that each operator must process only one single item at one time on subsequent stations. The last operator who has completed the work task should then follow the TSS backward rule. TSS backward rule requires the last operator to move upstream and take over the task in the previous station once the task in current station is completed. In such situation, the process is reset where the first operator will need to start processing a new item and follows the TSS forward rule. De et al. (2013) introduced the concept of bucket brigades into a manual packing line for leather bags to achieve the best balance of workloads. The assembly line consists of four different product models and each model possesses a distinct processing sequence. In the existing packing line, operators are assigned to a fixed station whereby each operator is only trained for that particular task issued by a foreman. This arrangement will result to unbalanced line that affects the line productivity as the operators are not trained to deal with unusual and unexpected situations. Another drawback of this production arrangement is that the foreman is required to re-distribute the job to every operator with respect to each product change. From the experimental study, it showed that the bucket brigades has successfully improved the overall line performance with a reduction in cycle time of a product and throughput time of the line. At the same time, bucket brigades model helps to reduce the amount of work-in-process (WIP) and eliminate the bottlenecks in the production line as the work tasks are carried out continuously by flexible operators. Bartholdi and Eisenstein (2005) implemented bucket brigades in TUG and successfully helped the company to transform from craft manufacturing to assembly lines. TUG is an industrial tractor assembly company that supplies more than 10 different tractor models in the market, which include those typically used at major airports as luggage tractor. As there was no proper production line at the beginning stage of transformation, bucket brigades is a suitable concept to be implemented. This is because bucket brigades allows the assembly line to balance itself and thus it does not require specific task allocation to the operators. The advantage of having bucket brigades for a newly set up production line is that it would help to train up the workforce easily as the operators are trained to balance the production line by themselves. In the authors' study, the bucket brigade model is revised by introducing several rules to the workers. For bucket brigade model, the slowest worker will be assigned to the first workstation while the fastest worker to the last workstation. Therefore, during the production, only the first worker has the right to start a new process cycle and only the last worker could initiate a walk-back. Walk-backs and hand-offs of several workstations simultaneously is prohibited. Secondly, passing is allowed in the revised bucket brigade model as the self-balancing behavior and

21**proper sequence of slowest to fastest**

are maintained. Furthermore, the

21**bucket brigade assembly lines at TUG** are proved to be feasible as they substantially fulfilled the idealized circumstances in normative model. 2.3.3 Allocation under Machine Interference Problem Machine breakdown is often an important factor that inhibits the productivity of the manufacturing line. With proper operator-machine assignment, most of the impacts of machine interference problem (MIP) can be lessen such that parallel error occurrences can be attended by workers at the shortest possible time. In other words, it can significantly reduce the respond time and hence decreases the machine stoppage time. Samat et al. (2013) established an improved maintenance system that would provide better workforce allocation with shorter operator response time to the machine. The new maintenance

3system is implemented in a semiconductor company

in Malaysia which has four clusters with 160 machines and seven technicians assigned to the machine maintenance. The study focuses only on one cluster consisting 12 machines and 24 operators. An 6-phase improvement plan is constructed to implement new maintenance system. At the initial phase, the current system is revised to figure out the average operator response time to machine breakdown by outlining the detailed sequential maintenance procedures. Second phase is to determine the problems

3that lead to long response time

to machine breakdown. This process is done

3by identifying the Ohno's seven wastes:

3overproduction, waiting, transportation, overprocessing, inventory, motion and defects

by analyzing the chronology developed in the previous phase. In this case, three manufacturing wastes: waiting, transportation and motion are emphasized and studied. In phase 3,

3Value Stream Mapping (VSM) method is

applied for further problems verification. VSM is a powerful lean tool that illustrates the detailed process and material flows in the manufacturing line while

3identifying value-added and non-value-added activities.

Clarification of goal is then done to set the target. In this case study, the company targeted to reduce the response time by 30 percent within one month. Following that, phase 5 of the improvement plan is to identify the ideal solution to achieve the goal using brainstorming to generate and evaluate the feasibility of all possible alternatives. Lastly, the proposed solution in phase 5 is executed in real manufacturing line and determines the outcome of the implementation. In practical, the implementation of proposed improvement model is simple and convenient.

3Equipment failure can interrupt company production, eventually leading to productivity loss (Alsyouf, 2007). Hence, proper equipment maintenance

through an effective maintenance system is vital and plays as the decisive factor in establishing a cost-efficient production environment (Tan and Raghavan, 2007).

Hadad et al. (2013) proposed a multinomial model that is used

1to determine the optimum number of operators and qualified technicians for each machine failure type in order to reduce the

machine interference problem (MIP). The purpose of this model is to propose optimal workforce allocation for minimizing the manufacturing cost and simultaneously maximize the profit. A case study for this proposed model is

1based on a factory that manufactures a plastic irrigation product

equipped with

113 identical machines in the production line. In this case, the

machine will only request for

1two types of services where the first service is to be performed by the operator while the second service

will be carried out by qualified technician. Multinomial distribution is used to

1calculate the expected machine interference or waiting time for each service type.

Each type of machine failure is assumed to occur randomly and stochastically. Firstly, the theoretical cycle time to produce one product unit without machine interference is calculated. Next, the expected adjusted cycle time with all the possible assignment of operators and technicians to the machines is computed. In this case, there are a total of 169 possible combinations for 13 machines. Since

26the objective of this model is to minimize the manufacturing cost

and maximize the profit, the cost per unit and hourly profit for each possible combination are determined. By comparison, the optimal assignment for machine failure is four operators with two qualified technicians. The advantage of this proposed model is that it is simple to be applied to any manufacturing line with multiple identical machines. Besides that, this model requires only little data inputs obtainable from work measurements such as

1runtime of the machine, the average service time for each machine failure, the number of identical machines and number of

workers. Gurevich et al. (2015) recommended the use of binomial probability function in determining the economic number of operators in solving the machine interference problem. This method is applicable to the manufacturing line equipped with several identical machines that are designated to manufacture the same product and independent of each other. A

1case study is conducted in a factory that produces plastic irrigation product.

There are a total of three groups of machines that are operated by five operators. Each group of machines consists of different number of machines, such that five machines in group A, four machines in group B and six machines in group C. In the authors' study, the binomial probability function is used to compute the machine interference proportion. When there is machine interference in the production line, the operators are required to attend to the group of machines with highest priority. In such a case, the factory adopts the rule in which the machines that belong to that particular group with the shortest processing time and average service time is granted the service priority. Therefore, machines in group B has the highest priority, followed by machines in group A and group C. On the other hand, the formulation of the economic number of operators required to deal with the machine

1interference problem is based on the objective functions. The

two objective functions are to maximize the hourly yield and

1minimize the total cost per unit produced. In conclusion, the

optimal number of operator differs as different objective function is considered. Yang et al. (2007) proposed the

11multiple attribute decision-making (MADM) method to find a solution to a dynamic

11operator allocation problem for an integrated circuit (IC) molding workstation. The operator allocation problem is defined as dynamic

because the production planning is carried out weekly with respect to the actual production status. This study focuses only on the molding workstation because it is where the bottleneck occurs due to long setup time and frequent machine interference problem. The molding workstation consists of nine molding machines and each operator is assigned to at least two machines. Previously, Yang et al.(2002) did implement a simulation-based model that considers only the cycle time and service level for the dynamic operator assignment which may neglect other importance measures in the production line. To further enhance the practical pertinence of the simulation model, additional four system performances measures are studied in the process of multiple objectives decision making, namely: staffing level, system throughput, tool utilization and flow time. Besides that, AHP is used to compute the weightage of each measure according to the objective of study and figure out all the alternatives for operator assignment. Lastly, two MADM methods: a

18technique for The Order Preference by Similarity to Ideal Solution (TOPSIS) and fuzzy- based model were applied to

figure out the feasible solution for workforce allocation with reference to the relative performance ratings computed using AHP. Both methods contribute to similar outcome with the achievement of all predefined objectives in the study. Chien et al. (2013) employed an effective methodology to improve the system performance of a semiconductor company in Taiwan by solving the machine interference problem. This is achieved by identifying the optimal

2operator-machine assignment (Stafford 1988; Haque and Armstrong 2007)

through

2a hybrid approach of simulation model and optimization model.

2An empirical study with real- time data collection in

the company's testing facility is carried out to verify the feasibility of the proposed approach.

2A simulation model is developed to examine and analyze the

real manufacturing process where the movement of the operators and the machine operating conditions are focused. In the testing facility, there are a total of 66 machines with three distinct types. Besides that, there are five operators with two

2operators in each group, whereby the two operators are assigned to attend the same

machine in turn. Moreover, the manufacturing aspects

2such as product mix, operation details, and operations with different

priorities are considered in the

22simulation model. The output of the simulation model is the frequency of

machine errors which address frequency of machine interference. After that, (Chien, Zheng and Lin, 2013) came out with

2two algorithms: Heuristic Assignment Model with Mixture Experiment (HAM-ME) and Assignment Genetic Algorithm (AGA) to enhance the operator-machine assignment aiming to reduce the machine interference time.

Three main factors that contribute to the machine interference time were addressed, which are the

2number of machines assigned to an operator,

different product cycle time due to product variety and the priority of machine operation. A polynomial function is formulated in HAM-ME by utilizing the design of mixture experiment together with the response surface method (RSM). For AGA, global search is conducted with the use of genetic algorithms without involving much mathematical operations. In their study, they proved that both algorithms are suitable in determining the operator- machine assignment while the AGA is found out to be more effective than HAM-ME. 2.3.4 Allocation via Workforce Training In the manufacturing line, operators play a key role in running an efficient production. Therefore, operator training is essential as the operators equipped with higher level of skills can perform tasks more effectively in the sense of shorter processing time. For the production floor with manual assembly, the line productivity and the product cycle time are usually influenced by the worker's efficiency. With fixed- worker, the station with the slowest worker will have longest processing time, thus becoming the bottleneck of the assembly line. To improve this, previous research did by (Mileham et al. 2000) is to assign buffers between the stations. However, this solution is only effective to the production line with constant demand and it restricts the flexibility of production line. Therefore,

28Wang et al. (2007) introduced the concept of flexibility into a

local small and medium enterprise (SME) by having walking-worker instead of fixed-worker in the assembly lines. In linear walking- worker

25assembly lines, the workers are cross-trained so that

they are familiar with all the end-to-end process work tasks. In this study, the relationship

7between the number of workstations and the number of walking workers

are investigated by using a WITNESS simulation model to determine the optimal operator-machine assignment. The company set up three parallel assembly lines for three product families (A, B and C series). All the product families share a 'prepare-zone' line for raw materials preparation before proceeding to the production line. From the simulation result, a few conclusions can be drawn. Firstly, as the

7number of walking workers and workstations increases, the overall line output will increase until the maximum output where the number of

walking workers is equivalent to the number of workstations. Secondly, utilization of

7linear walking-worker assembly lines offers the

flexibility in

7adjusting the number of walking workers corresponds to

the daily production demand. The proposed method is applicable as the addition of extra workstations in the production

7line will not increase the overall cycle time

but help to reduce the processing time at other workstations. Wang et al. (2007) concluded that linear walking-workers assembly line offers higher adaptability and proficiency in terms of workforce allocation and line output compared to liner fixed-worker assembly line under similar operating conditions. Mccreery and Krajewski (1999) promoted workforce flexibility to enhance the performance of

5an assembly environment with the presence of learning and forgetting effects. The nature of

the task assigned to the operators will determine the rate of worker learning and forgetting. For simple task, operators tend to learn faster and the knowledge acquired is comparatively long-lasting. Contrary, operators find it difficult in learning complex task and there is a higher probability of forgetting. Moreover, the rate of learning and forgetting of workers increases as the product variety increases. Therefore, in order to demonstrate the learning and forgetting effects, two manufacturing variables are defined:

5product variety and task complexity. Discrete-event simulation is utilized to

simulate four different manufacturing environments with respect to these two variables. A case study is conducted on a discrete-parts manufacturing line. There are a total of twelve distinct processes assigning to twelve operators for each product. The assembly line is arranged in U- shaped to facilitate the movement of workers between workstations and allow the workers to assist each other in case of unbalanced line. In this study, the importance of workers' cross-training is emphasized and the level of cross training required is mainly based on the manufacturing condition. For low

5product variety and task complexity, the optimum solution is to

have moderate

5level of cross training and high flexibility in

allocating workers to designated tasks. For high

5product variety and task complexity, it is suitable to have high level of

cross training with restricted workforce flexibility. In addition, simple task with

5high product variety requires high level of cross training with

high workforce flexibility. While complex task with low product variety only requires minimal cross training with restricted workforce flexibility. In short, this study highlighted the importance of cross training of workers and their flexibility in dealing with different manufacturing conditions to improve the line performance. Hopp et al. (2004) suggested two types of cross-training strategies: cherry picking and skill-chaining for optimal workforce allocation in serial production line. From their study, they found out that the skill-chaining strategy is relatively more effective as it offers higher flexibility in workforce coordination. In practice, cross- training is vital for all the manufacturing industries in the effort to eliminate the bottleneck and work-in-process (WIP) inventories where possible. For a serial production line

8without cross-training of workers, the maximum capacity of the line is restrained by the bottleneck

station. To counter this, it is feasible to increase the capacity by diverting the

8excess capacity from low-utilization stations to the high- utilization stations with the

assistance from cross-training manpower.

8Ruud Lighting, Inc. of Kenosha, Wisconsin

with high level of product variety is one of the companies that employed the skill-chaining strategies in their production lines. There are two parallel and identical lines such that each consists of five workstations that are utilized to produce industrial and security lighting products. Each production line is responsible for

8three product families with a total of more than 1000 different product models.

A simulation model is being set up with a constant work-in-process of 12 units in the production line to determine the system throughput for each possible cross-training pattern. The simulation results showed that partial training in both the production line is not effective to maximize the system throughput. Therefore, complete chaining is proposed with different types of manufacturing layouts and validated by using the simulation model. U-shaped production line is tested and it was found to have the highest system throughput. In spite of that, U- shaped production line could not be implemented due to difficulties in material- handling. The optimum solution in this case is to include additional two moving workers to assist the ends of both production lines. As a result, this case study proved that complete skill chaining is applicable and capable of maximizing system throughput without altering workforce capacity. 21 Table 2.1: Workforce allocation strategies Source [1] [2] [3] [4] [5] [6] [7] [8] [9] [10] [11] [12] [13] [14] [15] [16] [17] Year of 2006 2008 2014 2011 2011 2003 1996 2013 2005 2013 2013 2015 2007 2013 2007 1999 2004 Publication Workforce allocation strategies Bucket Brigades √ √ √ Cross-training √ √ √ √ √ √ Holonic Workforce Model (HWM) Workforce Flexibility √ √ √ √ √ √ √ √ √ √ √ √ Modelling tool √ √ √ √ √ √ √ Water-spider Rules Setting √ √ √ √ All workers optimization is initiated with dissection and improvement of individual task times, followed by optimizing work contents of workers. Mathematical modelling tool is widely used to solve various workforce allocation problems due to its simplicity to be applied to situations involving multiple manufacturing attributes. However, mathematical modelling restricts the flexibility of workforce allocation when there is an unexpected disturbance in manufacturing environment. To respond to different disturbances, multi-skilled workers are required. By referring to the table above, only a handful of papers talk about workers with different skills for a given task, rest papers assume same skills for a given task. The self-determination of HWM allows the workers to deal with real-time disturbances and thus introduces the flexibility of workforce allocation into the manufacturing system. Therefore, HWM is selected as the primary strategy in this study. Additionally, to further enhance the adaptability of HWM in manufacturing system, the concept of water-spider with predetermined tasks is integrated. In this study, the water-spider does not restricted to replenishment tasks only but also responsible for the regular tasks that do not have to be carried out in every cycle. Water-spider is utilized to assist the operators in the main process flow on maximizing the system productivity and keep the flows of manufacturing system smooth.

19**CHAPTER 3** 3 **METHODOLOGY 3.1 Introduction This chapter discusses the methodology** of the **research.**

31**Figure 3.1 shows the flow chart** that illustrates **the**

chronological order of the research. START Literature Review and Analysis on Workforce Planning Selection of Process for Case Study Selection of Parameters, Variables and Performance Measures Data Collection of Current Model NO Construction of Current Model Validated ? YES Propose Solutions for FutYuEreSModel Filtering of Unfeasible Solutions for Future Model Construction of NO Future Models to Select Best Model Verified ? YES Implementation of Future Model END Figure 3.1: Flow Chart 3.2 Methodology At the early stage of the research, literature review is to be done by reading through articles and filtering them based on the relevant topics about the study. The case study focuses on the workforce allocation in a semiconductor manufacturing that adopts job shop. Detail reading is performed to summarize and analyze various strategies of workforce allocation proposed by different researchers

under different manufacturing circumstances. As such, the articles are categorized into four main workforce allocation sections: Holonic Workforce Allocation Model (HWM), workforce allocation via standard operating procedures (SOP), workforce allocation to solve machine interference problem and workforce training. HWM is one of the strategies proposed by the researchers in which the operators are characterized as holons who are autonomous and with high flexibility relative to production changes. Workforce allocation can also be done by altering the SOP for the operators to perform work. SOP is important to ensure high quality of the products manufactured and also consistent and flexible line productivity. Several reviews stated that the objective of having effective workforce allocation is mainly to minimize the impact of machine interference problem by reducing the response time of the operator to the machine stoppage. Effective workforce allocation can also be achieved with the assistance of proper workforce training for the operator. The reviews are summarized into table 1 in page 15 and analyzed to determine strategies most commonly utilized in workforce allocation. A comprehensive understanding on the operating conditions of the selected production is required in order to propose a novel and feasible strategy for manufacturing processes improvement. A case study is carried out in a global electronics manufacturing company that manufactures electronic components such as power inductor and EMI suppression filter. Manufacturing of power inductors involves a few processes. The scope of the case study is narrowed down to focus on one of the manufacturing processes of the power inductor, namely electrical sorting and taping (EST) process. At current stage, there is no standard rule instructed to the operators on how they should carry out their tasks according to the priority of the tasks. In EST process, the workforce allocation is not flexible enough to deal with uncertainties and unexpected events

6**in the manufacturing environment.** Therefore, **the** objective **of this study is**

to improve the manufacturing process in term of workforce flexibility with proper workforce allocation. The number of workstations, number of machines, cycle time of the production line, cycle time of each individual task carried out by the operators, machine stoppage time, response time of operators to each shortstop and also the solving time are used for the construction of current model. The performance measures which include the worker productivity, total machine stoppage time, total machine setup time, machine efficiency are the indicators of the performance of the production and reflect the effectiveness of the future model compared to the current model. Data collection is carried out specifically on the EST line on a twice-a-week basis for six weeks, with each individual data collection lasting for two hours. The study is narrowed down to observing all ten machines and the operators assigned to respective machines. Time study is adopted to observe the operating behaviour in two perspectives: operator-bound and machine-bound. For operator bound, the focus is placed on determining job tasks sequencing as well as the cycle time of each individual tasks. For the machine bound, the details gathered are about the types of shortstops, response time of operator to each shortstop, and the duration required for solving. The data collected is constructed using machine- worker activity chart to obtain the operator-machine interaction over time. A worker-machine activity chart is a multiple activity chart that is used to demonstrate the relationship between the operator and the machines on which the operator works, and is evaluated in parallel with the timeline. A series of the job tasks performed by the operator is plotted against a time scale. By analyzing this chart, the utilization of both worker and machine times could be interpreted. Worker-machine activity chart is comprised of two parts: operator and machine. For operator, the cycle time for each individual task, operator's idle time and walking time are included based on the data collected. For machine, duration of each machine shortstops, machine breakdown, machine setup and machine interference were included. In this study, manual simulation is performed instead of the application of simulation software because the job tasks performed by the operator do not follow an exact sequence. The job tasks sequencing is solely dependent on the machine conditions. Furthermore, there are certain uncontrolled variables that are infeasible to be used as input in software simulation. After obtaining the performance measures of the EST production line on the machine efficiency and human labour productivity, a validation is done to check the reliability of data collected to ensure the feasibility of current model. Any significant deviation will indicate inaccurate model and thus the parameters need to be re-selected for another data collection before proceeding to the subsequent step which is the development of future model. In order to depict and reflect the actual operating conditions with the constructed model, the performance measures obtained from the current model, such as the machine uptime and the operator utilization are validated with the data provided by the company and must fall within the acceptable range. After the pre-analysis on the operating conditions of EST process, HWM is selected as the primary strategy for workforce allocation to improve the flexibility of the manufacturing line and also minimize the machine interference problem. HWM is implemented with additional of one operator into the manufacturing system as water spider to facilitate the workforce allocation. Thus, there are four operators with one water spider who are responsible for ten machines. Four possible solutions with different job tasks allocation between operators and water spider are proposed for the construction of future model. The main objective of this study is to minimize the machine interference problem by reducing the machine stoppage time. As machine errors are random and unpredictable, operator must be ready to deal with machine shortstops by assigning some tasks to water spider. The similarity between the four cases is that the machine solving tasks are assigned to the operators instead of water spider. This is because there is only one water spider who needs to take care of ten machines and could not respond quickly to all the machine shortstops that occur frequently. Manual simulation is then performed to investigate the outcome for two final cases for the construction of future model. At this stage, performance

measures such as work ratio, total machine interference time and machine efficiency are evaluated from the results of manual simulation as they act as the clinchers to justify which case yields a better performance. For verification purpose, several test runs are carried out in the EST process with the job tasks allocation proposed in the two final cases. In scenario where there is a high deviation between the test run results and the simulation results, it has to return to the previous stage to check the feasibility of the two proposed cases or propose alternative feasible solutions. Implementation of future model can only be carried out once the verification process is completed. At the initial stage of the implementation, the process layout and the footwork which illustrate the movement of the operators and water spider within the manufacturing system are drawn. The SOP of the water spider is established and a little amendment is done to the SOP of the operator in the current model. Workforce training is then provided to the operators and the water spider by production according to the SOP. During the implementation, the movements of the operators and water spider are observed and issues encountered by the manufacturing system are recorded. Once the manufacturing system achieves its stability, data collection is carried out to evaluate the performance measures which reflect the effectiveness of the future model as compared to the current model. CHAPTER 4 4RESULTS AND DISCUSSIONS 4.1 Introduction This chapter divided into 10 sections and each stage of the research is discussed in detail in each section. Section 4.2 describes the selection of the case study. Section 4.3 outlines the selected parameters, variables and performance measures that required to construct and evaluate the current and future models. Section 4.4 describes the execution of data collection to gather the necessary information required for the construction of current model. In section 4.5, the current model of EST process is constructed with the data collected. The validation procedures are discussed in section 4.6. In section 4.7, several feasible solutions are proposed to optimize the productivity of the EST process. The unfeasible solutions are then filtered out in section 4.8. Section 4.9 outlines the simulation model that is performed to elect the optimal solution that obeys the objectives of the case study. In section 4.10, verification of constructed future model is presented. With verified future model, the implementation of future model is

6**described in section 4.** 11. In **the** last section, **the** result **of** the **implementation** is compared with the simulated model in section 4.9. 4.2 Selection of Process for Case Study The case study is carried out on the EST process. Among the manufacturing processes of the power inductor, EST process involves the most number of operators and machines where proactive improvement on the EST process is needed to maximize the output of the manufacturing system. The current process flow and the work tasks carried out by the operators are observed and studied before the data collection can be carried out. The input to the process is the inductor cores while the output of the process is a complete reel of inductors. Figure 4.1 shows the process flow of the EST process. 1. Lot Preparation 2. Subsample Preparation 3. Reel Label Printing 4. Machine Setup 8. Update Workslip 7. Lot Completion 6. Labelling 5. Machine Starts 9. Prassing 10. Inventory Figure 4.1: Electrical Sorting and Taping (EST) Process Flow Figure 4.2 shows the layout of the EST process. The movement of operator while carrying out tasks throughout the process is indicated in the layout. Before the production starts, lot preparation by operator is required. The operator is required to bring along a tray from the respective machine workstation and proceed to the EST material rack to collect the raw materials which are the inductor cores stored inside a container. Details written on the container are checked to be identical with those stated on the workslip before transferring back to the machine workstation. After that, the operator will proceed to subsample preparation at outgoing quality control (OQC) station where the cores are calibrated and inspected before they go into production. The calibration result is updated to the system by using main computer located near the OQC station. Reel label printing is then carried out by using the main computer located near the raw materials rack. 22 labels are printed as a complete lot consists of 22 reels of power inductors. After lot preparation, machine setup is performed. The work tasks performed by the operator during machine setup include closing of the previous lot, machine cleaning, machine calibrating, manual input of lot details into the machine, workslip updating and sample checking. The machine will starts operation after the machine setup is accomplished. During the process, the labelling task is carried out by the operator once for every 5 reels manufactured. The labelled reels are then packed into box after 5 reels. After the completion of lot, the workslip is updated with the production details such as the lot starting and ending time. Prassing is performed at the main computer where the production details are updated into the system. At the last stage of the EST process, the boxes with the inductor reels are transferred to the rack to be further processed such as box label printing and appearance checking. Figure 4.2: Layout of Electrical Sorting and Taping (EST) Process EST job shop model consists of ten machines operated to produce two main types of power inductors, namely H-type and S-type. Among the ten machines, six machines are used for S-type products while four machines are used to manufacture H- type products. As shown in figure 4.2, there is a total of four operators involved in EST process. The four dashed line boxes indicate the operator allocation to the machines. For S-type machines, one operator is assigned to three machines while for H-type machines, one operator is assigned to two machines. By referring to the current layout of EST process, the main computers that are used for prassing, the material replenishment racks and the inventory racks are located at the two sides of the ten machines. Therefore, except for solving machine shortstops and updating workslip, the operators need to travel out from the machine areas to perform the other work tasks. Principally, machine interference problems are encountered when the operators could not attend to the machines immediately to solve the machine errors. Machine efficiency decreases as the machine stops operating. 4.3 Selection of Parameters, Variables and Performance

Measures The main objective of the case study is to improve the productivity of the manufacturing system in terms of machine efficiency. In order to achieve this, optimal workforce allocation is targeted. Operators play an important role in deciding the machine efficiency. The shorter time that they use to solve the machine shortstops, the higher the machine efficiency. In current manufacturing system, the operators are assigned with similar and fixed tasks that provide no flexibility to the manufacturing line and hence inevitably lengthen the operator’s machine solving time. Therefore, Holonic Manufacturing System (HMS) is introduced as it allows flexibility in operator's work tasks allocation. HMS is one of the intelligent manufacturing systems in which the decision making process is carried out at each manufacturing stages and hierarchy levels by the workers that are trained to become the holon workers. With the improvement in decision making process, the effectiveness of information transfer within the manufacturing system could be improved as well. The operator's work tasks allocation could be adjusted depending on the condition of the manufacturing line. Water spider is mainly responsible for the non-value added activities within the manufacturing system such as material replenishment. The concept of water spider is implemented together with HMS so that the operator can shorten the machine solving time with the assistance of water spider. Water spider in this case is an example of holon worker where he must be a well-trained worker as the work task sequence must be determined wisely to ensure a smooth flow of production. The number of workstations and machines are observed from the manufacturing system while the cycle time of the EST process, the cycle time of each individual task carried out by the operators, the machine stoppage time, the response time of operators to each shortstops and also the solving time are recorded during the data collection. The collected data is used to compute the performance measures such as worker productivity, total machine stoppage time, total machine setup time and machine efficiency. The worker productivity and machine efficiency are the main performance measures to evaluate the effectiveness of the future model. Worker Productivity = Total time operator is occupied Total available time −−−−−−−−−−−(1) Worker productivity is determined by dividing the total time whereby the operator is performing tasks, with the total available working time. Machine Efficiency = Total machine running time Total available time −−− −−−−−−−(2) Machine efficiency is computed by dividing the total time whereby the machine is running, with the total available time. In this study, the available working time is defined as the duration of data collection. Increase in machine efficiency with appropriate level of worker productivity is targeted in proposing feasible solutions for the construction of future model. 4.4 Data Collection of Current Model Time study is performed on the EST process using stopwatch for data collection. The time study focuses on two aspects which are operators and machines. For each interval of data collection, one operator and his/her assigned machines are observed. The movement of the operator and the time taken for the operator to perform the work tasks are observed and recorded. The six general tasks performed by the operator are raw materials replenishment, machine setup, machine solving, workslip update, prassing and inventory regulating. At the same time, the machines are monitored to identify the types of machine shortstops occurred throughout the entire inductor reels production. The response time of the operator to attend to the respective machine shortstops and the solving time are recorded as well. Two data collectors participate in the data collection where one data collector observes the movement of the operators while another data collector observes the operating conditions of the operator’s assigned machines. Different operator and machines are observed for each data collection in order to have a complete overview on the EST process, such that the required data about the four operators and the ten machines are gathered. 4.5 Construction of Current Model With the collected data, worker-machine activity chart is plotted to analyze the interaction between the operator and the machines. Figure 4.3 shows one of the worker- machine activity charts plotted that illustrates the operator’s activity and the three S-type machines conditions in parallel. The first row of the chart represents the time frame for data tabulation. There is a total of 688 columns with each column scaled to 15 seconds duration. For better visual presentation and tabulation of the operator work tasks, colours are used for highlighting the six distinct general task categories as well as the other non- value-added activities which include off positioning, idling, and moving or walking of the operator. These work tasks categories are listed on the left column of the table. By referring to table 4.2, the operator’s work tasks legends are defined to ease the data representation. For machine part, the machine conditions for the three S-type machines, on which the operator works on, are listed with different cell colours on the left columns as well. Table 4.3 shows the legends for the machine’s condition. As the operator is required to work on at least two machines and most of the work tasks involving walking and material transportation, it takes a longer respond time for the operator to attend to each machine shortstop. The machine interference problem could be observed with ease by referring to the black coloured cells. The black coloured cells could also reflect the response time of the operator to the machine shortstops. Table 4.1: Work Tasks Allocation between Operator and Water Spider for Four Cases Opearator's tasks 5S 1 Machine Solving (Core stuck) - Use vacuum or air gun Add Machine Solving (Core missing / Empty pocket - use tweezer add core) Machine Adj Solving Tape Problem (Adjust tape) Solving Cut E Machine Solving (Cut Tape due to machine error) TW Machine solving (Core stuck- Use tweezer) Refill Machine Solving (Insufficient cores in the machine – pour the cores into the feeder) 5S 2 5S (Routine) - Use air gun ** Machine cleaning after every 2nd and 4th lot Cal Calibration (Set up) Use the standby sample - pour the cores inside the container to the machine Cut S Cut Tape (Stick on workslip, act as standby cores for machine error solving) Key Data Key In (Machine) Setup Rej Setup (Remove rejected cores from machine and pour into plastic) Rec Record - Workslip (Quantity produced) Replenish Replenishment (Core - place the core container to the ment machine) Refill Refill - Core (Pour cores inside the container to the machine) Label Label the last few reels after inspection RC Reconnect the tape Replenishment Replenishment - from the Material Replenishment Rack - Embossed tape - Cover tape - Adhesive tape - Plastic reel Refill Refill - Core (Pour

cores inside the container to the machine) - Tape (Install Embossed/cover/adhesive tape into the machine) - Plastic Reel (Put plastic reel into the machine) Record Record - Workslip - Daily Operator Record (DOR) - Label plastics used to keep rejected cores from machines - Machine breakdown record (logbook) Main PC Issue Machine Breakdown/ Prassing / Confirmation of standby lot PC QC Key in core details after subsample preparation and also print label SP Setup (Subsample preparation - Calibration) N Clean Non-routine cleaning on machine (Use cotton bud and liquid - IPA) Inp Inspection on final product (reel) before labelling - every 5 reels Label Labelling after inspection Others R Confirm Reel Confirmation - Take 1 complete reel to QC (ON-line Checking) RC Reconnect Cut Tape Inv Transfer Finished Goods RT Re-taping (Removes the reusable cores from the tape and put into container) Throw Clean trash (Tape) inside the bins located at machine Inp T Checking (Make sure the position of cores in tape within the specification) Cut QC Cut Tape (Inpection / Embross carrier tape peeling force testing) Cut S Cut Tape (Stick on workslip, act as standby cores for machine error solving) Key Data key in Cal Calibration of machine using standby cores Off Position Operator is out of working area IDLE Operator is not performing task Walking Operator travel from one wokstation to another workstation Table 4.2: Machine's Conditions Legends Machine's Conditions Operation Machine is operating Non-operation Non-operation of machine (Machine breakdown/Machine setup) Shortstop Machine shortstops Interference stop Machine interference (Operator is busy with other tasks while the machine shortstop occurs or during machine setup) 39 OA's tasks Time 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 679 680 681 682 683 684 685 686 687 688 5S 1 Add Machine Adj Solving Cut E TW Refill 5S 2 Cal Cut S Key Setup Rej Rec Replenishment Refill Label RC Replenishment Refill Record Main PC PC QC SP N Clean Inp Label R Confirm Others RC Inv RT Throw Inp T Cut QC Cut S Key Cal Off Position IDLE Walking Total 1 1 1 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 M1 Operation Non-operation Shortstop S S S S S S S S S S S S S S S S S S S Interference stop M2 Operation Non-operation Shortstop Interference stop M6 Operation Non-operation Shortstop Interference stop Figure 4.3: Worker-Machine Activity Chart Based on the plotted worker-machine activity chart, a preliminary analysis is performed to evaluate the essential performance measures such as the machine efficiency and worker productivity. Four worker-machine activity charts averaged the ten machines and four operators are interpreted to determine the operating conditions and to provide an overview of the current EST model. Table 4.1 shows the performance measures computed that could reflect the operating conditions of the EST process. Table 4.3: Operating Conditions of EST Process Machine Current Average Machine Efficiency 72.6% Average Machine Breakdown Time 7.1% Average Setup Time Interference Actual 3.5% 6.3% 9.8% Average Machine Shortstops Time Interference Actual 3.5% 7.0% 10.5% TOTAL 100.0% Worker Current Average Worker Productivity 76.4% The average machine efficiency of the current model is 72.6% where the remaining 27.5% of time, the machines are not operating due to machine breakdown, machine shortstops and also machine setup. In this study, the main concern is to reduce the machine interference time for machine setup and machine shortstop which will help to improve the machine efficiency. For machine setup, it weighs 9.8% of the total machine operating time. Out of the 9.8% of machine setup time, 6.3% is the actual machine setup while the remaining 3.5% of time, setup interference occurs. Besides that, for the 10.5% out of the total machine operating time, the machines experience shortstops which is the decisive factor leading to the reduction in machine efficiency. Out of 10.5% of machine shortstops time, the actual shortstops time is only 7.0% while the remaining 3.5% of time, the operators could not attend to the machine immediately after the shortstops occur. The operator's performance is evaluated in term of worker productivity with the average of 76.4% for the current model. 4.6 Data Validation The

16**collected data is** verified **with the data** provided **by the**

company. Table 4.2 shows that the constructed EST model reflects the actual operating conditions of the EST process as the variations is small which stay between 0.7% to 4.4%. This indicates that the complete cycle of EST process could be observed with 2 hours of data collection over four data sets. Table 4.4: Comparison between Collected Data and Company's Data Collected Data Company's Data % Error Average Machine Efficiency 72.6% 68.2% 4.4% Average Machine Breakdown Time 7.1% 10.3% 3.2% Average Setup Time 9.8% 11.7% 1.9% Average Machine Shortstops Time 10.5% 9.8% 0.7% 4.7 Propose Solutions for Future Model In order to deal with machine interference problem, optimal job tasks allocation within the operators is the main target. Workforce flexibility is essential for job shop manufacturing system. Holonic Workforce Model (HWM) is proposed for EST process. As the work tasks for the operators in EST process involve a lot of transportation within the working area, the concept of water spider is recommended to incorporate with the HWM. At the current stage, the workforce level is maintained at 4 operators as requested by the company. Therefore, one of the operators is trained to become the water spider. The water spider is mainly responsible for the transportation and replenishment tasks for all the machines in the EST process. The water spider has to assist another 3 operators by taking up some of the work tasks to reduce the occurrence of machine interference problem during machine setup and machine shortstops. The water spider is an important element in HMS as he acts like a holon where he must be familiar with the EST process and capable of analyzing the job task priorities sequencing throughout the manufacturing system. Four possible cases with distinct work tasks allocation between the operators and the water spider with the concept of holonic are proposed. Table 4.3 shows the work tasks allocation between the operator and the water spider for the four cases proposed. Priority rule is developed to make the operators and water spider more holonic where they are required to identify their

optimum work task sequences according to the work tasks' priority. Work tasks that would directly affect the machine operation such as machine solving are given higher priority as compared to other non-value added activities such as workslip update. Preemption is only allowed when there is a machine shortstop occurs while the operator is performing a work task with lower priority and the less-prioritized task is to be continued subsequently. For water spider, work tasks such as material replenishment that would indirectly affect the machine setup or machine operation are given higher priority as compared to other work tasks such as clean trash and re-taping that do not contribute to machine operation. Apart from that, a little amendment is suggested to the current layout of EST process. In the current layout, all the workstations are located near to the EST machines except the outgoing quality control (OQC) station. Thus, it is more convenient to the operator if another OQC station is located near to the EST machines which could help to shorten the distance travelled by the operator. Table 4.5: Work tasks allocation between operator and water spider for four cases Work tasks (√ - Operator, X – Water Spider)

27**Case 1 Case 2 Case 3 Case 4**

5S 1 √ √ √ √ Machine Add √ √ √ √ Solving Adj √ √ √ √ Cut E √ √ √ √ TW √ √ √ √ Refill √ √ √ √ 5S 2

4**X X** √ √ Cal **X X** √ √ Cut S **X X** √ √ Key **X X** √ √ Setup Rej **X X** √ √ Rec **X X** √ √ Replenishment **X X** √ **X** Refill **X X** √ √ Label **X X** √ √ RC **X X** √ √ Replenishment **X X X X** Refill √ √ **X** √ Record √ √ **X** √ Main PC **X X X X** PC QC **X X X X** SP **X X X X** N Clean √ √ √ √ Inp √ √ **X** √ Label √ √ **X** √ R Confirm **X X X X** Others RC **X** √ **X** √ Inv **X X X X** **RT X X X X** Throw **X X X X** Inp T **X** √ **X** √ Cut QC √ √ **X** √ Cut S √ √ **X**

√ Key √ √ √ √ Cal √ √ √ √ For case 1, machine setup and all the tasks that involve material transportation which is one of the manufacturing wastes are assigned to the water spider. Basically, the operator is responsible for the work tasks that could be carried out within the machine area which include machine solving, materials refill, workslip record and labelling. The operators in this case could stay within the operator working area and always available for solving machine errors and thus reduce the machine stoppage time. In this case, although machine setup is performed within the machine area, machine setup is assigned to water spider. Since the water spider is responsible for machine setup, two machine-based tasks which are RC and Inp T are assigned to water spider as well. For case 2, the overall job tasks allocation and the movement of operator and water spider is similar to case 1 with minimal changes by shifting the two machine-based tasks which are RC and Inp T from water spider to operator. Figure 4.4 shows the work tasks allocation and the movement of operator and water spider for case 1 and case 2. Figure 4.4: Work Tasks Allocation and Movement of Operator and Water Spider (Case 1 and 2) For case 3, the job tasks allocation is mainly based on inner and outer work tasks. Inner work tasks are the non-value added activities whereby the machine is not running during the task execution. Outer work tasks do not affect the productivity of the manufacturing system whereby the operator performs the tasks while the machine is running. In order to improve on the system productivity, the inner work tasks are carried out by the respective operator while the water spider is responsible for the outer work tasks for all the ten machines. Figure 4.5 shows the work tasks allocation and the movement of operator and water spider for case 3. Figure 4.5: Work Tasks Allocation and Movement of Operator and Water Spider (Case 3) For case 4, the job tasks are categorized into online tasks and offline tasks. Online task is defined as the work tasks that are executed by the operator within the operator working area while offline tasks are the work tasks that need to be carried out by the operator outside the operator working area. Transportation is considered as one of the offline tasks. In this case, the online tasks are assigned to the operator while the offline tasks are assigned to the water spider. Machine setup which consists of online and offline setup tasks is performed by both operator and water spider respectively. Figure 4.6 shows the work tasks allocation and the movement of operator and water spider for case 4. Figure 4.6: Work Tasks Allocation and Movement of Operator and Water Spider (Case 4) 4.8 Filtering of Unfeasible Solutions for Future Model The four cases proposed are analyzed to filter the feasible solutions that could trigger a distinct improvement on the machine efficiency and at the same time maintain the suitable level of worker productivity. This is done to simplify the analysis by reducing the unnecessary effort in evaluating non-feasible solutions. Among the four cases, the machine setup job is categorized into three distinct scenarios. For the first and second cases, the entire setup process is performed by the water spider. The operator is responsible for machine setup job in the third case. Whereas in the fourth case, the setup tasks are shared between them such that operator deals with on-spot setup job tasks while setup tasks that must be done outside working area are handled by water spider. For case 1 and case 2, the water spider is solely responsible for the machine setup as it has long task time and to avoid preemption during machine setup. By comparing case 1 and case 2, the only difference is the allocation of the two machine-based tasks between the operator and water spider. The two machine-based tasks are assigned to water spider in case 1 to maintain the process flow of the production as these two tasks are performed after the machine setup. In case 2, except for machine setup, the water spider is responsible for all the work tasks that need to be performed outside the machine area. Therefore, the two machine-based tasks are performed by the operator instead of water spider. Case 2 is preferable with the consideration that the two machine-based tasks could only be performed after the machine starts operating for a period time. The operator who always stays within the machine area could perform these tasks more conveniently while the water spider could proceed to other work tasks right after the machine setup. By comparing case 3 and case 4 in term of operator's availability to machine shortstops, operators in case 4 can always attend to machine shortstops quickly as the operators only perform their work tasks within the working area. Besides that, in case 3, the water spider is responsible for the inner tasks of all the ten machines. Since the machines are running at most of the time, it can be anticipated that there are much more inner tasks than outer tasks hence resulting in overloading workload of the water spider in contrast to the workload of the operators. From the perspective of conducting workforce training and to deliver clear and straightforward instructions within the manufacturing system, job tasks allocation in case 4 is desirable as there is no overlapping working area between the operator and water spider. Therefore, among the four proposed solutions, case 2 and case 4 are the feasible solutions proposed for the future model. 4.9 Construction of Future Models to Select Best Model Manual simulation is performed to illustrate the system performance of EST process with the job tasks allocation stated in case 2 and case 4. In order to ensure the validity of the simulation results, several assumptions are made during the manual simulation. Firstly, the time where the machine errors occur in the current model is remained in the simulation for the construction of future model. Principally, when the machine error time is maintained in the simulation, the probability and stochasticity of errors are well-retained, yet simultaneously any significant change in worker response time after the implementation can be observed clearly and compared in analytical phase. Secondly, the machine breakdown time is remained constant as machine breakdown is attended by the technicians and the operators do not responsible for solving machine breakdown. At current stage, the manual simulation is performed with the workforce level remained as four operators for EST process as requested by the company. The simulation involves only eight machines whereby two H-type machines are excluded. This assumption is made due to the consideration of one of the operators is trained to become water spider and an operator can only afford to handle maximum of three machines at one time. Besides that, the three operators are assumed to be identical with same level of skills and abilities. The operator that trained to become the water spider is assumed to be an experienced or senior operator that familiar with all the work tasks in EST process. Future models are constructed with the proposed feasible solutions with different task allocation between operators and water spider by using the concept of HMS. The best model is selected based on the effectiveness of the model in solving machine interference problem in EST process. Table 4.3 shows the comparison between the performance measures of case 2 and case 4. Table 4.6: Comparison between the performance measures of Case 2 and Case 4 Machine Current Case 2 Case 4 Average Machine Efficiency 72.6% 77.6% 78.2% Average Machine Breakdown Time 7.1% 7.1% 6.4% Average Setup Time Interference Actual 3.5% 6.3% 9.8% 0.2% 6.5% 6.7% 0.6% 7.2% 7.8% Average Machine Shortstops Time Interference Actual 3.5% 7.0% 10.5% 1.9% 6.7% 8.6% 1.5% 6.1% 7.6% TOTAL 100.0% 100.0% 100.0% Worker Current Case 2 Case 4 Average Operator Utilization - 52.4% 60.7% Water Spider Utilization - 85.8% 58.0% Average Worker Utilization 76.4% 60.8% 60.1% Standard Deviation Current Case 2 Case 4 Machine Efficiency 0.1655 0.1914 0.1901 Worker Utilization 0.0800 0.2007 0.0622 By referring to table 4.3, it could be concluded that both case 2 and case 4 show feasibility in improving the average machine efficiency whereby the average machine efficiency is improved from 72.6% to 77.6% and 78.2% respectively. Case 4 has the highest increased percentage in machine efficiency of 5.6%. The average machine breakdown time remained constant during the simulation as the operators do not responsible in solving machine breakdown. Principally, the average machine efficiency is improved by reducing the average setup time and machine shortstop time. From the table, it is shown that the average setup time in case 2 and case 4 is reduced as compared to the current model from 9.8% to 6.7% and 7.8% respectively. The average machine shortstops time of the current model is 10.5% and it could be reduced to 8.6% in case 2 and 7.6% in case 4. The focus of this study is to minimize the machine interference problem during machine setup and machine shortstops. In term of machine setup, case 2 is preferable as the average interference machine setup time is reduced from 3.5% to 0.2% with a total reduction of 3.3%. For case 4, the total reduction in average interference machine setup time is only 2.9% which is from 3.5% to 0.6%. In term of machine shortstops, case 4 is preferable as the average interference machine shortstops time is reduced from 3.5% to 1.5% with a total reduction of 2.0%. For case 2, the total reduction in average interference machine shortstops time is only 1.6% which is from 3.5% to 1.9%. In the current model, all the operators are performing the similar work tasks on their respective machines in EST process. The overall worker utilization is 76.4%. For both proposed feasible cases, water spider is introduced into the EST process. Water spider has a distinct work tasks allocation from the ordinary operators. Hence, in order to better monitor the utilization of all the labors and ensure workload balancing between the operators and the water spider, the utilization rate of both operator and water spider are computed individually. The average worker utilization rate is reduced from 76.4% to 60.8% in case 2 and 60.1% in case 4. Both case 2 and case 4 have the similar average worker utilization rate with a minimal difference of 0.7% as the overall work tasks allocation in both cases is almost identical. In case 2, the average operator utilization is 52.4% and the water spider utilization is 85.8%. Whereas in case 4, the average operator utilization is 60.7% and the water spider utilization is 58.0%. In this study, the standard deviation is calculated to determine the variability for the average machine efficiency and the average worker utilization in case 2 and case 4. The standard deviation value for both cases are slightly higher than the current model. This is because there are only a few machines encountered machine breakdown during data collection where the machine breakdown time is assumed to be a constant variable in the simulation model. The implementation of holonic workforce allocation does not improve on the machine breakdown time. Machines encountered machine breakdown during the data collection tend to have lower machine efficiency as compared to other machines that operate normally during data

collection. The value of standard deviation for average machine efficiency is 0.1914 for case 2 and 0.1901 for case 4 with a slight difference of 0.0013. The value of standard deviation for average worker utilization is 0.2007 for case 2 and 0.0622 for case 4 with a difference of 0.1385. This is because in case 2, the machine setup is fully assigned to water spider while in case 4, the machine setup tasks are assigned to both operator and water spider. Machine setup consumes the longest time compared to the other tasks as it consists of a series of work tasks and thus results in higher variation in the worker utilization of each operator in case 2. As compared to the current model, case 4 with lower standard deviation is preferable as the workload for all the workers is more equitable with the proposed workforce and work tasks allocation. Based on the objective of this study, better workforce and work tasks allocation are targeted to improve on EST system output and machine efficiency. Overall, the improvement on the machine efficiency of EST process could be achieved with the reduction of interference machine shortstops and machine setup. Through the study and analysis on the EST process, the occurrence of machine shortstops is more frequent as compared to the machine setup and thus the shortstops interference reduction is highly valued in contrast to setup interference reduction. Therefore, case 4 with greater significant reduction in machine interference shortstops time is selected. Besides that, in case 4, the operators are responsible for the online tasks within the machine area while the offline tasks that need to be carried out outside the machine area are assigned to the water spider. There is no overlapping of working area for the water spider and the water spider in performing their respective work tasks. With the workforce and work tasks allocation proposed in case 4, workforce training is more effective and easier to be conducted without confusion in work tasks allocation between the operators and the water spider. Apart from that, case 4 is selected as the best model with its lower standard deviation values for both machine efficiency and worker utilization. Theoretically, lower standard deviation is preferable as it indicates that the variation in performance between the machines or the workers is smaller and hence the result is more reliable. For the application in real industry environment, case 4 illustrates better workforce planning by allocating similar workload among all the workers in EST process. Table 4.7: Simulation Analysis (Case 2) Machine Current Case 2 Difference Average Machine Efficiency 72.6% 77.6% +5.0% Average Machine Breakdown Time 7.1% 7.1% 0.0% Average Setup Time Interference Actual 3.5% 6.3% 9.8% 0.2% 6.5% 6.7% -3.3% +0.2% -3.1% Average Machine Shortstops Time Interference Actual 3.5% 7.0% 10.5% 1.9% 6.7% 8.6% -1.6% -0.3% -1.9% TOTAL 100.0% 100.0% - Worker Current Case 2 Difference Average Operator Utilization - 52.4% - Water Spider Utilization - 85.8% - Average Worker Utilization 76.4% 60.8% -15.6% Table 4.4 shows the analysis of the simulation results for case 2. The average machine efficiency is increased from 72.6% to 77.6% with the difference of 5.0%. The average machine breakdown time is a constant between the current model and case 2. For machine setup, the average setup time is reduced from 9.8% to 6.7% with a difference of 3.1%. Currently, each machine setup in EST process consumes about 12 minutes of time but with the improvement suggested in case 2, the machine setup time could be reduced to about 8 minutes. In current model, the machine setup is preemptive as the machine shortstop has a higher priority than machine setup and therefore setup interference occurs. In case 2, the machine setup tasks are assigned to the water spider and thus the setup interference time is reduced as the machine setup is carried out by the water spider and not affected by any arisen machine shortstops. The average setup interference time is reduced from 3.5% to 0.2% with a difference of 3.3% which is about 4 minutes in time. The setup interference in this case is due to the water spider is performing other tasks outside the machine area and as a result the setup might be delayed. By comparing the average machine shortstops time in case 2, it has been reduced from 10.5% to 8.6% with the total reduction of 1.9% as compared to the current model. This is because the operator can always focus on solving machine shortstops as all the machine setup tasks and the work tasks that involve transportation such as material replenishment are assigned to water spider. This also leads to the reduction of average interference shortstops time from 3.5% to 1.9% with a difference of 1.6%. However, the average worker utilization rate decreases from 76.4% to 60.8% due to the fact that water spider and the operators have different workloads. Table 4.8: Simulation Analysis (Case 4) Machine Current Case 4 Difference Average Machine Efficiency 72.6% 78.2% +5.6% Average Machine Breakdown Time 7.1% 6.4% +0.7% Average Setup Time Interference Actual 3.5% 6.3% 9.8% 0.6% 7.2% 7.8% -2.9 +0.9 -2.0% Average Machine Shortstops Time Interference Actual 3.5% 7.0% 10.5% 1.5% 6.1% 7.6% -2.0 +0.9 -2.9% TOTAL 100.0% 100.0% - Worker Current Case 4 Difference Average Operator Utilization - 60.7% - Water Spider Utilization - 58.0% - Average Worker Utilization 76.4% 60.1% -16.3% Table 4.5 shows the analysis of the simulation results for Case 4. With the operators and work tasks allocation proposed in case 4, the average machine efficiency could be improved from 72.6% in current model to 78.2% with a difference of 5.6%. The average machine breakdown time is remained almost constant with only a minimal difference of 0.7% between the current model and case 4. The average machine setup time is reduced from 9.8% to 7.8% with a total reduction of 2.0% which is about 2 minutes in time. The average interference setup time reduced is 2.9%, which is about 4 minute in time. The average interference setup time is reduced from 3.5% to 0.6%. The reduction of average machine setup time is smaller as compared to case 2. This is because the machine setup in case 4 is carried out by both the operator and the water spider and thus the some of the setup tasks that are assigned to the operator might be interfered by the occurrence of machine shortstops. For case 4, the operator is responsible for all the online tasks which could be carried out within the machine area whereas the water spider is responsible for the remaining offline tasks which require him to travel out from the machine areas. In addition, the machine shortstop has the highest priority among the assigned tasks to the operator as most of the online tasks are preemptive. As a result, the average interference machine shortstops time could be reduced from 3.5% to 1.5%, a total reduction of 2.0%. This leads to the reduction of average machine shortstops time of 2.9%, which is from 10.5% to

7.6%. The average worker utilization for case 4 is 60.1%, which is lower than the current model of 76.4%. This is due to the water spider and the operators are now having slightly different workload as compared to the current model where all the workers are having equal work tasks and workload. 4.10 Implementation of Future Model 4.10.1 Workforce Training First of all, the workforce training has to be done before the actual implementation could be carried out in the EST process. The senior or experienced operators are trained to function as the water spider. In order to ensure smooth production flow and high process output, the company had decided to recruit one extra operator to assist the EST process. As such, the workforce level of EST process is increased to 5 workers which consist of 4 operators and 1 water spider. Through the analysis, the unusual events that commonly faced by the company are the absence of workers and breakdown of multiple machines at the same time. With holonic workforce allocation, the workers are trained to be more holonic and the decision making process on the EST process could be carried out more efficiently. In the event of multiple machines breakdown, one of the operators could be shifted to perform the water spider's job tasks. For example, there will be a combination of 2 WS + 3 OA instead of 1 WS + 4 OA under normal operation. Whereas in the event of absenteeism of worker, the trained water spider is reverted back to an ordinary operator, whereby no distinct work tasks allocation among the workers. The workforce in EST will then contain with ordinary operators only, which is synonymous to current model. Cross-training is introduced in workforce training in order to improve the flexibility of workforce planning and the ability of EST process to deal with unusual events. All the workers are trained to perform job tasks under two distinct operating situations: with and without water spider. Among the 5 workers, 3 senior workers are cross-trained to ensure they could shift between ordinary operators and water spider under unusual events. The training of operators took about 3 weeks time. 4.10.2 Layout Modification Minor changes were applied to the current layout of EST process to facilitate the movement of workers while performing their work tasks. In order to shorten the travelling distance of the water spider, one additional outgoing quality control (OQC) station is placed near to the machine area as shown in Figure 4.8. In the proposed model, the coverage of the work area for water spider is larger compared to the ordinary operators as the water spider is responsible for all the offline tasks that involve abundant of movement outside the machine area. Indicator lights are newly installed next to each machine in order to alert the water spider about pending work tasks. For example, as soon as the operator on-line completed the machine setup, the operator would actuate the indicator light so that the water spider could move to the station and proceed with the next work task such as prassing for the particular machine. Besides that, water spider is equipped with a trolley to eliminate the redundant movement while performing work-in-process (WIP) transportation. For example, the water spider could perform material replenishment at the raw material racks for multiple machines simultaneously because a trolley can accommodate the required raw materials for more than one machine at once. 4.10.3 Test Run Several test runs are conducted to determine the outcome of the proposed model and to ensure all the workers are familiar with their new job scope. EST process consists of 2 working shifts with a daily production time of 1305 minutes. Day shift covers 675 minutes whilst night shift comprises 630 minutes. In this study, data collection on EST process was performed during the day shift and thus the test run is initiated on the day shift. The test run involves all the 10 EST machines as an additional worker is added to assist in the EST process. There are 5 workers which are 4 operators and 1 water spider participated in the test run. During the test run, the movement of the workers and the difficulties faced by the workers especially for the water spider while performing their tasks are observed. 4.11 Suggestions for Future Implementation 4.11.1 Workforce Planning Through the test run, the company found out that the water spider utilization could be further improved by allocating extra work tasks from the appearance checking process (APP3). The workstations of APP3 are located next to the EST process. Figure 4.7 shows the work tasks that need to be performed by the operators and water spider in both the EST and APP3 processes. The newly assigned tasks to the water spider are the material replenishment and inventory tasks in APP3. Figure 4.8 shows the movement of the operators and the water spider. 1. Lot Preparation 2. Subsample Preparation 3. Reel Label Printing 4. Machine Setup 8. Update Workslip 7. Lot Completion 6. Labelling 5. Machine Starts 11. Material 9. Prassing 10. Inventory Replenishme 12. Inventory nt (APP3) (APP3) Figure 4.7: Operators and Water Spider's Work Tasks Execution Flow Figure 4.8: Work Tasks Allocation and Movement of Operator and Water Spider In addition, the flexibility of the EST process could be further improved by promoting cross training among all 5 workers in EST process. All the workers should be trained to work as operator and water spider for the ease of workforce allocation during unusual situation. Unlike in most manufacturing line, step-by-step instructions are given by the line leaders to the operators for roles or job tasks switching. In this case, all the workers are characterized more towards holons where every worker is autonomous and capable of analyzing job task priorities sequencing. For example, during unusual scenario such as multiple machine breakdown and whereby all available workers are cross-trained, they can easily switch between the role of normal operator and water spider with highest flexibility. A holonic manufacturing system would allow EST process to deal with dynamic production. CHAPTER 5 5CONCLUSION AND RECOMMENDATIONS 5.1 Conclusion Continuous improvement on the manufacturing system by improving the manufacturing productivity and product quality is a crucial factor for a company to uphold its market position and maintain the competitive edge among the competitors. In this study, a research is conducted based on a case study in a global electronic company that manufactures and supplies electronic components. Process-oriented layout is adopted in the manufacturing system so that the company could provide a wide range of product varieties in order to satisfy different customers' demand. Electrical Sorting and Taping (EST) process which is one of the manufacturing processes of reel inductors is chosen for the case

the manufacturing system by introducing better worker-machine allocation and also work tasks allocation among the workers in EST process. The reduction in average machine efficiency in EST process is mainly caused by the machine interference problem. Machine interference problem occurs when there are two or more work tasks pending to be completed by the operators at the same time. Currently, there is no any specific rule that acts as the guideline for the operators to deal with the machine interference problems. They only follow one rule that is set by the company whereby they must complete the work tasks on hand before they can perform the following tasks as preemption is prohibited in EST process. Therefore, the machine interference problem recurs as machine shortstop occurs frequently in EST process and it is unpredictable. Besides that, in the current manufacturing system, all the operators in EST process are assigned with similar and fixed tasks. The flexibility in workforce and work tasks allocations are restricted especially when there are some unusual events such as multiple machines breakdown simultaneously. Holonic Manufacturing System (HMS) is proposed for EST process to improve the average machine efficiency with flexible workforce and work tasks allocations. It also helps to reduce the occurrence of machine interference problem. By introducing holonic workforce allocation, the operators are trained to be more holonic where they are able to identify the optimum work task sequence by considering the work tasks' priority. Work tasks that directly affect the machine operation such as machine shortstop have higher priority as compared to other non- value added activities such as workslip update. Preemption is only allowed when there is a machine shortstop occurs while the operator is performing a work task with lower priority and the less-prioritized task is to be continued subsequently. By doing this, the machine stoppage time could be effectively reduced so as to increase the average machine efficiency of EST process. Besides that, water spider is introduced to facilitate the holonic workforce allocation. Water spider is solely responsible for non-machine based work tasks to increase the availability of the operators on-line for solving machine shortstops. The senior and experienced workers are trained as water spider. This is because the water spider has to behave like a holon where he is able to take care of the whole EST process by identifying the work tasks priority based on his own skills and experience. Apart from that, cross training is promoted among the operators to encounter the unusual event such as absence of worker. The operators are trained to deal with two different scenarios which are with water spider and without water spider. In this study, data collection is performed on EST process and worker- machine activity chart is utilized to illustrate the interaction between the operators and their assigned machines. Manual simulation is carried out to demonstrate the actual operating condition of the current EST process and the simulation result is validated with the actual data provided by the company to determine the effectiveness of the manual simulation model. Four different cases of work tasks allocation between the operator and water spider are proposed to reduce the machine interference problem in EST process. One similarity among the four cases is that the operators are fully responsible on the machine solving tasks for their respective machines. The significant difference between the four cases is the allocation of the machine setup tasks between the operator and the water spider. For case 1 and case 2, the machine setup tasks are fully performed by the water spider while in case 3 the machine setup is fully performed by the operator. In case 4, the machine setup is performed by the operator with the aid from water spider the operator. In case 4, the machine setup is performed by the operator with the aid from water spider. Case 1 and case 2 have similar work tasks allocation between the operators and the water spider. The only difference between these two cases is that the two machine- based activities that are assigned to the water spider in case 1 are instead conducted by the operators in case 2. Case 2 is preferable as the machine interference time could be kept at minimal if the two machine-based activities are allocated to the operators who stay at the machine area for most of the time and to avoid confusion. For case 3 and case 4, the machine setup tasks are conducted by the operators. A slight difference in case 4 as compared to case 3 is that the water spider assists the operators in conducting the setup tasks that need to be done outside the working area such as material replenishment. In case 3, the operators are responsible for all the inner tasks where the machine stops operating until these tasks are completed. The water spider is responsible for all the outer tasks in which the machine continues to operate while these tasks are ongoing. In case 4, the operators are assigned with online tasks which keep them to stay within the working area during their execution of tasks while the water spider is responsible for the offline tasks that need to be done outside the working area. Therefore, case 4 is preferable as the operator could focus on the machine setup and machine solving without the need of travelling outside the working area. As a result, case 2 and case 4 are selected as the feasible cases which could help in achieving greater improvement on the average machine efficiency. For the two feasible cases, simulations using chosen parameters are carried out for constructing the future models in order to obtain the respective performance measures. The feasible model that could result in larger machine interference time reduction is chosen for implementation. For case 2, the resulting average machine efficiency is 77.6% with an increase of 5.0% as compared to the current model of EST process. According to the simulation results, the average interference setup time in case 2 is 0.2% and the total average machine setup time is effectively reduced to 6.7% of the total machine operating time. Besides that, the average machine shortstops time is also reduced to 8.6% due to the reduction in the average interference machine shortstops time to 1.9% of the total machine operating time. For case 4, the average machine efficiency obtained from the simulation results is 78.2% which is higher than case 2 and with an increment of 5.6% as compared to the current model of EST process. In term of average machine setup time, case 4 has slightly higher percentage of 7.8% than case 2 with only 6.7%. The average interference machine setup time in case 4 is also higher as compared to case 2 with a total percentage of 0.6%. However, case 4 has

a more significant improvement on the average machine shortstops than in case 2. The average machine shortstops time is reduced to 7.6% as compared to case 2 with the shortstops time of 8.6%. This is also indicates that case 4 has greater reduction in average interference machine shortstops time to 1.5% than case 2 with the interference time of 1.9%. By comparing case 2 and case 4 using the simulation results, case 4 is preferable as it could result in greater improvement in the average machine efficiency, which is 78.2%. Based on the evaluation on machine efficiency improvement, case 2 excels in terms of reducing the interference machine setup time whereas case 4 tops in terms of shortening the interference machine shortstops time. Case 4 is conclusively chosen. This is because the occurrence of machine shortstops in EST process is more frequent as compared to the machine setup and thus the improvement on machine shortstops is more significant than machine setup. The work tasks allocation in case 2 and case 4 are similar where the operators stay within the operator working area at all time and are always standby for attending machine shortstops. The difference between the two cases is the task allocation for machine setup. Machine setup in case 2 is fully performed by water spider while both the operators and the water spider are involved in machine setup in case 4. In actual implementation, the workforce and work tasks allocations in case 4 is more desirable as there is no overlapping of working area between the operators and the water spider that helps to avoid confusion in task allocation and thus the training of operator could be done effectively. Most importantly, case 4 achieves the main objective of this study in resulting higher average machine efficiency than case 2. In this study, manual simulation is utilized for the construction of current model to reflect the actual operating situation of the EST process. Manual simulations are also performed to compare the feasibility of the future models constructed based on the workforce and work tasks allocation proposed in case 2 and case 4. However, manual simulation has its limitations whereby it can only include a few parameters such as the work tasks completion time, machine shortstops time, machine breakdown time and machine setup time. Manual simulation is also more time consuming and complex to be carried out for EST process that involves ten machines and four operators. Besides that, the results of implementation could not be obtained immediately as proper operator training is necessary for the operators to be more holonic before the real implementation can take place in EST process. This is because the cross training into implementation takes time to achieve significant improvement, whereby depending on uncontrollable factors such as learning curve of operators and water spider. The outcome of the operator training differs for individual operators depending on their personal experiences and skills. 5.2 Recommendations for Future Studies There are several recommendations for future studies in order to achieve more significant improvement: ? A more reliable simulation model such as simulation software could be used to replace manual simulation in order to incorporate more essential parameters into the simulation model such as desired daily production, takt rate, operator's working shift, operator's daily working hour and etc. ? Cross training performed only on experienced operators which attain high level of skills instead of inexperienced operators or trainees for implementation. A steep learning curve with a substantial time-effective learning process can be acquired due to the familiarization of experienced operators with existing work tasks. ? Replicate for other labor intensive process to verify findings. ? Restructuring of layout to facilitate water spider-operator movement. ? Raw material better replenishment activities to improve efficiency of process. 5 REFERENCES 5 APPENDICES 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64