A simulation and modeling approach to lean manufacturing

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Abstract

Lean Manufacturing (LM) has been applied in various manufacturing sectors and has gained great acceptance and momentum over the last few decades. However, LM implementation does not always succeed due lack of understanding of lean concepts, lack of proficiency in selection of appropriate LM tool, inappropriate shop floor employees' attitude, unavailability of LM experts in a company, difficulty in implementing some LM tools without support, inability of LM tools in addressing various interdependent processes in the production line, lack of tools to quantify effectiveness of LM implementation, and lack of self-learning educational software for LM tools. The deficiency in the current user training programme (UTP) for LM tools is also among the main culprits leading to failure of LM implementation.

The current UTP for LM tools still lacks the ability to demonstrate and convince the users on the impact of implementing LM tool on a production floor before they actually apply the tools. Thus, users will have to conduct pilot studies and other experiments in the production floor post-training to study the impact of applying those LM tools to their manufacturing process. In other words, there is a gap between attending UTP and confidently applying LM tool in real production floor.

To overcome all these hassles, simulation-based approaches are proposed as an effective method in supporting and evaluating LM tools, in assessing current and future state of manufacturing process, in performing "what-if" analysis, and in measuring impact of improvement after LM implementation. However, the simulation software tools are generally more suitable for simulation engineers who know how to design, build or analyse a simulation model and how to integrate the simulation model to LM tool software. These approaches are not suitable for other domain experts in the lean project (process engineer, mechanical engineer, quality engineer, production engineer, materials engineer, marketing executive, and finance executive) who are familiar with neither simulation software nor LM tool software. Misunderstanding between simulation engineers and other domain experts may lead to development of a biased simulation model and impair decision-making in LM implementation.

Therefore, some appropriate niche techniques to bridge the gap between domain experts and simulation-based approaches are expected to support LM implementation.

Motivated by the need to fill in the gaps in the current UTP for LM tools and simulation-based decision support in LM implementation, this research proposes three solutions. The first proposed solution is a training framework that integrates Lean Manufacturing Tools Training System (LMTTS) with the current UTP for LM tools. LMTTS is a training system that consists of e-learning module and S-module (simulation module). LMTTS in this study covers Single Minute Exchange of Die (SMED) training. By providing a learner-centric orientation of learning, user's comprehension and confidence levels towards LM tools are increased and the overall training results of the LM tools are enhanced by LMTTS. Most importantly, LMTTS provides a dynamic and flexible learning environment for users to study the LM tools. Users could experiment with the simulation models using input parameters from their production floor and immediately see the effects of the changes. This way, the time spent in garnering possible solutions to problems within their production floor will be reduced.

The second proposed solution is a simulation-based decision support system (SDSS) to assist the decision making in LM tool implementation. SDSS provides four functions through an interactive use of process simulation namely layout, zoom-in/zoom-out, task status, and Key Performance Indicators (KPI) status. These functions are incorporated into a process model of a coolant hose manufacturing (CHM) factory developed in this study. Feasibility study showed that the SDSS was able to address complex interdependent input parameters in manufacturing line. SDSS provided lean practitioners with time to react to emerging problems, evaluate potential solutions, and decide on LM implementation. SDSS could also be used and in supporting decision-making process to replace the existing manufacturing process with a lean system.

Lastly, an intelligent agent named Muda Indicator (MI) agent is proposed in this research to provide decision support functionality to lean practitioners in pursuing LM implementation. MI agent acts as an expert assistant to lean practitioners in using LM tool software and to support their decision making by quantifying waste in manufacturing simulation. MI agent continuously monitors the status of Muda (waste) during simulation runs and provides Muda level indication by means of RAG status. Feasibility study showed that MI agent handled the

dynamic nature of manufacturing processes autonomously and pro-actively translated the results of waste quantification by means of RAG status during simulation, which was easily understood by the user. This research has provided important insights into a simulation and modelling approach to lean manufacturing and highlighted some associated issues.

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Chapter I

Introduction

1.1 Motivation of study

Manufacturing has evolved tremendously over the past 20 years. Nowadays, the traditional manufacturing system has been progressively replaced by agile manufacturing whereby manufacturers have the capability to adapt quickly and profitably to unexpected and continuous changes in the manufacturing environment (Leitão et al., 2001). Heightening challenges in global manufacturing competition have prompted many companies to seek initiatives for greater productivity improvement. However, there are many manufacturing problems that make it difficult for such initiatives to take place, such as the need to cater to customer's demand on time, increasing number of inventories, prolonged cycle time and lead time and low productivity. Therefore, solutions to these manufacturing problems must be sought. A typical approach used in addressing the manufacturing problems is Lean Manufacturing (LM) implementation (Holweg, 2007).

LM has been applied to various manufacturing sectors and has gained great acceptance and momentum over the last few decades. The core concept of LM is to identify and eliminate waste throughout the production system using proper tools and techniques in order to develop a cost-effective operation that produces product and services of higher quality (Slack et al., 2007; Evans & Alexander, 2007). Literatures on LM are also proliferating in tandem with the ever growing LM environment (Bahsin & Burcher, 2006; Wong et al., 2009b; Rathje et al., 2009). A comprehensive review of the use of different LM tools by different researchers can be found in Choudhary (2012).

Álvarez et al. (2009) study the use of value stream mapping (VSM) as a tool in LM implementation by redesigning an assembly line by means of 'Kanban' and 'Milkrun'. They measure the effectiveness of lean initiatives in improving production flow through lean route and dock to dock time. Bepari (2012) also illustrates how value stream mapping and other

tools can be used for LM implementation in an assembly line of a switchboard manufacturing plant.

Despite the effectiveness of LM tools, implementation of LM does not always succeed even if some of these LM tools are applied (Bahsin & Burcher, 2006). Companies either fail to implement LM or do not get it right at the first time (Rathje et al., 2009). The two main barriers to implementing LM, as reiterated by Nordin et al. (2010), are lack of understanding of lean concepts and inappropriate shop floor employees' attitude. Wong et al. (2009a) assert that 40% of the reasons for failed implementation are due to lack of proficiency in selection of appropriate LM tool for each specific situation. This is because the expertise to select appropriate LM tool for specific situation is not always available in a company (Achanga et al., 1998). Other obstacles in LM implementation include difficulty in implementing some LM tools without support (Tuček & Dlabač, 2012b), inability of LM tools to address various interdependent processes in the production line, lack of tools to quantify the effectiveness of LM implementation (Detty & Yingling, 2000), and lack of self-learning educational software for LM tools (Kao and Chen, 1996).

Besides these obstacles, the current user training programs (UTPs) for LM tools, e.g., classroom training (lectures using PowerPoint slides, projector, whiteboard, printed handouts, and notes), workshops (group discussions), simulation games (e.g., using Lego to represent assembling a product in a production floor), on-job training, and factory visits are also often viewed as deficient and redundant (Anand & Rambabu, 2011). It appears that the current UTPs have some disadvantages that lead to the failure in implementation of LM tools (Mohamad, 2009).

To overcome these obstacles, simulation-based approaches are proposed as an effective method in supporting and evaluating LM tools, in assessing current and future state of manufacturing process, in performing "what-if" analysis, and in measuring impact of improvement after LM implementation. Simulation-based approaches are also beneficial in terms of time-compression, component integration, risk avoidance, physical scaling, and repeatability (Fowler & Rose, 2004). However, most studies use simulation to design, test, and improve lean system. Yet, studies on usage of simulation to support decision-making process in replacing an existing manufacturing process with a lean system are still lacking

(Detty & Yingling, 2000). Consequently, the decisions to adopt LM are often made based on faith in LM philosophy and experiences of other management teams that have implemented LM (Abdulmalek & Rajgopal, 2007).

There is also a gap between LM practitioners and simulation-based approaches in terms of expertise in utilising the simulation software tools. The simulation software tools are generally more suitable for simulation engineers who know how to design, build, or analyse a simulation model and how to integrate the simulation model to LM tool software (Janca & Gilbert, 1998). Therefore, some appropriate niche techniques are required to bridge the gap between LM practitioners and simulation-based approaches to achieve successful LM implementation.

The addition of agent-based technology to simulation-based approaches is expected to solve manufacturing problems that can already be solved by simulation in a significantly better way. This is because an agent is by its nature is active (i.e., add value), autonomous (can operate without external intervention), and modularised (i.e., has a human-like behaviour) (Wenger & Probst, 1998). Agent is also reactive, proactive, adaptive, and able to support a wide range of less-computer-literate users.

1.2 Scope of the study

Motivated to fill in the gaps in current UTP of LM tools and simulation-based decision support in LM implementation, this study proposes three solutions:

1. A training framework that integrates Lean Manufacturing Tools Training System (LMTTS) with the current UTP for LM tools, which consist of e-learning module and S-module (simulation module). LMTTS is a training system targeted to increasing comprehension among users and their confidence levels towards LM tools as well as enhancing overall training results of the LM tools. LMTTS in this study covers Single Minute Exchange of Die (SMED) training.

2. A simulation-based decision support system (SDSS) to assist the decision making in LM tool implementation. SDSS provides four functions through an interactive use of

process simulation, namely layout, zoom-in/zoom-out, task status, and Key Performance Indicators (KPI) status. These functions are incorporated into a process model of a coolant hose manufacturing (CHM) factory developed in this study. A feasibility study showed how the SDSS enhanced the visual perception and analysis capabilities of lean practitioners through availability of the specific functions in the simulation model. Hence, decisions in LM implementation could be made correctly and with increased confidence by lean practitioners.

3. An intelligent agent named Muda Indicator (MI) agent to provide decision support functionality to lean practitioners in pursuing LM implementation. The MI agent acts as an expert assistant to lean practitioners in using LM tool software and to support their decision making by quantifying waste in manufacturing simulation. Unlike other closed self-contained agent-enabled application, MI agent is designed to be an independent agent, i.e., the MI agent could be incorporated freely in the simulation model of manufacturing production line. Once incorporated, MI agent will learn about the rule set for it and adapts its action accordingly. MI agent continuously monitors the status of Muda (waste) during simulation runs and provides Muda level indication by means of RAG status.

1.3 Thesis Outline

This thesis consists of six chapters. *Chapter I* presents the introduction of this study including the motivation of work and scope of the research. *Chapter II* deals with the research background, which includes literature reviews on related topics of the research namely LM, simulation-based approach to LM implementation, and agent-based approach to LM implementation.

Chapter III discusses the first objective of this research, i.e., proposing a training framework that integrates Lean Manufacturing Tools Training System (LMTTS) with the current UTP for LM tools. The benefits of adding e-learning to simulation are discussed followed by details on the design of LMTTS and its training procedure based on the new framework focussing on SMED LM tool. The architecture of e-learning module is then presented followed by explanation on the development of S-module of LMTTS-SMED. A training

scenario is also provided at the end of the chapter to provide a structured approach of using LMTTS-SMED to the target users.

Chapter IV introduces a simulation-based approach to decision support for lean practitioners, followed by overview of SDSS and its specific functions. Then, the development of simulation model for CHM factory, verification, and validation of the simulation model and the feasibility study for SDSS are discussed.

Chapter V discusses waste quantification in manufacturing simulation by intelligent agent-based approach. The chapter begins with introduction on Muda Indicator (MI) agent followed by definition of Muda level in simulation model, how MI agent works, and MI training procedures. Finally, feasibility study of MI agent is discussed using CHM factory simulation model.

Chapter VI presents the concluding remarks and summary of the findings of this research. The contributions of this research and recommendations for future works are also presented in this chapter.

Chapter II

Research background

2.1 Overview of Lean Manufacturing (LM)

Following the overwhelming competition of mass production system during and after World War II, Toyota Motor Company created the Toyota Production System (TPS). The key principle of TPS is eliminating all forms of waste in the production process. The Just-in-Time philosophy was then developed in the framework of TPS, followed by other elements such as Kanban and setup reduction. In 1980's, researches on "lean manufacturing" (LM) were introduced. The term LM was pioneered and introduced by Womack et al. (1990) in the book entitled "The Machine That Changed the World". The LM philosophy was claimed to be a refined, improved, modified, and Americanised version of the TPS (Murakami, 1998). More details on the origin and evolution of LM can be found in Womack et al. (1990) and Papadopoulou & Özbayrak (2005). Treville & Antonakis (2006) define LM as a philosophy aiming at detecting and eliminating waste throughout a product's value stream by means of a set of synergistic tools and techniques. Examples of LM tools and techniques are Single Minute Exchange of Die (SMED), Kanban, 5'S, Value Stream Mapping, Preventive Maintenance, Cellular Manufacturing, Standardised Work, Heijunka, and Poka Yoke. Detailed explanation on concept, objectives, implications, structure, and tools of LM can be acquired from Womack & Jones (1996) and Kumar & Kumar (2012).

In recent years, LM has been widely applied to various sectors including automotive, aerospace, electronics, fabrication plants, and consumer product manufacturing, to improve their productivity. The following are examples of benefits accrued by companies that have successfully implemented LM. TRW Automotive Electronics Group has reduced its lost man-days by 81%, reduced the time to move raw material by 61%, increased production inventory turns by 28%, and decreased capital expenditures by 70% after successfully implementing LM (Motwani, 2003). Lockheed Martin Missile and Space Corporation, on the other hand, has acquired significant reduction in cost and cycle times by 50% after incorporating LM practices in their production floor (Motwani, 2003). Pattanaik & Sharma (2009) propose a

design of cellular layout for LM implementation using an example of a manufacturing industry dealing with ammunition components. In the study, it is noted that with cellular layout, the production flow among cells is optimised. Mukhopadhyay & Shanker (2005) dealt with the implementation of Kanban system in a continuous production line of a tyre manufacturing plant. They observed a cost reduction of INR 315 500 per annum due to reduced work in progress, increased output due to setup time reduction, increased machine uptime, and reduced defects.

Muslimen et al. (2011) investigated LM implementation in Malaysian automotive components manufacturer using semi-structured interview and open-ended questionnaire. The researchers found that their case study company used project-based approach and focused on reducing major waste as this measure would indirectly reduce other wastes as well. In the project-based approach, a team was formed followed by model line determination and continuous improvement of the model line.

Table 2-1: Types of Muda and Description

Types of Muda (M)	Description
M1: Transportation	*Unneeded product movements in performing certain process*
M2: Inventory	*Raw materials that are not processed*
M3: Motion	*Unnecessary movement of people or equipment to perform the processing*
M4: Waiting (delay)	*Inactive people, processes or work-in-progress while waiting for the next production step*
M5: Overproduction	*Producing items before they are actually needed*
M6: Overprocessing	*Unneeded steps in processes resulting from poor tool or product design*
M7: Defects	*Producing defective products due to poor preventive quality system*

As mentioned earlier, eliminating waste is the key objective in LM system. Waste is often called “Muda” and is regarded as any activity that does not add value to the production process (Tuček & Dlabač, 2012a). TPS points out seven types of Muda (M1 to M7) in

manufacturing process as shown in Table 2-1. By eliminating waste, production can be carried out in a compressed time thus resulting in greater productivity, lower production costs, better product quality, shorter delivery time, and ultimately increasing customer satisfaction.

However, to successfully implement LM, in-depth understanding of the LM concept is required. The willingness to change from existing manufacturing system to a lean system is also needed. Thus, as Gordon (2001) in the book *Lean and Green* remarks, "*To encourage people to make any kind of change, we have to start with sharing a vision, providing training and support and setting expectations*".

The current user training program (UTP) for LM tools includes classroom training (lectures using PowerPoint slides, projector, whiteboard, printed hand-outs, and notes), workshops (group discussions), simulation games (for example using Lego to represent assembling a product in a production floor), on-job training, and factory visits. Classroom training and workshops usually involve lectures using figures, diagrams or pictures to represent a concept or process that requires the users (practising engineers/managing staffs) to imagine the whole manufacturing processes. However, today's users have low tolerance for repetitive lectures, limited attention span, and boredom of static media because they are more exposed towards digital technology (Deshpande & Huang, 2011). The lecture-based methods would not be able to promote interaction and increase concentration and understanding, especially if the users are not participative during the lecture (Figure 2-1).

Figure 2-1: Picture A: Classroom training; Picture B: On-job training

As a result, users would have difficulties to foresee what could be expected if LM tools are applied to their manufacturing production line, even after they have attended the UTP (Mohamad & Ito, 2012a; Mohamad & Ito 2012b). Furthermore, organising training workshops could also involve a high cost especially when it involves a large number of participants.

Other methods of UTP such as simulation games are capable to demonstrate the functions and controls of a manufacturing system. Simulation games offer "experiential learning" and allow users to experience how LM tools are applied on a production floor. On-job training and factory visits provide users with hands-on experience on how to apply LM in a real life production floor. However, this training method is costly and occasionally risky if users make mistakes while learning in the manufacturing production floor.

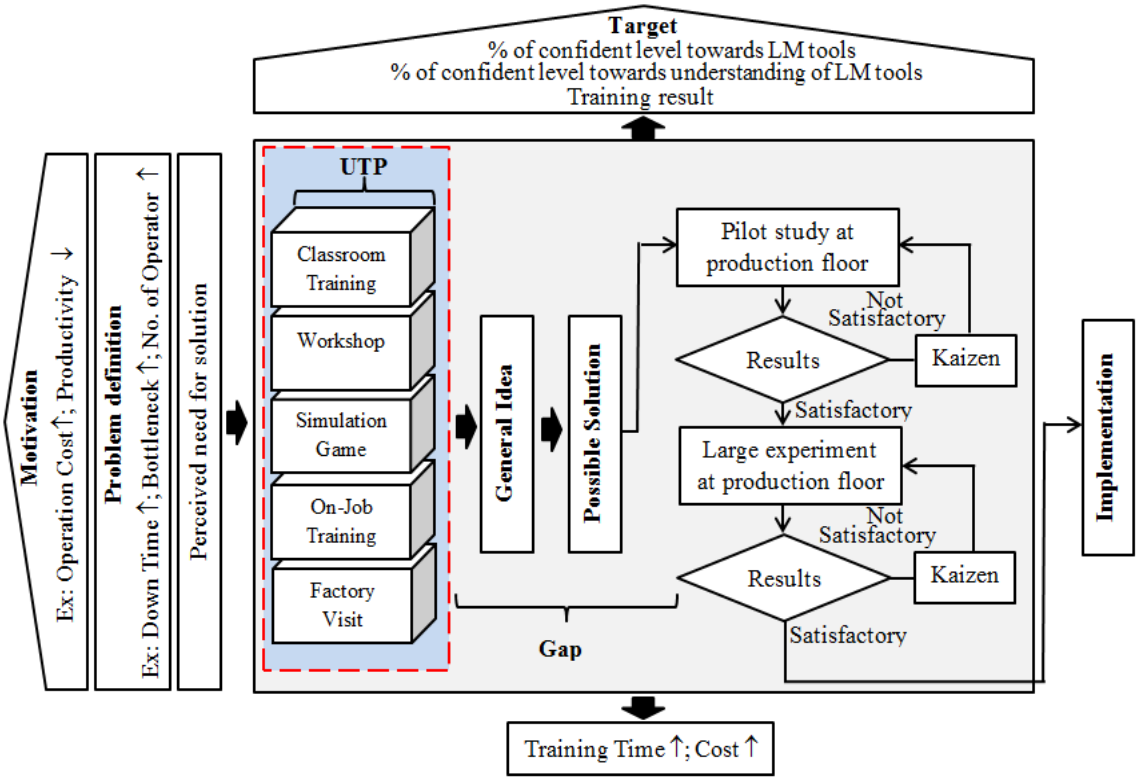


Figure 2-2: Framework of current UTP for LM tools

Usually, after attending a UTP for LM tool, users will have a general idea about the LM tool and they can think of plausible solutions for problems should anything arise on an actual production floor. Carrying out a pilot study for the LM tool on the production floor is the next

move. If the result of the pilot study is satisfactory, large-scale experiment is done. Next, if this experiment succeeds, then the LM tool is implemented. On the contrary, unsatisfactory results of any experiments will prompt kaizen (continuous improvement) and a repetition of the cycle (Figure 2-2).

Although this trial-and-error method will ultimately result in user learning, it is tedious and time-consuming, and involves high operation cost. It is also difficult for users to increase their confidence levels towards understanding and implementing the LM tools. This is because, via this method, users would not be able to foresee the impact of implementing the LM tool on their production floor until they have conducted the pilot study and other experiments. In other words, a "gap" will exist between attending UTP and confidently applying LM tool in real production floor.

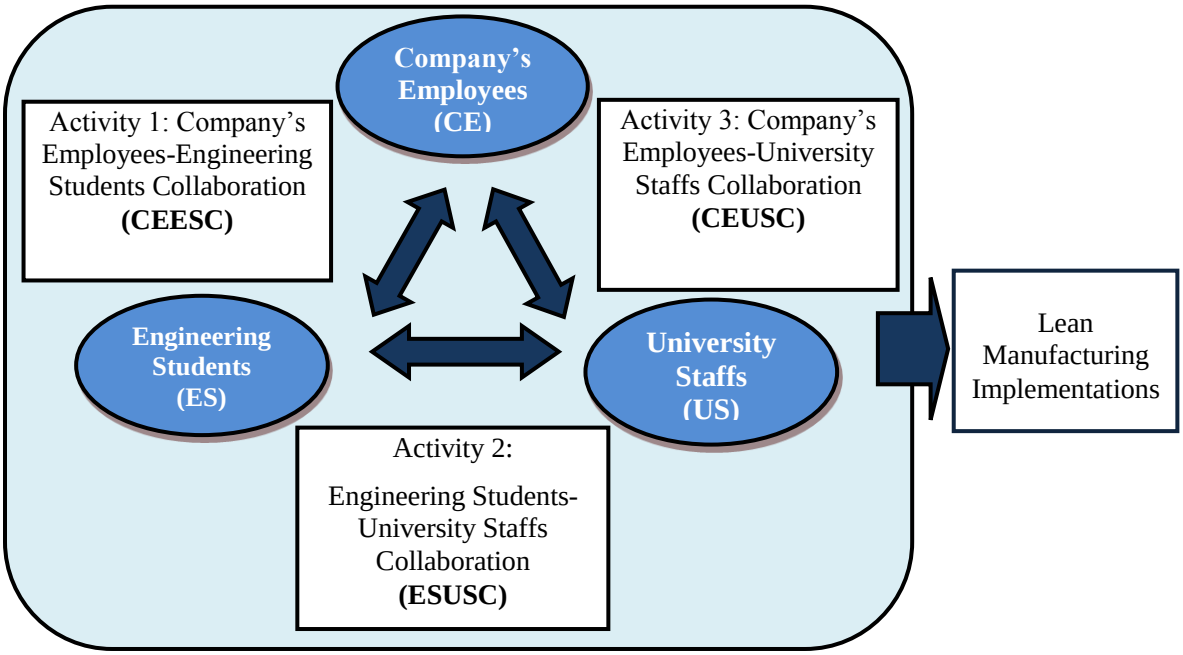


Figure 2-3: Theoretical University-Industry Collaboration Framework

Besides the aforementioned training method, there are also initiatives involving collaboration between universities and manufacturing companies to support the implementation of lean manufacturing in the companies. For example, Mohamad & Ito (2011a) propose a theoretical framework for university-industry collaboration in Lean Manufacturing (Figure 2-3). The framework consists of three groups of people namely company's employees (CE),

engineering students (ES), and university staffs (US) that are linked to each other by three main activities specifically planned for them. The first activity is Company's Employees-Engineering Students Collaboration (CEESC) whereby the engineering students are allocated a place at the company to do small projects for their internship programme. This programme takes six months to be completed and is led by the company's employees. The second activity is Engineering Student-University Staffs Collaboration (ESUSC). It involves the final year thesis for the engineering students, which will be carried out after completing the internship programme. A number of students continue their projects during internship programme and convert it into their final year thesis. Their works are supported by the company's employees and supervised by the university staff. The final year thesis takes one year to be completed. The third activity is Company's Employees-University Staffs Collaboration (CEUSC) whereby university staffs engage in industrial attachment programme. This programme includes training, workshops, and seminars and requires one to three years for completion depending on its agreement and research grants. The framework is proven to be feasible and can be applied in other university-industry collaboration involving Lean Manufacturing.

However, there are certain formidable challenges associated with LM implementation as discussed below:

- Extensive knowledge and expertise in lean concept and selection of appropriate LM tool for specific situation are required for successful LM implementation. However, all these are not always available (Achanga et al., 1998; Mohamad et al., 2008).

- Learning and applying LM tools involves explicit and/or tacit knowledge. However, tools that require tacit knowledge to apply is difficult to implement without support (Tuček & Dlabač, 2012b; Sandanayake et al., 2008).

- Most LM tools and techniques are based on "pencil and paper" technique involving analysis of static models (Sevillano et al., 2011). Although these tools and techniques could resolve many manufacturing issues, expected results cannot be seen before their implementation, including various performance measures pertinent to make informed decisions prior to implementation (Standridge & Marvel, 2006; Ito et al. 2013).

- The traditional approach in implementing LM tools is unable to account for various interactive processes and functions in manufacturing production line for decision-making purposes (Ramakrishnan et al., 2008).

- Commercially available simulation game packages for learning LM tools are abundant in the market but self-learning educational software in the form of interactive simulation games is rarely developed. This is due to challenges in programming concepts of LM tools (Kao & Chen, 1996).

- Managers' (decision-makers) understanding on how to implement LM and the impact of LM on performance measures and manufacturing process is still lacking (Anand & Rambabu, 2011).

- Oftentimes the decisions to adopt LM have to be made based on faith in LM philosophy and experiences of other management teams that have implemented LM (Abdulmalek & Rajgopal, 2007). This is due to the lack of tools to quantify the effectiveness of LM implementation and to convince the management team to implement LM (Detty & Yingling, 2000; Abdulmalek & Rajgopal, 2007).

2.2 Simulation-based approach to Lean Manufacturing (LM)

The effectiveness of simulation in LM implementation has been reported (Ramakrishnan et al., 2008; Sandanayake et al., 2008). Adams et al. (1999), Maas & Standridge (2005), and Standridge & Marvel (2006) illustrate how simulation can address the challenges in LM implementation. Generally, simulation is a kind of analysis method that involves systems, models, and applications to mimic the behaviour of real systems using appropriate software. Details on the concept of simulation terminology, types of models, taxonomy and usage of simulation in various real-life applications can be found in El-Haik & Al-Aomar (2006). Simulation is known to have the ability to support and evaluate LM tools (Czarnecki & Loyd, 2001). Simulation can also be used to assess current and future state of a manufacturing process, to measure the impact of improvements after LM implementation, to analyse "what-if" scenarios for manufacturing systems, and to enable manufacturers to make amendments to processes without interfering with the actual processes. Simulation could be done with less analytic requirements and could be easily demonstrated. In fact, experimental simulation runs

can be done in a compressed time because the model is simulated on a computer (Chung, 2004). Moreover, manufacturers will be motivated to obtain results as in simulation during actual LM implementation (Abdulmalek & Rajgopal, 2007).

Previously, the researcher has conducted a study on simulation-based approach to improve an assembly line in a pager manufacturing company in Malaysia (refer to Mohamad & Ito, 2010a; Mohamad & Ito, 2010b; Mohamad & Ito, 2011b; and Mohamad et al., 2012). The last study (Mohamad et al., 2012) proposes improvements of assembly line by assigning a Material Handler Operator (MHO) to transport box container from one station in the assembly line to another (Figure 2-4). Then, simulation is used to model the assembly line and to compare the production performance between assembly line with MHO (W-MHO) and without MHO (W/O-MHO) (Figure 2-5 & 2-6).

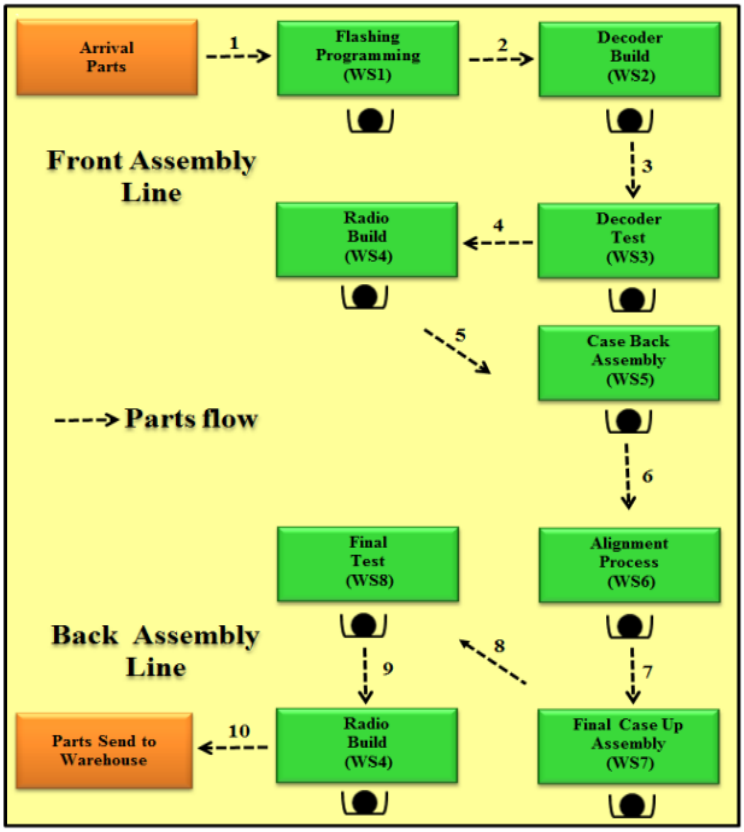


Figure 2-4: Assembly production line of pager manufacturing company

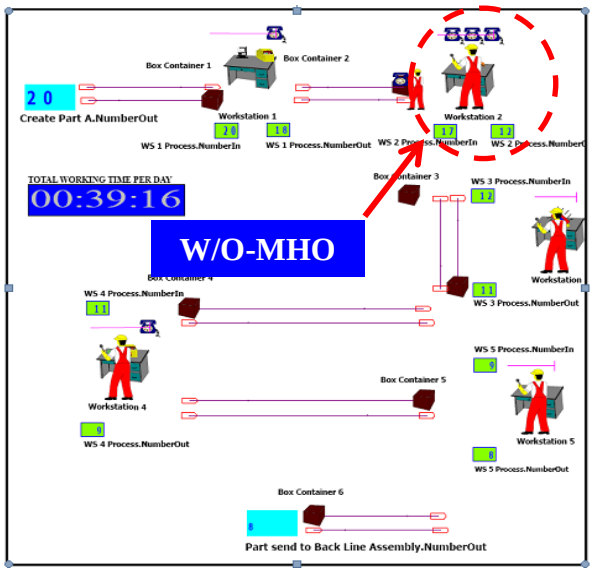


Figure 2-5: Snapshot of simulation model W/O-MHO

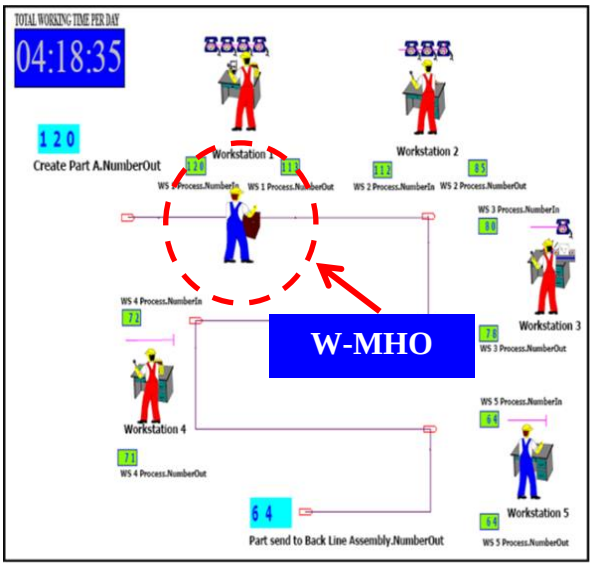


Figure 2-6: Snapshot of simulation model W-MHO

The results (Figure 2-7 & Figure 2-8) showed that the company's total performance increased by approximately 20% after the introduction of MHO. This is a proof that simulation is an invaluable tool in modelling an assembly line and in seeing the impact of improvement activities even before they are implemented. The results also showed the feasibility of a simulation-based approach for the comparison of performance (Mohamad & Ito, 2010; Mohamad & Ito, 2011b; Ito & Mohamad, 2011; Mohamad et al., 2012).

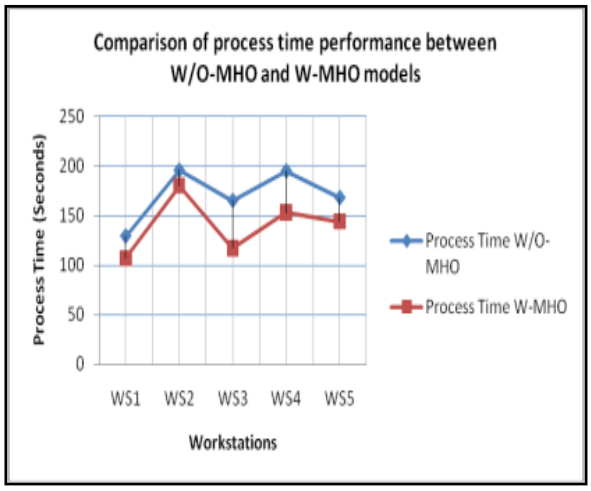


Figure 2-7: Comparison of process time between W/O-MHO and W-MHO models

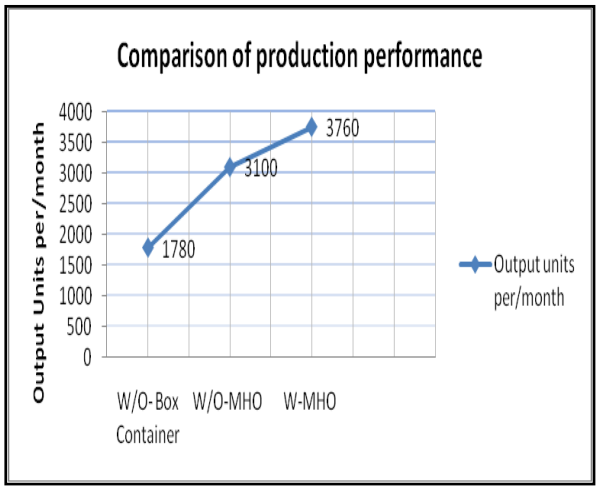


Figure 2-8: Comparison of production performance

Wang et al. (2009) used simulation-based approach to assist lean implementation and to quantify performance after lean implementation. They state that simulation-based approach is practical and more effective than value stream mapping for modelling and quantifying the performance of a complex and dynamic manufacturing system. In another research by Anand & Rambabu (2011), the usage of simulation to address the shortcoming of value stream mapping and the impact of LM tool on performance of organisation was studied using a case study.

Other advantages of simulation-based approach include its capability in visualisation, analysis, and optimisation of complex production processes by way of dynamic illustration of computer animation (Detty & Yingling, 2000). A simple simulation model of SMED implementation at ABC Industries using a case study is explained in the book "Quick Changeover for Operator: The SMED System" (Mohamad & Ito, 2012a; Mohamad & Ito, 2012b). The case study involves the overview of manufacturing processes before and after SMED implementation in ABC Industries and it is also presented using animation. Figure 2-9 and Figure 2-10 represent snapshots of animation for manufacturing process before SMED implementation (MPBSI) and manufacturing process after SMED implementation (MPASI), respectively.

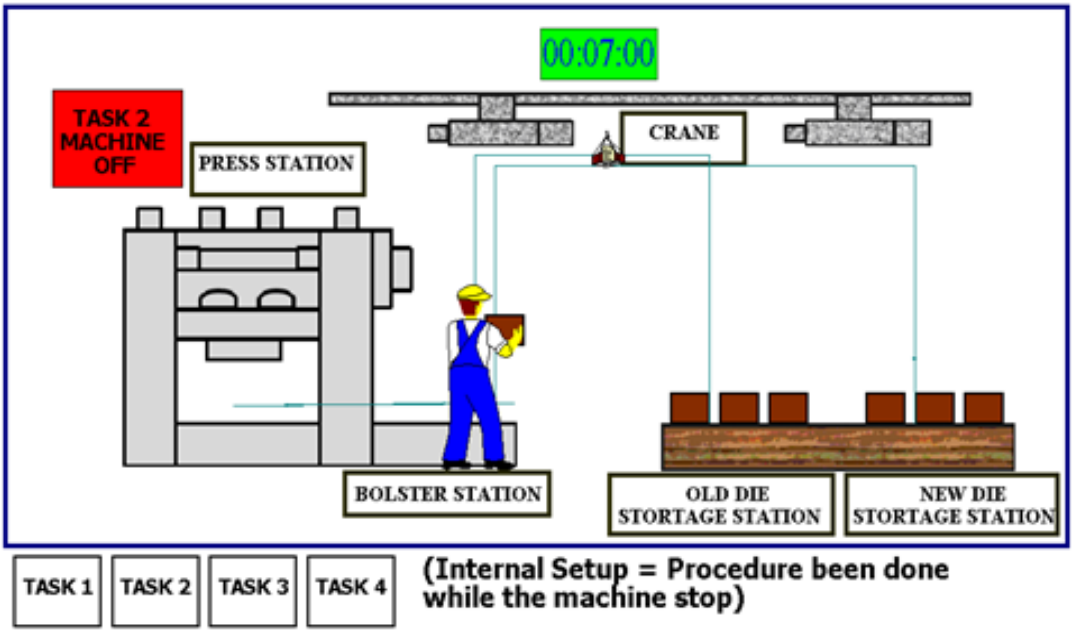


Figure 2-9: Animation of simulation model MPBSI at ABC Industries

When users run the simulation model for MPBSI, they will observe the animation for the following changeover procedures: **Task 1**: *After the machine has been stopped, the old die is extracted from the machine onto a moving bolster*; **Task 2**: *A crane hoists the old die from the moving bolster, carries the old die to the storage area, and lowers it*; **Task 3**: *The crane then hoists the new die from the storage area and transports it to the moving bolster*; and **Task 4**: *The new die is mounted and the machine is started up again for production*". Users will find these changeover procedures sensible and efficient because the procedures involve only two hoisting operations. However, the machine is in fact not productive during the time it takes up to put away the old die and carries in the new one.

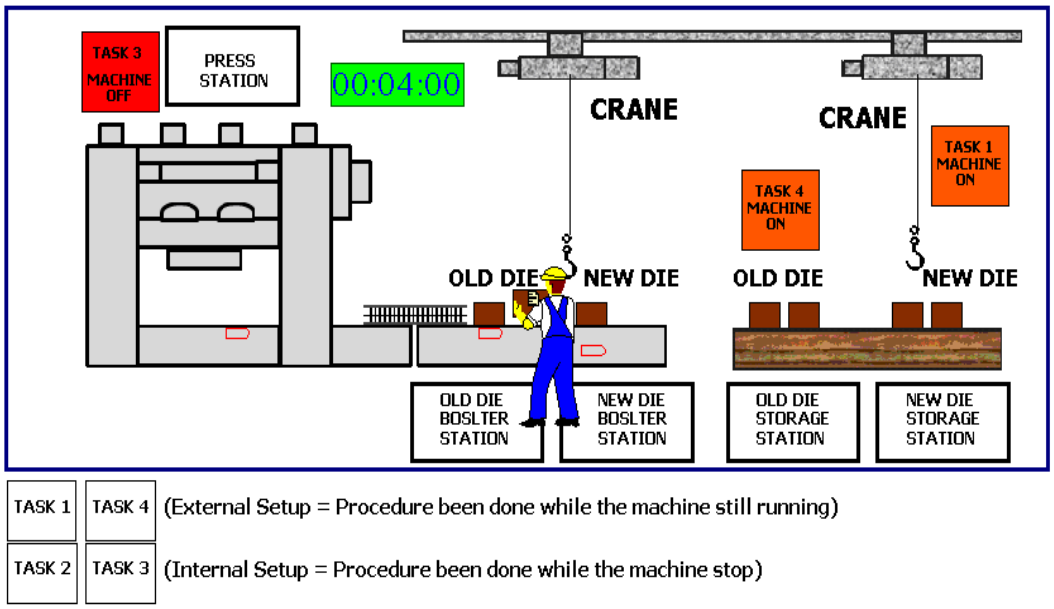


Figure 2-10: Animation of simulation model MPASI at ABC Industries

Next, users will run the animation for MPASI to observe the transformation in the production line after SMED has been applied. In this animation, users will observe the following changeover procedures: "**Task 1**: *Before the machine is shutdown, the crane brings the new die and places it next to the machine*; **Task 2**: *The machine finishes the previous operation and is stopped. The old die is removed onto the moving bolster. The crane hoists the old die from bolster, then sets it down near the machine*; **Task 3**: *The crane hoists the new die onto the moving bolster. The new die is mounted and the machine is started up*; and **Task 4**: *After the machine has begun the new operation, the crane hoists the old die and returns it to the*

storage area". After viewing MPASI animation, users will realise that the company manages to reduce its total changeover time from 14 minutes to 4 minutes by implementing SMED. The details on the design and development of this simulation model are available in Mohamad & Ito (2012a) and Mohamad & Ito (2012b). Basically, animation facilitates users in understanding the overall manufacturing processes. Therefore, users who are new and unfamiliar to SMED can understand this LM tool better.

Apart from the aforementioned advantages, simulation-based approach is also able to represent a large number of interdependent input parameters and to manage the complexity of interactions effectively (Papadopoulou & Mousavi, 2008). When simulation is used for LM tool implementation in an appropriate manner, various problems and solutions in production line could be identified at the planning and evaluation stages. Additionally, complexity of machine performance can also be simplified using simulation (Gross, 1992).

Simulation can also be used as a training tool to support the traditional UTP for LM tools (Lian & Van Landeghem, 2007). The use of simulation as a training tool for LM has been studied previously by Whitman et al. (2001), Zee et al. (2005), Gadre et al. (2011), Mohamad & Ito (2011c), Mohamad & Ito (2011d), Mohamad & Ito (2012a), Mohamad & Ito (2012b), Mohamad & Ito (2012c) and Mohamad & Ito (2013). Simulation is an effective teaching tool because it makes complex concepts easy to grasp (Verma, 2003). An example of model concept for SMED as shown in Figure 2-11 has been developed by Mohamad & Ito (2012c) to show how simulation can simplify a complex manufacturing concept. Detailed explanation on the model concept can be acquired in Mohamad & Ito (2012c).

Whitman et al. (2001) introduce a simulation game for training of LM tools. In the study, participants of the simulation game were assigned to operate workstations in a simulated aircraft assembly line. The participants were given a few scenarios by which they encountered problems with suppliers, quality control or at the service level. During the problem-solving process, they learnt about lean concept and implementation. Additionally, Zee & Slomp (2005) describe the use of simulation games for training purposes and mastering LM using a case example from the industry. The simulation game lets users to experience a manual assembly line for mail-inserting systems. The simulation game could be used to train personnel in making proper decisions following lean principles. Verma (2003) conducted an

extensive survey and identified seventeen factory simulation activities used by shipbuilders, educational institutions, and consulting firms. The factory simulation activities were used to engage students in role plays within the environments that simulated actual manufacturing processes using mainly a type of plastic cube (Lego etc.), to represent assembling a product on a factory floor.

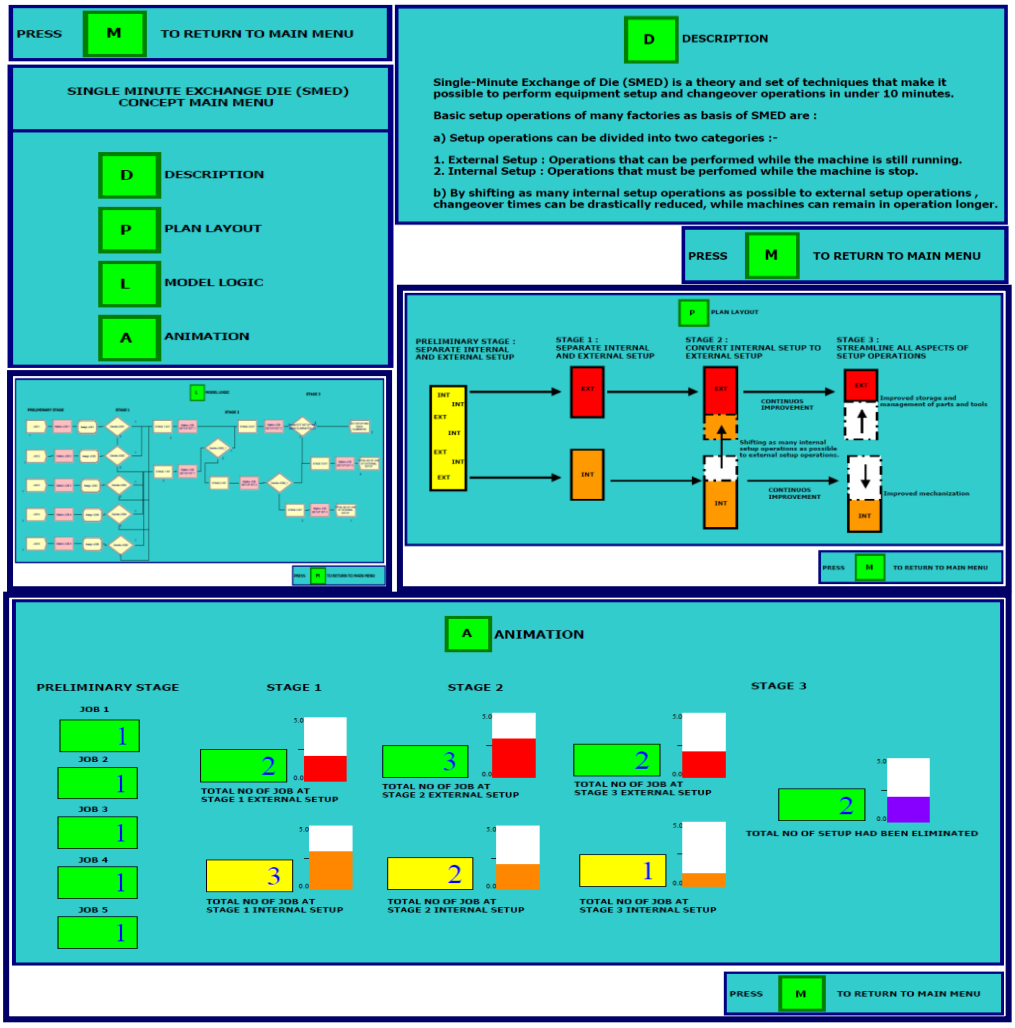


Figure 2-11: Example of model concept for SMED

Gadre et al. (2011) attempt to incorporate computer simulation in lean courses to give students the advantage of hands-on experience on real-life production line. This enables students to apply LM tools on a simulated production line and immediately see the effects of changes in the production line. Virtual simulation assignments are developed to give students an overview of how to apply LM tools to an existing production line. When students are familiar with real-life issues of LM tools implementation, their understanding on LM through

learning in the classroom will be fostered (Mohamad & Ito, 2013). Lian & Van Landeghem (2007) propose a simulation model generator as a training method for non-expert simulation user. They develop a VSM simulation model generator (named simVSM) that is able to generate simulation models of current and future state VSM scenarios quickly and automatically. The simVSM consists of VSM building blocks, standard icon, and model generator. After a few sessions of practices in using simVSM, trainees would be able to develop simulation models. At the same time, they could learn the concept of VSM and its effect on the manufacturing system.

The researcher has also incorporated simulation into training framework of LM tools. Consisting of current UTP, e-learning module and S-module (simulation module), the training framework is targeted to increasing users' comprehension and their confidence levels towards LM tools as well as enhancing overall training results of the LM tools. Details on this proposed training framework are elaborated in Chapter III.

Although simulation-based approaches provide an avenue of improvement for LM issues (Lian & Van Landeghem, 2007), they are not a widely used practice yet, partly due to the perception that simulation is too difficult to use in lean projects (Sevillano, 2011). There are certain drawbacks associated with the use of simulation-based approaches. Firstly, designing and developing a simulation model usually takes a long time and requires great expertise (Fowler & Rose, 2004). Secondly, it is difficult for a simulation model to represent the various interdependent input parameters and complex behaviour of manufacturing system accurately (Bodner & Reveliotis, 1997). Thirdly, simulation study in lean projects is usually managed by simulation engineers who know how to design the simulation model from scratch, build or analyse the simulation model, and integrate it to LM software. Therefore, real-time updating of simulation model can only be performed by the simulation engineers (Gourdeau, 1997). These approaches are not suitable for LM practitioners who are familiar with neither simulation software nor LM tool software. Misunderstanding between simulation engineers and other LM practitioners may lead to development of a biased simulation model (West et al., 2000). Therefore, some appropriate niche techniques to bridge the gap between LM practitioners and simulation-based approaches are expected to support LM implementation. One of the objectives of this research is to propose a solution to the above mentioned gap issue by deploying an agent-based technology. This solution is discussed in Chapter V.

2.3 Agent-based approach to LM implementation

This section provides an overview on the rapidly evolving area of intelligent agent. Over the past 20 years, there have been numerous studies on artificial intelligence, which can be defined as adding the ability to think to machines. Various artificial intelligence techniques have been introduced to interpret complex manufacturing system including experts system, neural network, genetic algorithms, and intelligent agents. In this research, the author focuses on intelligent agent (IA) development in supporting LM implementation.

IA is a computer system that is designed to execute flexible autonomous actions to accomplish tasks on behalf of its user (Nwana & Ndumu, 1998). IA is expected to solve problem that already can be solved in a significantly better way (Jennings & Wooldridge, 1998). Moreover, IA by its nature is active (i.e., adds value), autonomous (i.e., can operate without external intervention), and modularised (i.e., has a human-like behaviour) (Wenger & Probst, 1998). The agent is also reactive, proactive, adaptive, and decentralised.

IA implementations usually start as a university-industry collaboration project. However, the transition from its academic use to industrial use is not easy, mainly due to the difficulty to estimate the financial profit that can be gained by the IA although it is easy to determine the investment cost for developing the IA software (Denkene et al., 2005). Another drawback of IA is the difficulties in evaluating its efficiency due to few readily available applications (Caridi & Sianesi, 2000). Despite the challenges, to date, IA has been widely applied in industries such as in process control (e.g., ARCHON), manufacturing (e.g., YAMS), air traffic control (e.g., OASIS), and financial (e.g., Fin CEN Artificial Intelligence System) (Sycara et al., 1998). Shen et al. (2000) conducted an intensive review on applications of agent technology to concurrent engineering, e.g., Metamorph II (agent-based architecture for distributed intelligent design and manufacturing) and DIDE (agent-based approach for advanced CAD/CAM systems). Denkene et al. (2005) discuss the advantages of IA technology in manufacturing and its possible applications such as Agent.Enterprise (IA software research project designed for complex manufacturing supply chains) and MaBE (agent-based information and communication facility). Other related research includes a proposal of autonomous agent to solve mixed-model assembly lines sequencing problem (Caridi & Sianesi, 2000).

Other than that, Jahangirian et al. (2010) carried out an extensive review of 281 peer-reviewed papers between 1997 and 2006 and found out that intelligent agent system (IAS) is the fourth most popular simulation technique (usage rate of more than 5%) used in solving problems in manufacturing. IAS is preferred due to its capability to design manufacturing systems and its flexibility to accommodate dynamic nature of manufacturing processes (Burmeister et al., 1998).

Chapter III

Integration of e-learning and simulation to user training programme of LM tools

3.1 Introduction

Engineering education has evolved tremendously over the years. Fifty years ago, Cooperative Education which is a time-tested method of enhancing learning in engineering was introduced. Cooperative Education is basically a progressive engineering educational program involving theoretical and practical training in engineering field. This educational program enhances classroom training, makes training more cost effective and increases students' retention rates (Akins, 2005). The importance of training in engineering and its capability to transform a company are also emphasized by Pollitt, 2006. As Steve Turner, the director of Crusader Displays remarks "*Following the learning, managerial departments are working as one team. All departments attend daily production meetings, which improve communications. Office staff and shop floor operatives are working more closely together and every three month, a meeting of everybody ensures that information and plans are shared. In addition, one to ones with shop floor staff also occurs every three months*".

According to the Greenfield Coalition's Value and Beliefs about learning, if learning is integrated with real-world experience and students actively participate in it, students would be able to reach a deeper understanding of engineering and enhance their skills (Falkenburg, 2005). The current user training programme (UTP) for LM tools is seen to have infused these values by integrating theoretical learning (classroom training and workshops using PowerPoint slides, projector, whiteboard, printed hand-outs, and notes) with practical application (on-job training and factory visits). In spite of this, the current UTP still lacks the ability to demonstrate and convince the users on the impact of implementing LM tool on a production floor before they actually apply the tools. Thus, users will have to conduct pilot studies and other experiments in the production floor post training to observe the impact of applying those LM tools to their manufacturing process. In other words, there is a gap between attending UTP and confidently applying LM tool in real production floor.

In this chapter, author describes an approach of integrating e-learning and simulation to the current UTP to address this gap. Inspired by the Toyota style of organizational learning to keep classroom training to a minimum (Liker & Meier 2006), e-learning and simulation for LM tools are developed in this study to provide a dynamic and flexible learning environment for users to study the LM tools. Hence, the orientation of learning would be more learner-centric, time-saving, accessible, and easy. As reiterated by Falkenburg, 2005 and Lian & Van Landeghem, 2007, the addition of simulation as a training tool could enhance the current UTP. Apart from having the ability to evaluate LM tools and simplify complex LM concept, simulation could be easily demonstrated in compressed time and could be done with less analytic requirements (Czarnecki & Loyd, 2001 and Verma 2003,). With simulation, users could observe the various interdependent variables that affect manufacturing process besides learning on the application of LM tools. This type of learning is considered as "double-loop" learning as described by Liker et al., 1995 in their book "Engineered in Japan". In double-loop learning, the focus is on learning through "holistic approach" whereby emphasis is not only given to the newly-learnt techniques (in this case LM tools) but also to the enormous variables that affect manufacturing performance.

Therefore, in this chapter, a training framework that integrates Lean Manufacturing Tools Training System (LMTTS) with the current UTP for LM tools is presented (Figure 3-1). Consisting of the e-learning module and S-module (simulation module), LMTTS is a training system targeted to increase user's comprehension and their confidence levels towards LM tools as well as enhancing overall training results of the LM tools. In addition, users' time away from work would be minimised through e-learning (Fletcher, 1990).

As can be seen in Figure 3-1, LMTTS consists of e-learning module and S-module. Each of these modules provides systematic information and simulation-based training on SMED, Kanban, Poka Yoke, Preventive Maintenance, Autonomous Maintenance, Andon Light, Heijunka, and Cellular Manufacturing.

The e-learning module has three sub modules namely LM tools theory, LM tools success stories, and LM tools quizzes. LM tools theory comprises information on the definition, importance, and advantages of LM tools implementation. A compilation of success stories of companies that have implemented LM tools are presented in LM tools success stories. This

information is useful for benchmarking best practices and serves as a source of motivation for users who want to implement LM tools in their workplace.

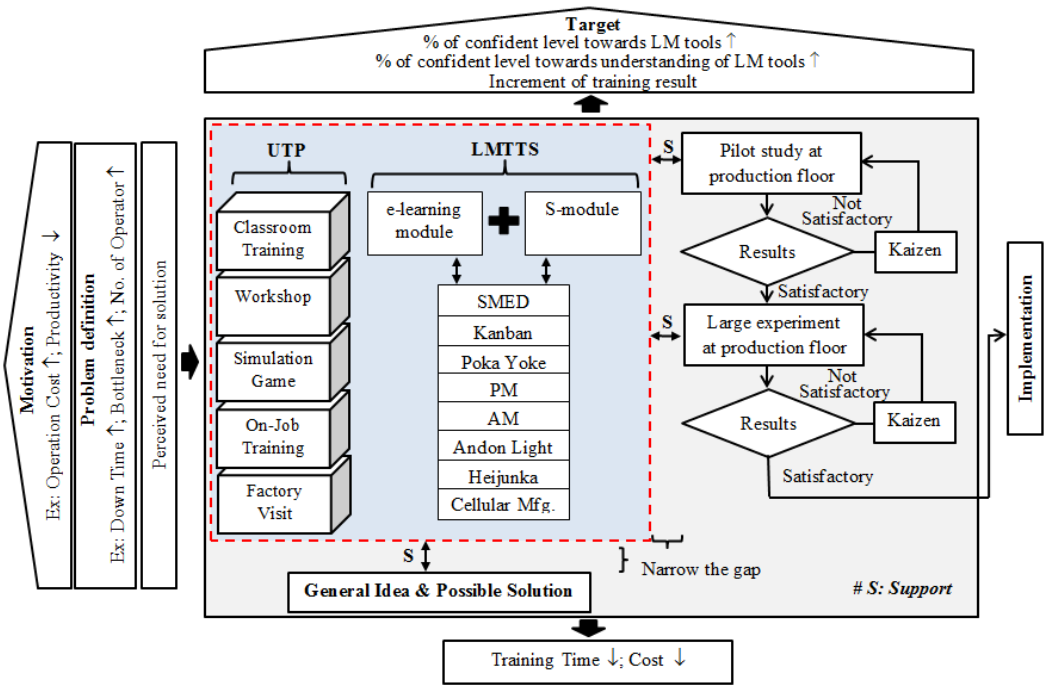


Figure 3-1: Framework of UTP for LM tools with integration of LMTTS

In LM tools quizzes, users' understanding on LM tools will be tested by a set of questions. Answers for these questions are also provided. This e-learning module provides consistent course delivery and relieves the trainer of the necessity to present repetitious lectures. Users could also revise what they have learnt in the current UTP whenever required.

Next, S-module consists of simulation models for LM tools. By following certain guidelines, users could utilise the simulation models to observe how LM tools could improve a production line. Users could experiment with the simulation models using input parameters from their production floor and immediately see the effects of the changes. This way, the time spent garnering general ideas and possible solutions to problems within their production floor would be reduced. Users' understanding of LM tools through current UTP would also be fostered. Moreover, efforts to execute pilot studies and experiments for LM tools would be assisted through prior testing with simulation models. Most importantly, the gap between attending UTP and confidently applying LM tools in a real production floor would be reduced

with integration of LMTTS to the current UTP for LM tools. The following sections discuss the design of LMTTS and its training procedure based on the new framework, focusing on an LM tool, i.e. SMED.

3.2 The design of LMTTS – SMED

3.2.1 SMED

SMED is a theory and a set of techniques that enables changeover operations to be performed in less than 10 minutes. SMED is one of the LM tools widely used by manufacturing companies nowadays in producing low cost but high quality products (The Productivity Press Development Team, 1996). Although SMED was originally used in Toyota (an automotive company), due to its universal nature, it is now used in a wide array of manufacturing processes such as electronics, food, and metal industries. Past research conducted by Deros et al. 2011 shows that SMED is an invaluable tool that can significantly reduce changeover time (CT) in an automotive battery assembly line by 35 per cent.

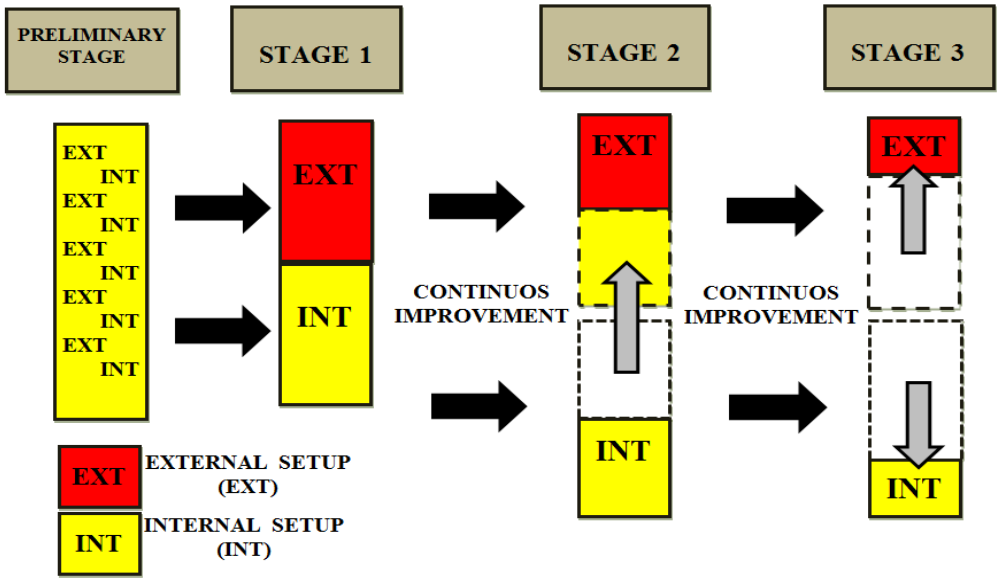


Figure 3-2: SMED's Conceptual Phase

By using SMED to shorten CT, production can be changed more often and production time can be reduced without the need to invest in extra production or packaging machines or lines.

SMED is suitable for production that requires more conversions. However, application of SMED depends on the conditions of each manufacturing process. Process improvement cannot be achieved if SMED is not applied properly. Therefore, it is mandatory to have skilful personnel capable of applying SMED to manufacturing processes in real situations.

Changeover operations of many factories are divided into two categories: External Setup (EXT) and Internal Setup (INT). EXT refers to operations that can be performed while the machine is still running. INT refers to operations that must be performed only when the machine is stopped. To implement SMED, users need to undergo the SMED conceptual phase that has four stages. In Preliminary Stage, INT and EXT are not distinguished. Next in Stage 1, INT and EXT are distinguished followed by Stage 2 in which INT is converted to EXT. Finally, in Stage 3, all aspects of setup operations are reorganised (Figure 3-2). The main target of SMED is to shift as many INT operations as possible to EXT operations, thus significantly reducing CT while machines can remain in operation longer (Shingō, 1985).

3.2.2 E-learning module

Basically, the SMED e-learning module presents its sub modules using text and figures in the document format of ".pdf", videos, and interactive webpage (Figure 3-3). E-learning can be accessed when it is needed in an easy-to-access format. The system is learner-centric whereby the responsibility of understanding the topics in these sub modules is on the users. The first sub module (Theory) provides introduction of SMED, benefits of SMED, and methods to implement SMED as well as definitions of important terms and concepts.

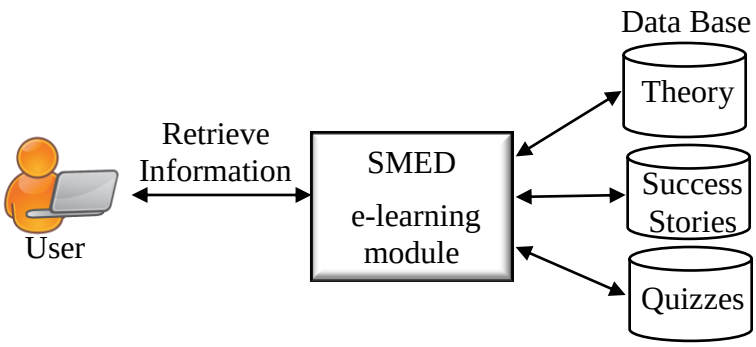


Figure 3-3: Architecture of SMED e-learning module

The next sub module (SMED Success Stories) provides users with a compilation of stories of companies (metal pressings manufacturer, paperboard manufacturer, train manufacturer, etc.) that have successfully implemented SMED (Figure 3-4). Information in these sub modules is obtained from many sources such as journals, websites, newspapers, articles, and magazines.

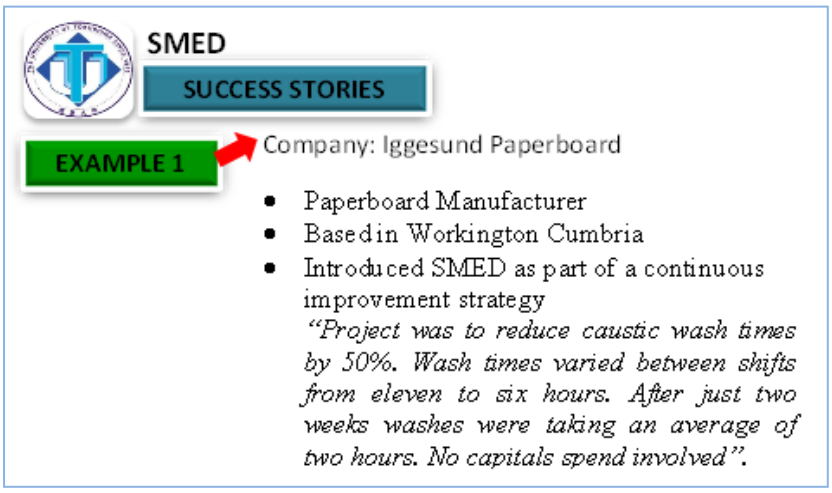


Figure 3-4: Example of Success Stories

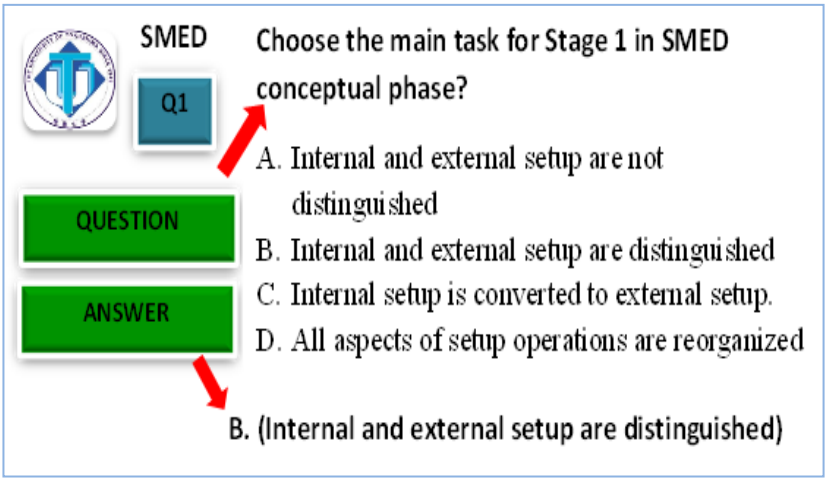


Figure 3-5: Example of Quiz

SMED Quizzes (Figure 3-5) contain multiple choice questions (MCQs) that test the users' understanding on topics in the previous sub modules. Each set of questions consists of ten MCQs. The purpose of the quizzes is to capture the attention of the users by the elements of

scoring metric. Users have a sense of achievement or failure and receive a performance index in terms of score after participating in the quizzes. Users need to achieve a certain score in order to advance the learning process. The desire to improve the score drives the users to study the sub modules thoroughly.

3.2.3 S-module

The simulation model for SMED is based on the theory of changeover and SMED implementation in a manufacturing production line. Firstly, the layout of a manufacturing production line is developed as displayed in Figure 3-6.

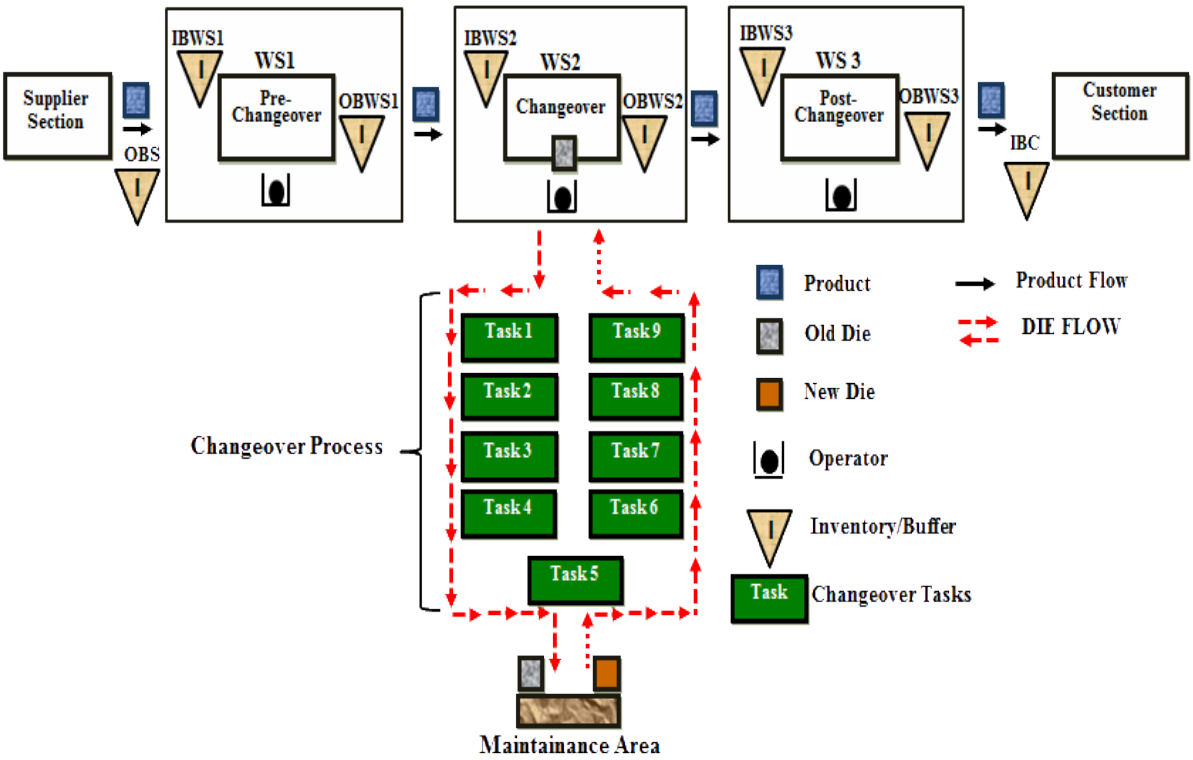


Figure 3-6: Model layout of manufacturing production line

Due to run-time constraints, the simulation model is limited to supplier section, workstation section, and customer section. A flow diagram is then created for each of these sections (Figure 3-7 to 3-9). The supplier section is the section that provides products to the manufacturing production line. In this case, the supplier section represents the incoming warehouse. Next, the workstation section includes three workstations: Workstation 1 (WS1):

workstation pre-changeover; Workstation 2 (WS2): workstation for changeover; and Workstation 3 (WS3): workstation post-changeover.

Products from supplier will be sent from Outbound Buffer Supplier (OBS) to Inbound Buffer Workstation 1 (IBWS1) in WS1. After receiving products from OBS, WS1 begins its production. Then, the products will be sent to Inbound Buffer Workstation 2 (IBWS2) via Outbound Buffer Workstation 1 (OBWS1).

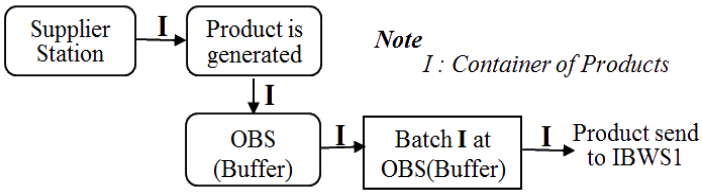


Figure 3-7: Flow diagram of supplier section

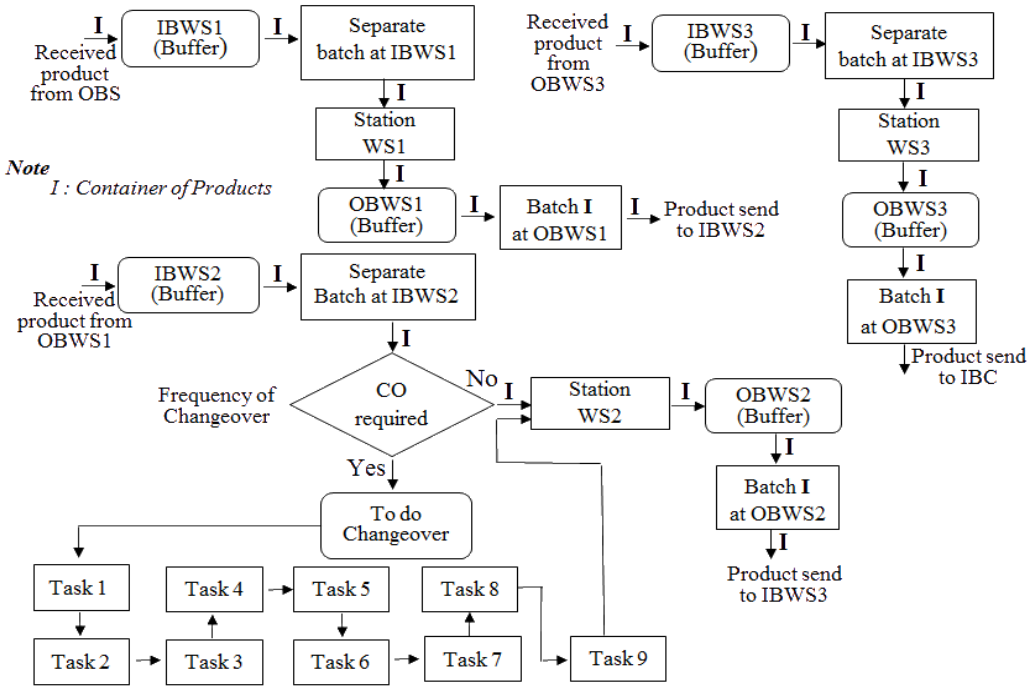


Figure 3-8: Flow diagram of workstation section

At WS2, production continues and the frequency of changeover and changeover tasks time will be determined. This simulation model is predicated upon certain assumption, in which there are nine changeover tasks. Each task represents changeover procedures as follows: Task

1: Pre-machine shutdown time; Task 2: Removing old die from machine; Task 3: Transporting old die to get new die; Task 4: Organising time at Storage/Maintenance Area; Task 5: Exchanging die block (to get new die at Storage/Maintenance Area; Task 6: Transporting new die to the machine; Task 7: Attaching/Positioning new die at the machine; Task 8: Other various adjustments; and Task 9: Trial-run machine uptime before production.

Next, production is continued by sending the product from Outbound Buffer Workstation 2 (OBWS2) to Inbound Buffer Workstation 3 (IBWS3). Similarly, WS3 performs production after receiving the products from OBWS2.

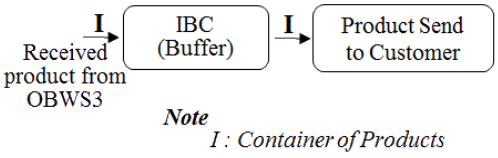


Figure 3-9: Flow diagram of customer section

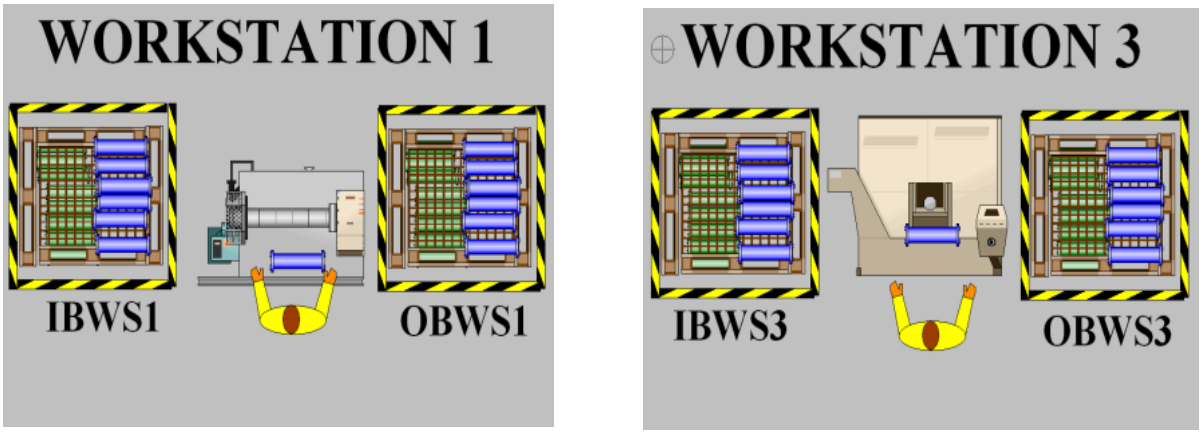


Figure 3-10: Caption of animation for WS1 and WS3

Subsequently, products will be sent from Outbound Buffer Workstation 3 (OBWS3) to Inbound Buffer Customer (IBC) that represents the outgoing warehouse. Based on the flow diagrams of supplier section, workstation section, and customer section, model logic is created using Arena 12.0 Professional Edition. This is followed by using the completed model

logic to produce animation (Figure 3-10). The details of simulation methods are acquired from the book “Simulation Modelling and Analysis with Arena” by Altiok & Melamed, 2007.

Then, four types of windows are developed using Visual Basic Application (VBA) to enhance the usage of simulation model. These windows represent the stages in the SMED conceptual phase (Preliminary Stage, Stage 1, Stage 2, and Stage 3) that users need to go through to implement SMED (Figure 3-11).

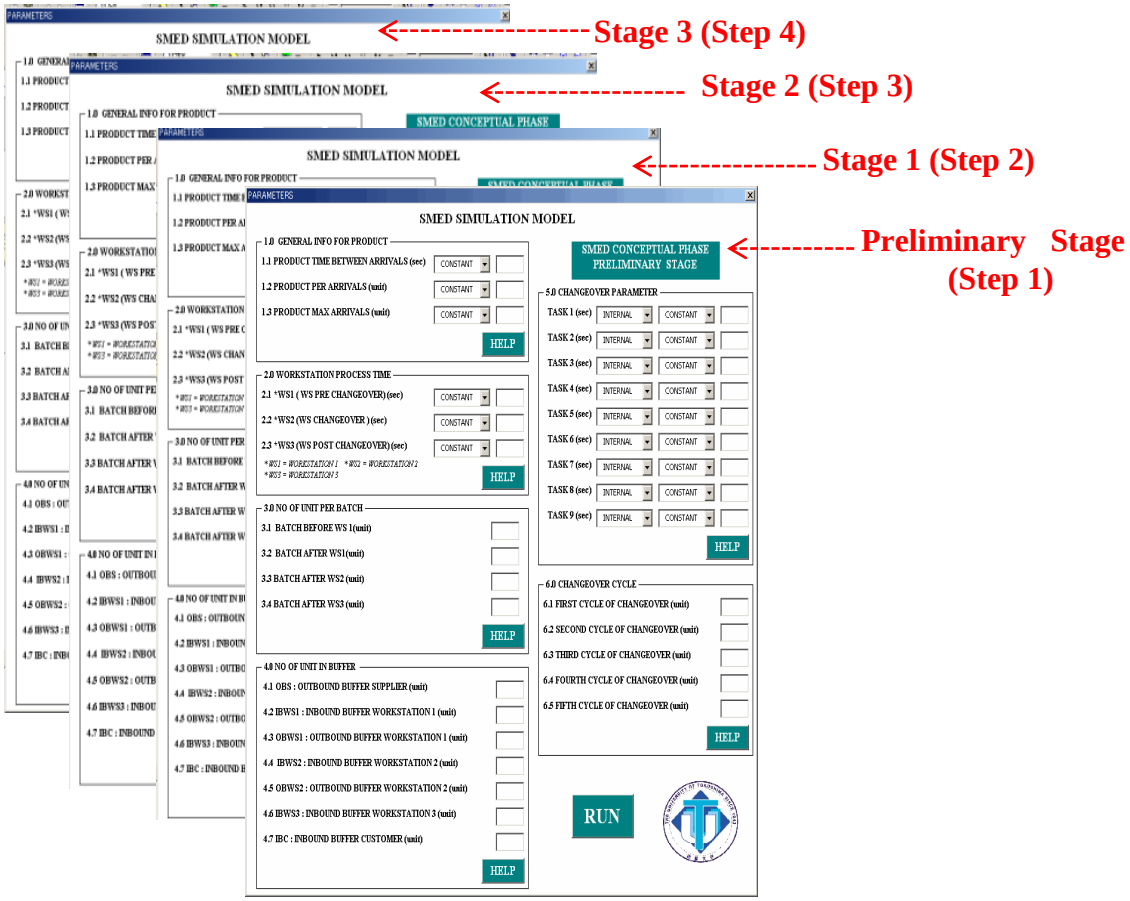


Figure 3-11: Captions of four types of windows representing SMED conceptual phase.

Each window contains six segments. The first segment contains general information of the product that includes “product time between arrivals: type of arrival stream to be generated (seconds)”, “product per arrivals: number of product that will enter the system at a given time with each arrival (seconds)”, and “product maximum arrivals: maximum number of arrivals that this simulation model will generate (per/unit).” The second segment is process time in

three workstations: WS1 (t_0, 1) process time (seconds), WS2 (t_0, 2) process time (seconds) and WS3 (t_0, 3) process time (seconds). Number of units to be batched, *k* (unit) between all workstations is in the third segment. The fourth segment represents the number of units in buffer size, *B* (unit).

The fifth segment is changeover tasks (in seconds). Each changeover task is categorised into External Setup (EXT) which is operations that can be performed while the machine is still running and Internal Setup (INT) which is operations that must be performed only when the machine is stopped. The sixth segment consists of frequency of changeover.

Additionally, "Help" button and "Run" button are also provided. The "Help" button assist users in filling up the parameters in each segments while the "Run" button helps users to conduct simulation runs.

3.2.4 Verification and validation of simulation model

There are several assumptions that need to be considered in this simulation model, among others: the manufacturing production line is considered to be in a steady state; all workstations are operating at full capacity; and all workstations have deterministic process time, product arrival according to a deterministic arrival pattern, and the buffers have infinite capacity (Rooda and Vervoort, 2007).

To ensure that the simulation model behaves in the way it is intended according to the modelling assumptions, a verification process is carried out. This work includes ensuring that the simulation model runs properly (Kelton et al., 2010). For validation of the simulation model, the Second Principle (Little's Law) (Fig.3-12) is used (as shown below). Maximum throughput (δ_{max}) is one of output parameters that can be calculated for validating the simulation model (Rooda and Vervoort, 2007).

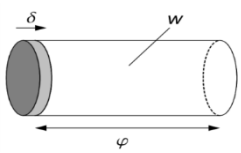


Figure 3-12: SI model manufacturing production line as pipeline

$$w = \delta \cdot \varphi \tag{1}$$

Where,

w (work in progress): Total number of units in the manufacturing production line, i.e., in the factory or in the machine (measured in units).

δ (Throughput): The number of units per time-unit that leaves manufacturing production line (measured in units/time-unit).

φ (Flow time): The time a unit is in the manufacturing production line (measured in time-unit).

For cases that have different values of batch size , k and different batch processing time t_{batch} in each WS, the calculations of flow time, φ of the first and last units in a batch, k is congruently :-

$$\varphi_{first} = \varphi_{wait\ for\ batch} + t_{batch} = \frac{k-1}{\lambda} + t_{batch} \tag{2}$$

$$\varphi_{last} = t_{batch} \tag{3}$$

$$\bar{\varphi} = \frac{\frac{k-1}{\lambda} + t_{batch} + t_{batch}}{2} \tag{4}$$

As long as $\lambda < \lambda_{max}$ mean flow time $\bar{\varphi}$ is

$$\bar{\varphi} = \frac{k-1}{2\lambda} + t_{batch} \tag{5}$$

Where $t_{batch} = k.t_0$

k = number of units in a batch

t_0 = process time at WS

λ = release rate (units/seconds)

For release rate $\lambda > \lambda_{max,}$ the mean flow time grows to infinity (Rooda & Vervoort 2007).In this study where SI consists of three workstations, the calculations of flow time, φ is as follows:

$$\varphi_{total} = \varphi_{ws1} + \varphi_{ws2} + \varphi_{ws3} \tag{6}$$

$$\varphi_{\text{total}} = \sum_{i=1}^{3} \left(\frac{k\text{-}1}{\lambda_{t_{di}}} + k.t_i \right) \tag{7}$$

$$\bar{\varphi}_{overall} = \frac{1}{n} \sum_{i=1}^{3} \left(\frac{k\text{-}1}{2\lambda_{t_{di}}} + k.t_i \right) \tag{8}$$

** Where n = number of workstation, n = 3*

The parameters of the production line are as follows: product demand = 600 units; product time between arrival = 36 s; product per arrival = 1 unit; maximum arrival = 600 unit; WS1 process time t_0,1 = CONSTANT (46.5 s) ; WS2 process time t_0, 2 = CONSTANT (93.2 s); WS3 process time t_0, 3 = CONSTANT (47.45 s); changeover frequency = every 120 units of product produce in WS2; task for changeover time = "Task 1:120 s; Task 2:600 s; Task 3:300 s; Task 4:900 s; Task 5:2100 s; Task 6:300 s; Task 7:900 s; Task 8:450 s; and Task 9:120 s"; batch size = 1 unit; and buffer size has infinite capacity. A one-day shift (7.5 hours) is used as a baseline for validating the model.

To calculate the maximum throughput using a mathematical equation, the first step is to calculate utilisation (u) for each WS in terms of the release rate λ units/seconds. Utilisation denotes the fraction that a machine is not idle. A machine is considered idle if it is able to begin processing a new lot. Thus, processing time and downtime contribute to the utilisation. Utilisation can never exceed 1.0 and has no dimension. Utilisation ≈ 1.0 happens when the process time is longest (Rooda and Vervoort, 2007). At release rate λ units/second, WS1 is processing 46.5λ units every second, u_1 = 46.5λ. WS2 is processing 93.2λ units every second, u_2 = 93.2λ (considering four times of changeover with nine tasks of each changeover). WS3 is processing 47.45λ units in every second, u_3 = 47.45λ. Therefore, WS2 is the bottleneck because it has the longest processing time (δ_{max} is attained when u_2 = 1). Therefore, u_2 = 93.2λ = 1, will result in λ_{max} = δ_{max} = 1/93.2 = 0.0107 units/second = 38.5 units/hour. If the same parameters are used in the simulation model, Maximum throughput (δ_{max}) is calculated by dividing Total Production Output with Total Time Production, which is 600/55953.95 units/second, equivalent to 0.0107 units/second or 38.5 units/hour. This result shows that the simulation model result and mathematical result are identical; ergo the simulation model is verified and validated.

3.3 Training Scenario – Integrating LMTTS-SMED with the current UTP.

As mentioned earlier, the target users for the new training systems are practising engineers and managing staffs of manufacturing companies. After attending current UTP, users are provided with LMTTS-SMED e-learning module for them to revise what they have learnt in the current UTP (continuous learning). Users are also provided with LMTTS-SMED simulation module for them to learn how SMED is applied in a real-life production floor. Table 3-1 shows the step-by-step procedure for using the e-learning module and S-module of LMTTS-SMED.

Table 3-1: Procedure for using LMTTS-SMED

e-learning module
• To retrieve information on SMED from this sub module, users have to download a .pdf file. • Quizzes are in the form of multiple choice questions. Users will be provided with questions and answers (Q&A).
S-module
• To retrieve information from this module, users will need to open .doe file using Arena software. • In the .doe file, there are four input windows representing four stages in SMED Conceptual Phase (Preliminary Stage, Stage 1, Stage 2, and Stage 3). • Step 1: Select “Preliminary Stage” • Step 2: Fill up segment 1 (General information of product) • Step 3: Fill up segment 2 (Workstation process time) • Step 4: Fill up segment 3 (Number of units per batch) • Step 5: Fill up segment 4 (Number of units in buffer) • Step 6: Fill up segment 5 (Changeover parameter) • Step 7: Fill up segment 6 (Changeover cycle) • Next, run the simulation model and view the result(s). • Repeat the same process for Stage 1, Stage 2 and Stage 3 of SMED conceptual phase. • Users can experiment with the parameters to achieve desired result(s). • “Help” button can be used to guide user in filling up the parameters.

Nevertheless, a few considerations need to be made by the users. In some segments, users need to ascertain the type of input parameter: CONSTANT (users specify the constant value, e.g. 100), UNIF (3.5, 6) – uniform distribution with a minimum value of 3.5 and a maximum

value of 6; NORMAL (83, 12.8) – normal distribution with a mean of 83, a standard deviation of 12.8; or TRIA (10, 15, 22) – triangular distribution with a minimum value of 10, mode (most likely value) of 15, and a maximum value of 22.

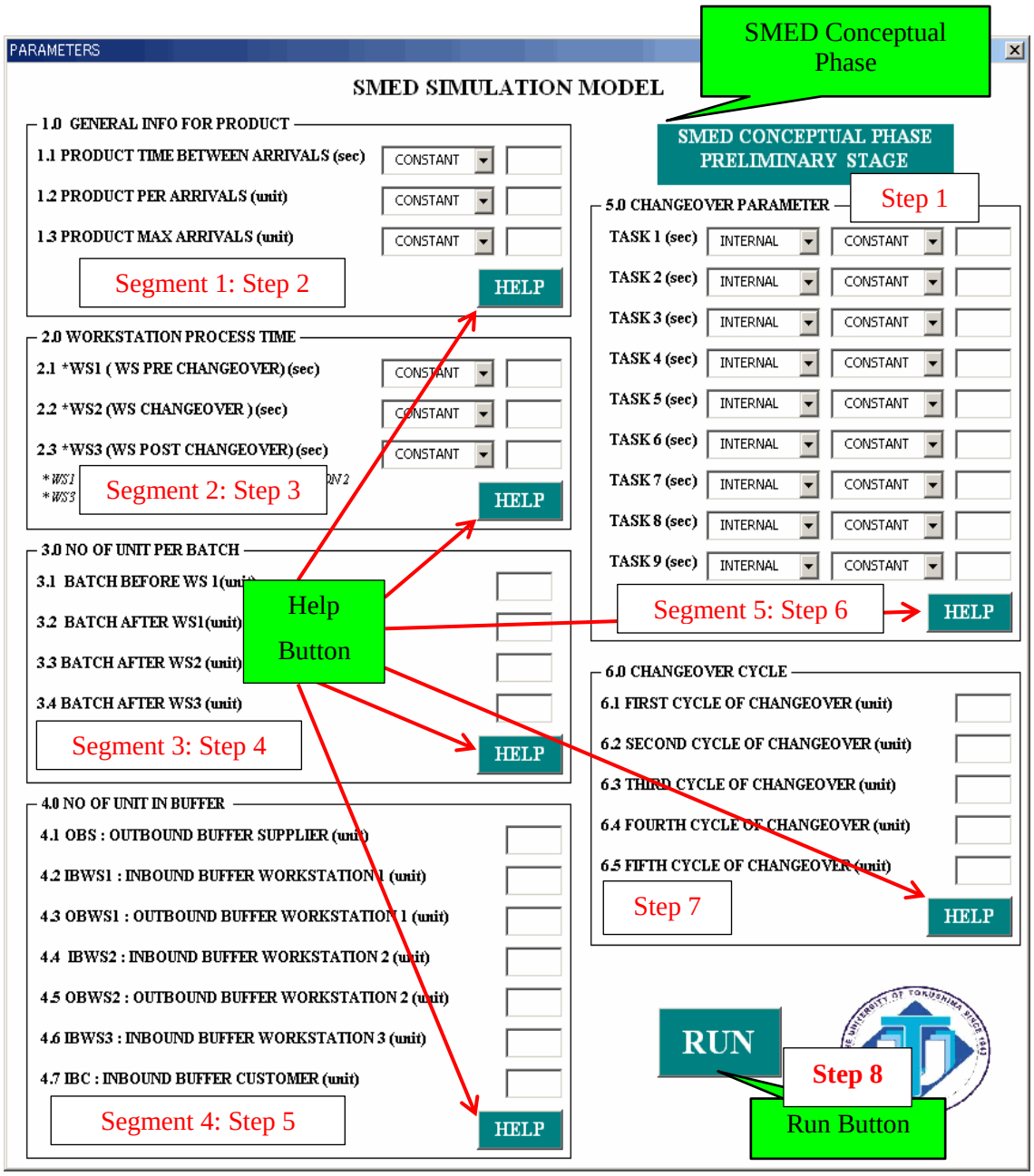


Figure 3-13: Caption of simulation model

The input parameter for time must be in seconds while the input parameter for numbers must be per unit. The input parameter must not be written in alphabets, negative value, and less

than three decimal values. A detailed caption of the input window for a simulation model is exemplified in Figure 3-13.

Output of the simulation model is generated in the form of data for Total Production Time, Total Production Output, and Maximum Throughput (δ_{max}). Maximum Throughput (δ_{max}) is acquired by dividing Total Production Output with Total Time Production. Coloration between Total Production Time, Total Production Output or Maximum Throughput (δ_{max}) with different number of unit per batch (k), and different numbers of buffer (B) etc. for each SMED conceptual phase can be appreciated. This variation provides options for users to decide and choose the best combination of parameters for their production line

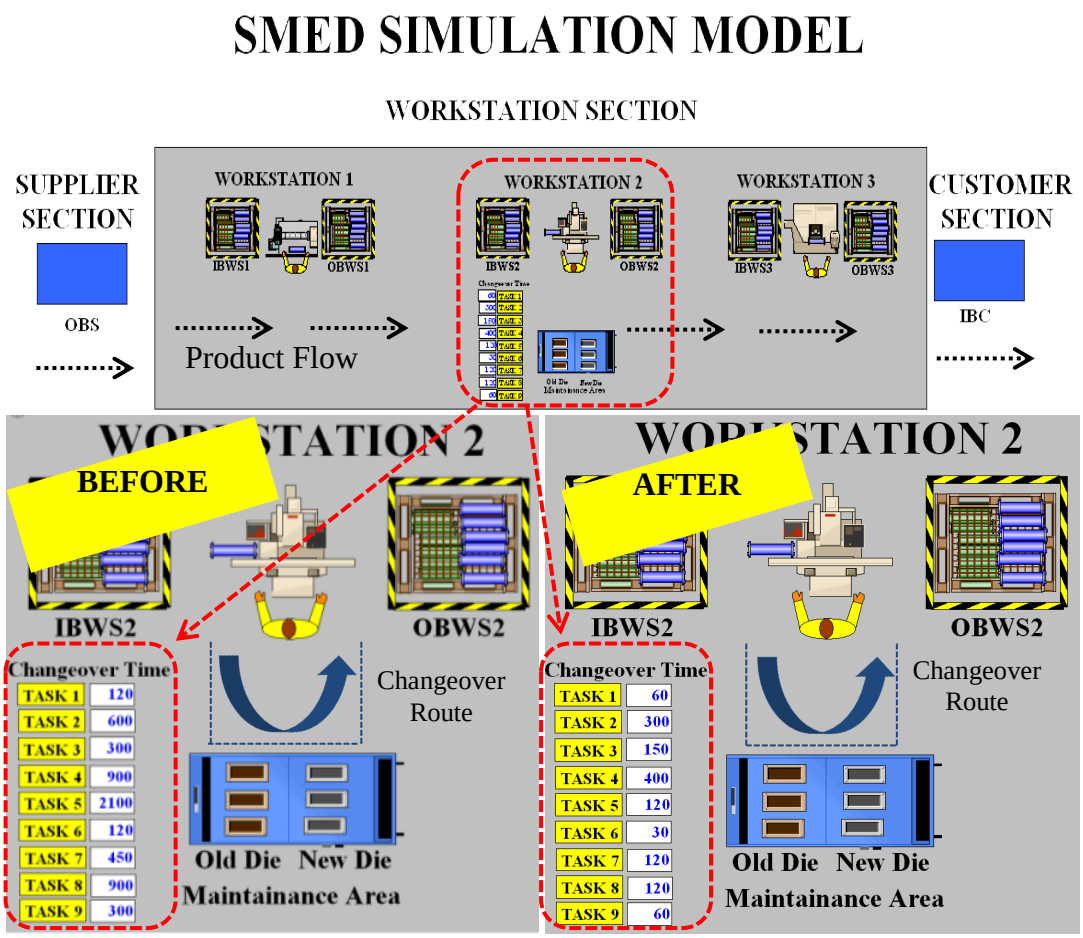


Figure 3-14: Caption of simulation model before and after the implementation of SMED

Outputs are also generated in the form of animation (Figure 3-14). Animation provides users with a dynamic illustration of manufacturing production line and a grasp on the complex

concept of the tools. Users can also repeatedly run the simulation to recapitulate parts that need clarification

This way, users' understanding and confidence levels towards SMED will increase. It will become a source of motivation for them to generate ideas and possible solutions for problems in real production floor. When users are motivated and can foresee the effect of applying SMED on their production floor, conducting pilot study and large experiments will be easier and can be completed in a shorter duration.

Users who have completed the training programme (both UTP and LMTTS-SMED) are assessed through semi-structured interview and questionnaire. Users are asked about their confidence level towards understanding of LM tools and confidence towards LM tools implementation. Moreover, questions on feasibility of LMTTS in terms of its interface, generated output, accessibility of its modules etc. are also inquired. Users are informed that their feedback and suggestions would help to improve the proposed framework.

In essence, author has introduced a theoretical training framework which supports LM implementation and provides the basis for its integration. The proposed framework could be easily extended in the future to support other LM tools. The next chapter deals with simulation-based approach to decision support for lean practitioners.

Chapter IV
A simulation-based approach to decision support for lean practitioners

4.1 Introduction

To date, the lean manufacturing (LM) philosophy has been applied to many manufacturing processes and its feasibility has been reported so far (Detty & Yingling, 2000). By identifying and eliminating waste throughout a product's entire value stream by means of a set of LM tools, companies are able to produce and assemble any product range in any order or quantity. In order to do these, personnel needs to have the expertise in deciding which LM tool to implement at the right time and on the right place. However, this expertise is not always available (Achanga et al., 2006; Wong et al., 2009). The decision making in manufacturing systems is becoming more difficult nowadays due to increasing amount of data and complex interrelations between manufacturing processes (Heilala, 2010). Nevertheless, decision making in manufacturing process plays a critical role in determining the future of a company (Kingstam & Gullander, 1999).

Simulation has been asserted as a tool to quantify the effectiveness of LM tool implementation and assist lean practitioners in their decision to implement LM (Detty & Yingling, 2000; Ramakrishnan et al.,2008 ;Sevillano et al.,2011). Simulation is an effective method to support and evaluate LM tools, to assess current and future state of manufacturing process, to perform "what-if" analysis and to measure impact of improvement after LM implementation. Most importantly, simulation could represent a large number of interdependent input parameters and manage the complexity of interactions effectively (Papadopoulou & Mousavi, 2008) .By using simulation, lean practitioners to forecast the output of manufacturing processes base on the input values. Simulation are able provides the lean practitioners with time to react to emerging problems, evaluate potential solutions and decide on LM implementation.

However, most studies use simulation to design, test and improve lean system. Yet, studies on usage of simulation to support decision-making in replacing an existing manufacturing process with a lean system are still lacking (Detty & Yingling, 2000). Lean practitioners (decision-makers) understanding on how to implement LM and the impact of LM on performance measures are also still lacking (Anand & Rambabu, 2011). Thus, the decisions to adopt LM are often made based on intuitions, faith in LM philosophy, consulting the experts, utilizing handbooks, experiences of other management teams who have implemented LM and using their own calculation methods (Heilala, 2010 ;Abdulmalek & Rajgopal, 2007).

Researches on application of simulation-based approaches in decision making of LM implementation are available. A research conducted by Schramm et al. (2007) uses simulation to support decision-makers in production design and operations while the study of Heilala, (2010) deployed simulation in operational scheduling system. Heilala, (2010) concluded that simulation-based approaches could alleviate the works required to plan day-to-day scheduling, ensure conformance of customer order due date, synchronize flow through the plant, reduce changeover time and forecast potential problems.

Nevertheless, there are minor drawbacks associated with simulation-based approaches in decision making of LM implementation. As far as the limitation of these approaches are concerned, the biggest obstacle is to develop a system capable of supporting operational (real-time) decision making as opposed to strategic manufacturing decision making (Fowler & Rose ,2004). Another obstacle is the “gap” which exists between lean practitioners and simulation-based approaches in terms of expertise in utilising the simulation software tools. The simulation software tools are generally suitable for simulation engineers who know how to design/build/analyse a simulation model, and how to integrate it to LM tool software (Janca & Gilbert, 1998). Moreover, simulation studies in lean projects and real time updating of simulation model are managed by simulation engineers. (Gourdeau, 1997). Thus, simulation-based approaches are not suitable for lean practitioners who are familiar with neither simulation software, nor LM tool software. Misunderstanding between simulation engineers and other lean practitioners may lead to development of a biased simulation model (West et al.2000). A structured approach of using simulation software tools is required to increase the understanding of decision-makers and support decision-making process in LM implementation.

Motivated to address this issue, Mujber et al. (2005) developed a decision support system targeted for users who are not experts in simulation. The decision support system was developed using Visual Basic Application and designed to work with Witness package and Superscape VRT software to enable non-expert users to develop simulation and virtual models. Users were able to interact with the simulation models in real time using voice commands and observed the virtual model using head mounted display. With the decision support system, the targeted users could develop simulation models of manufacturing systems and address their behaviour.

In this study, a simulation-based decision support system (SDSS) is proposed to address the gap between lean practitioners and simulation-based approaches in terms of expertise in utilising simulation software tools. SDSS is a system capable of supporting operational (real-time) decision making by providing four functions through interactive use of process simulation to assist lean practitioners (who are not experts in simulation) in their decision to implement LM tools.

The functions of SDSS are layout, zoom-in/zoom-out, task status and Key Performance Indicators (KPI) status. Following simulation runs, results (SDSS output) will be saved in an independent database. The results can be retrieved during or at the end of simulation runs in the form of total production output, total production time, changeover time, bar chart, Work in Progress (WIP) and Inbound/Outbound buffer values. From the results, lean practitioners can detect problems in the simulated production line and select the most suitable LM tool to be applied to solve the problems. For example, if the result shows high changeover time, lean practitioners could choose Single Minute Exchange of Die (SMED), implement it into the simulation model and conduct simulation run again to observe the improvement brought by the chosen LM tool (Figure 4-1).

The process could be repeated countlessly until the desired results are achieved. By using this process simulation approach, lean practitioners are able to forecast the output of manufacturing processes and the effectiveness of LM tools base on the input values. This provides the lean practitioners time to react to emerging problems, evaluate potential solutions and decide on LM implementation. Feasibility of SDSS is studied using a

manufacturing process model of a Coolant Hose Manufacturing (CHM) factory developed in this study. The details of SDSS will be elaborated in the next section.

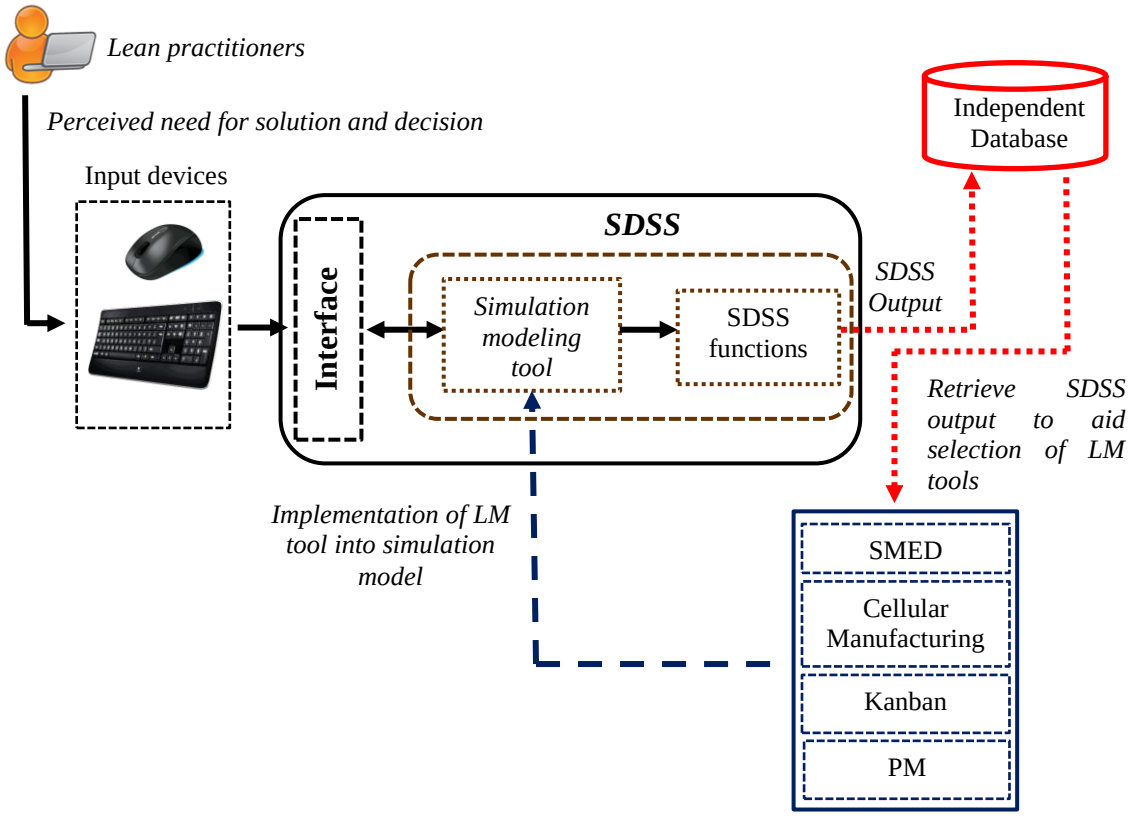
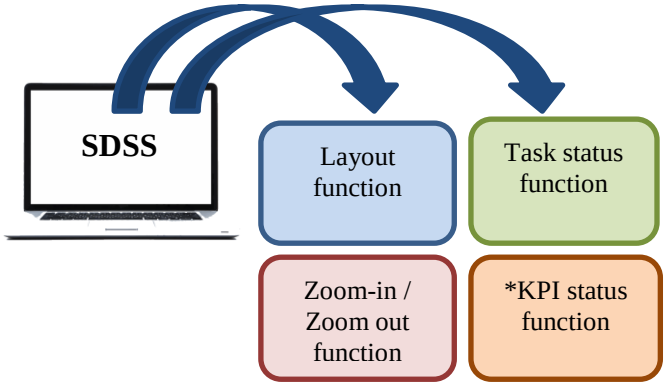


Figure 4-1: Simulation-based decision support system (SDSS) architecture

4.2 Overview of SDSS

As mentioned earlier, this study proposes SDSS to address the gap between lean practitioners and simulation-based approaches in terms of expertise in utilising simulation software tools. SDSS plays a critical role to support lean practitioners in real time decision making and selection of LM tools. SDSS provides four functions through an interactive use of process simulation to assist lean practitioners (who are not experts in simulation) in their decision to implement LM tools (Figure 4-2).



**KPI: Key Performance Indicators*

Figure 4-2: Functions of SDSS

The layout function of SDSS provides a bird's-eye view of the simulated factory floor. By using this function, lean practitioners could observe how the manufacturing process runs with the flow of materials and products throughout the manufacturing process. They could observe the movement of operators; identify workstation that causes bottleneck and other problems in the production line (Figure 4- 3).

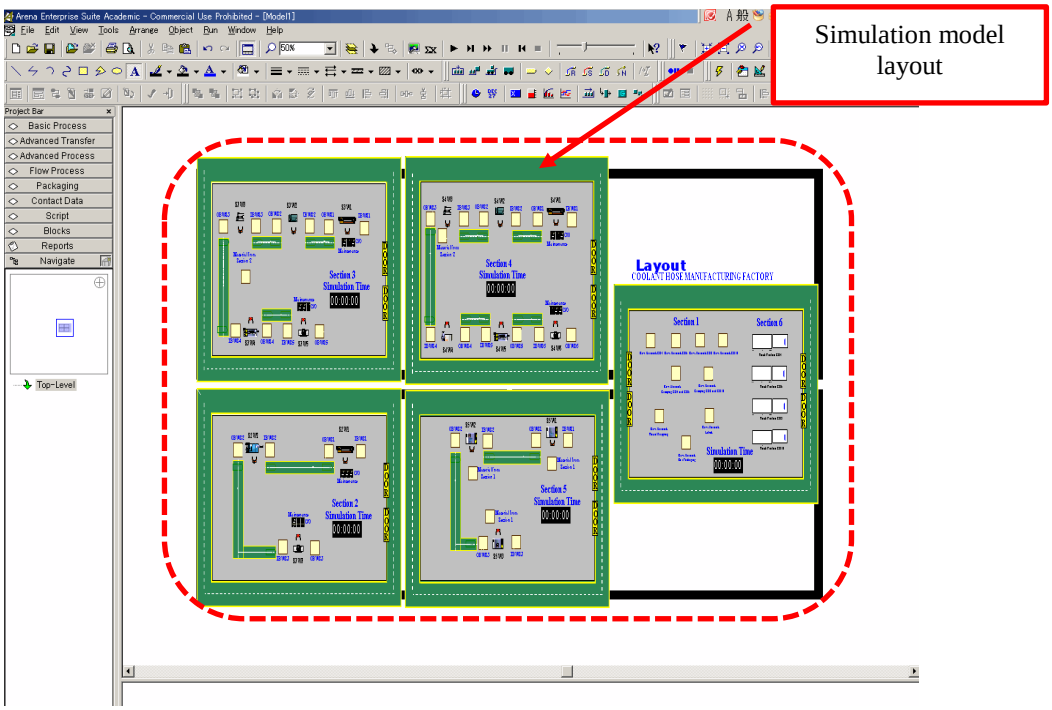


Figure 4- 3. Layout function of SDSS

The second function of SDSS is zoom-in/zoom-out function. The zoom-in/zoom-out function designed for obtaining a detail view of each section of manufacturing process (Figure 4- 4). For example, if the lean practitioners noted a section with product congestion during simulation run, they can click on the zoom-in button to get a better view of that particular section and find out the cause of product congestion. To find the cause of product congestion, they are provided with the third function of SDSS which is the task status function.

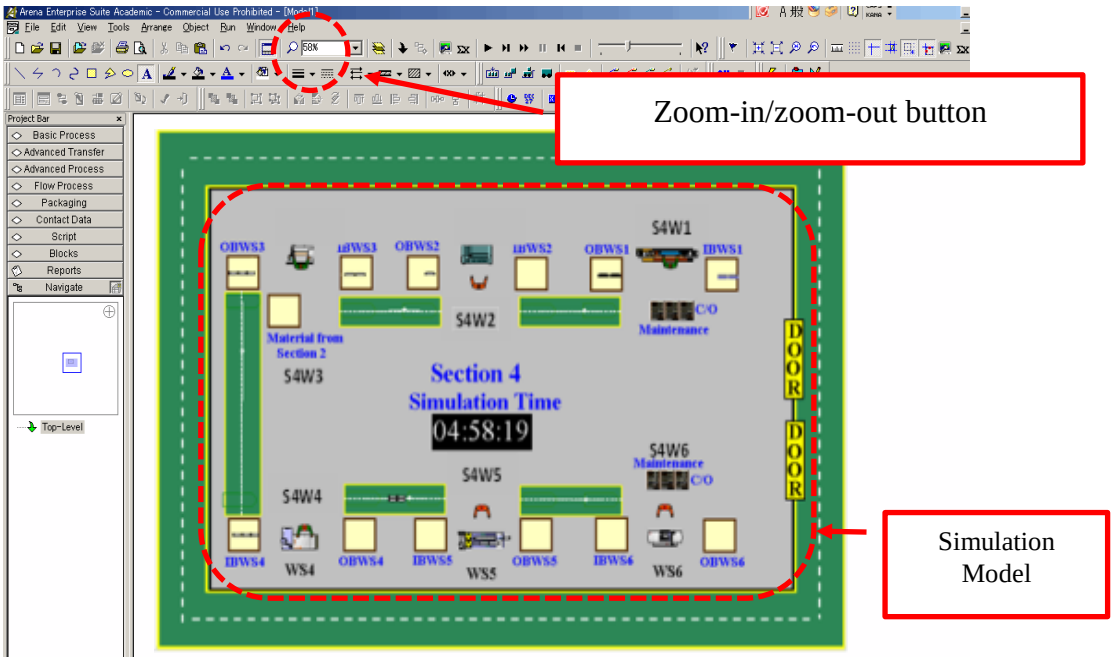


Figure 4- 4 Zoom-in/zoom-out function of SDSS

The task status function of SDSS provides three status illustrations i.e. busy, idle, and fail to represent operator status in every workstation in the factory (Figure 4- 5). The three task statuses of operator are differentiated by means of colours and locations of the operator from the machine. By observing these status illustrations, lean practitioners are able to understand the changing task status in real time during simulation runs. Once they understood the problem at the workstation, they can resume viewing the layout view by clicking on the zoom-out button. Following that, they are prompted to utilise the KPI (Key Performance Indicators) status function to acquire more information on the existing problem.

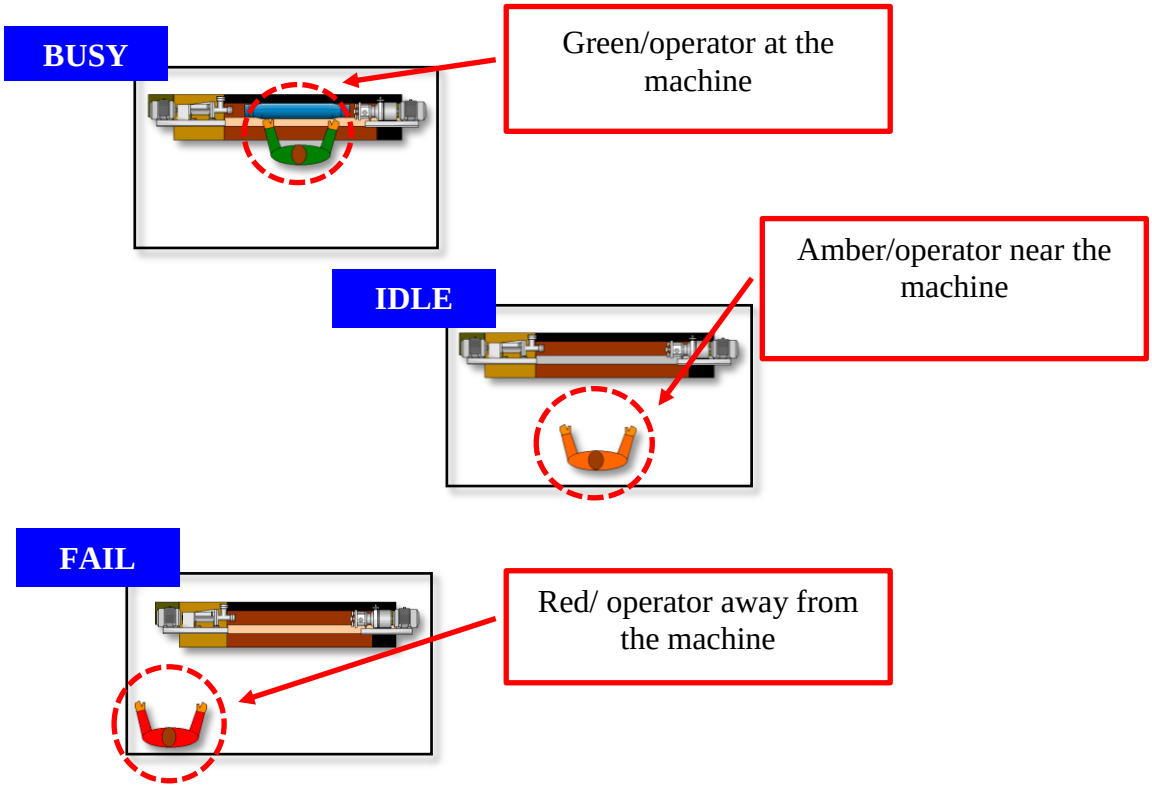


Figure 4- 5. Task status function of SDSS

The KPI status function which includes total production output and total production time (Figure 4- 6) and changeover (C/O) task time (Figure 4- 7), are presented by means of KPI tables. KPI values in this simulation model are generated and updated in real time during simulation. By conducting what-if analysis and observing the KPI, lean practitioners are able to observe the performance of the existing production line and compare it with the performance after LM tool implementation.

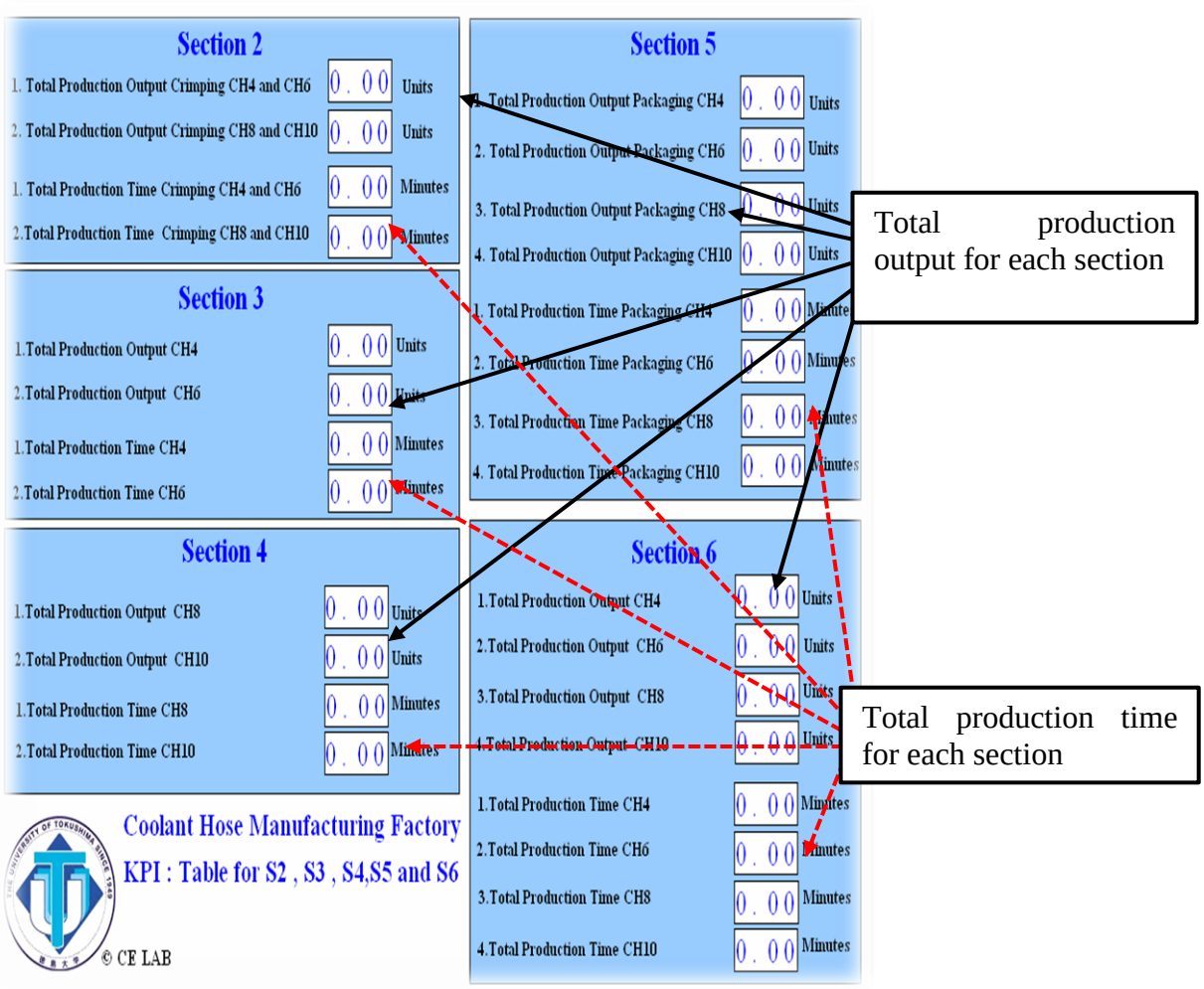


Figure 4- 6. Table of KPI status function (Total production output & Total production time)

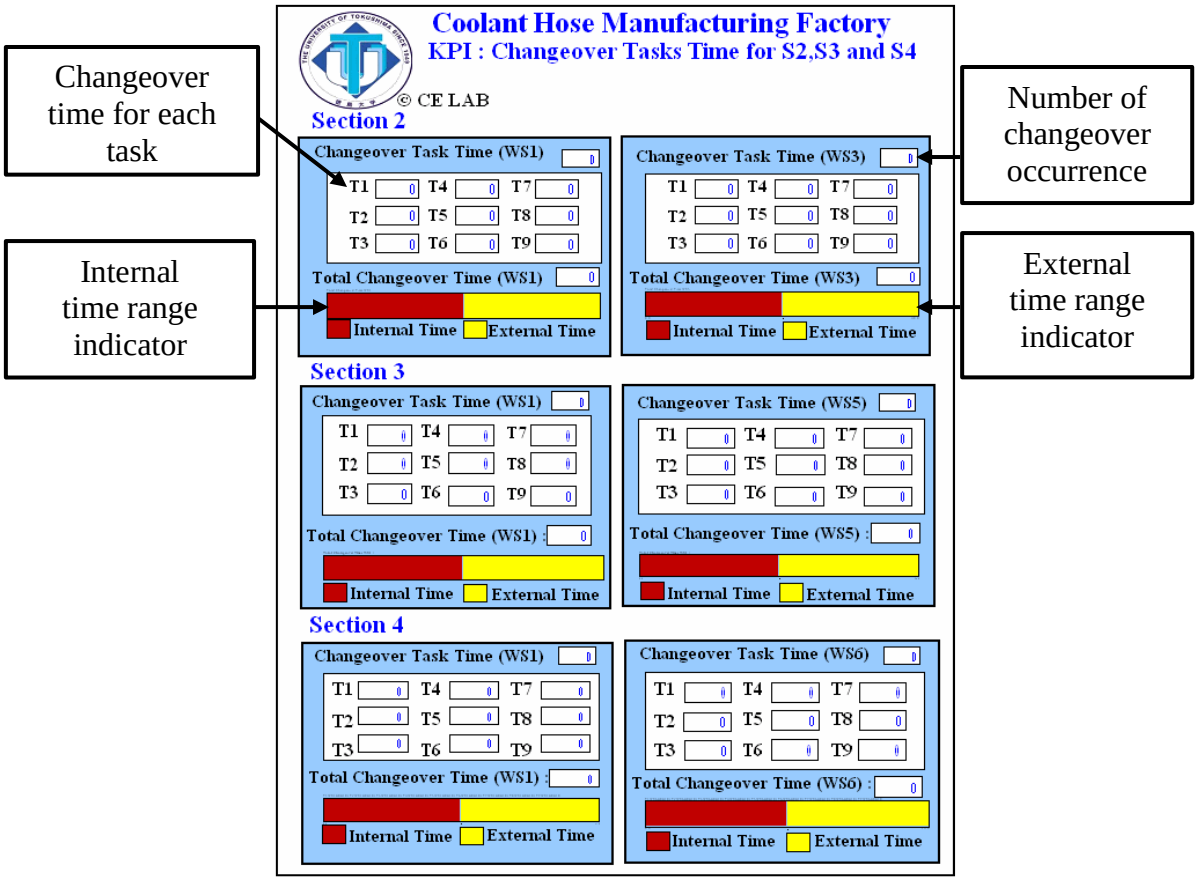


Figure 4- 7. Table of KPI status function (changeover)

For visual understanding of KPI, bar charts of KPI status are also generated and updated in real time during simulation (Figure 4- 8) The bar charts assist lean practitioners in their decision to implement LM tools by providing information on Work In Progress (WIP) and Inbound/Outbound buffer.

The layout function, zoom-in/zoom-out function, task status function and KPI status function mentioned in this section are later incorporated into simulation model of CHM factory. The design and development of simulation model of CHM factory is presented in the next section.

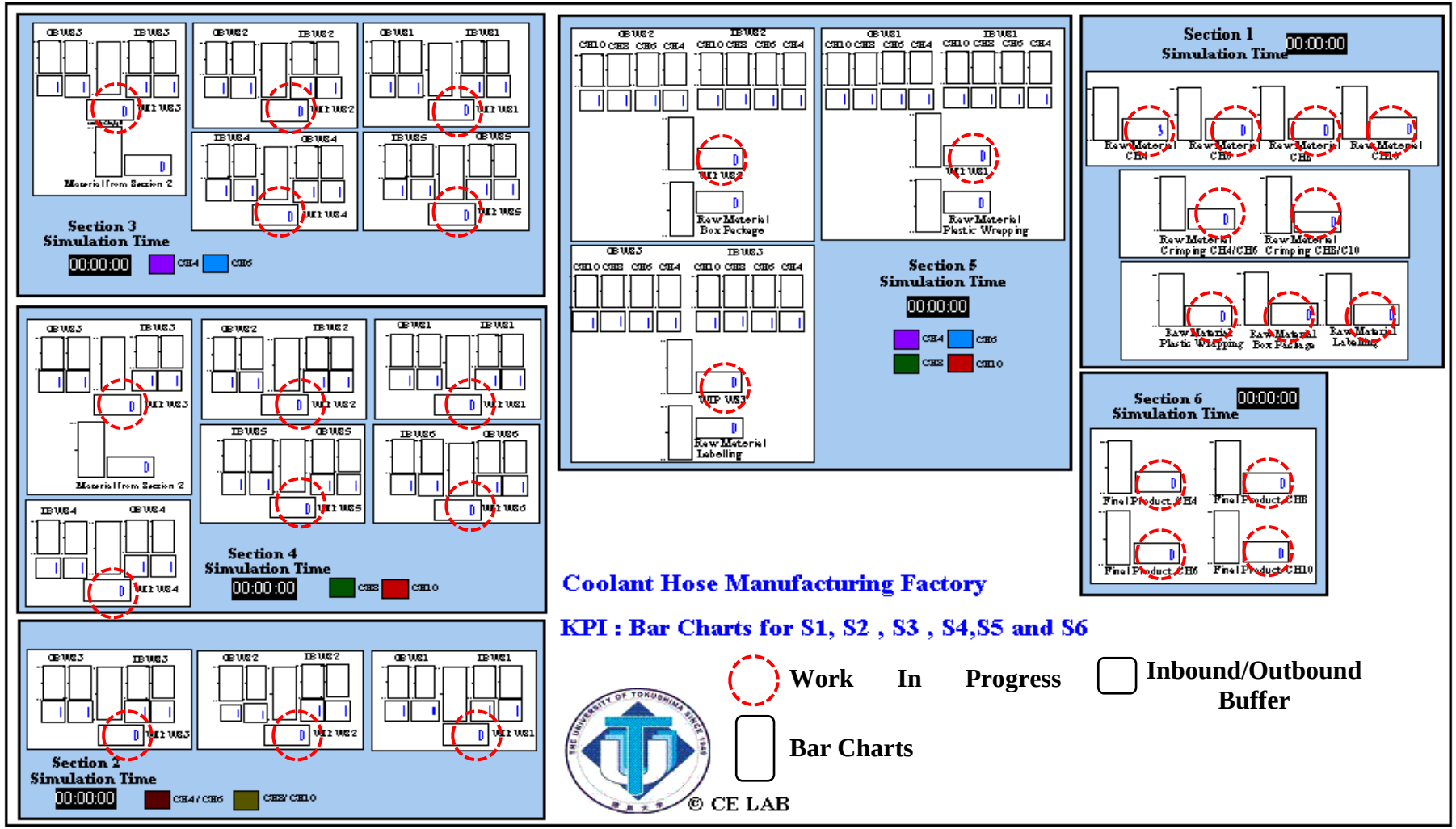


Figure 4- 8. Bar charts of KPI status function

4.3 Coolant Hose Manufacturing (CHM) Factory

In this study, SDSS implementation was shown using a process model of CHM factory. CHM factory is an automotive supplier producing four types of coolant hose (CH) products, namely CH4, CH6, CH8 and CH10 (Figure 4-9). The CHM factory floor is divided into six sections from Section 1 (S1) to Section 6 (S6) as can be seen from the process flow of CHM factory in Figure 4-10. Production capacity for each section is 150units/day in ten hours operation per shift. There is a 30 minutes unpaid lunch break and two 15 minutes breaks. Thus, the available production time is 540 minutes (32 400 second/shift). Material handling of the products in the production line is performed by either forklift or trolley.

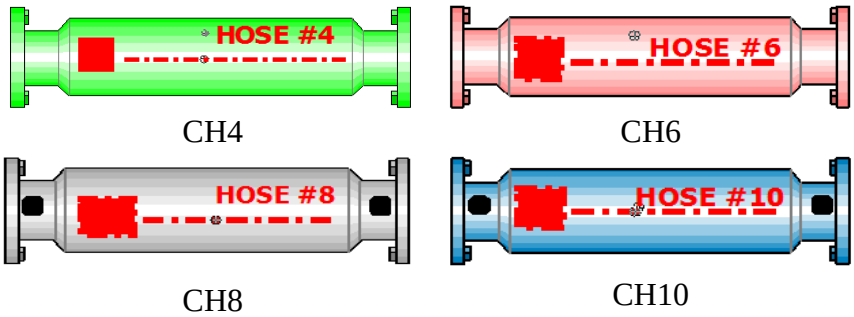


Figure 4-9: Types of coolant hose product of CHM factory

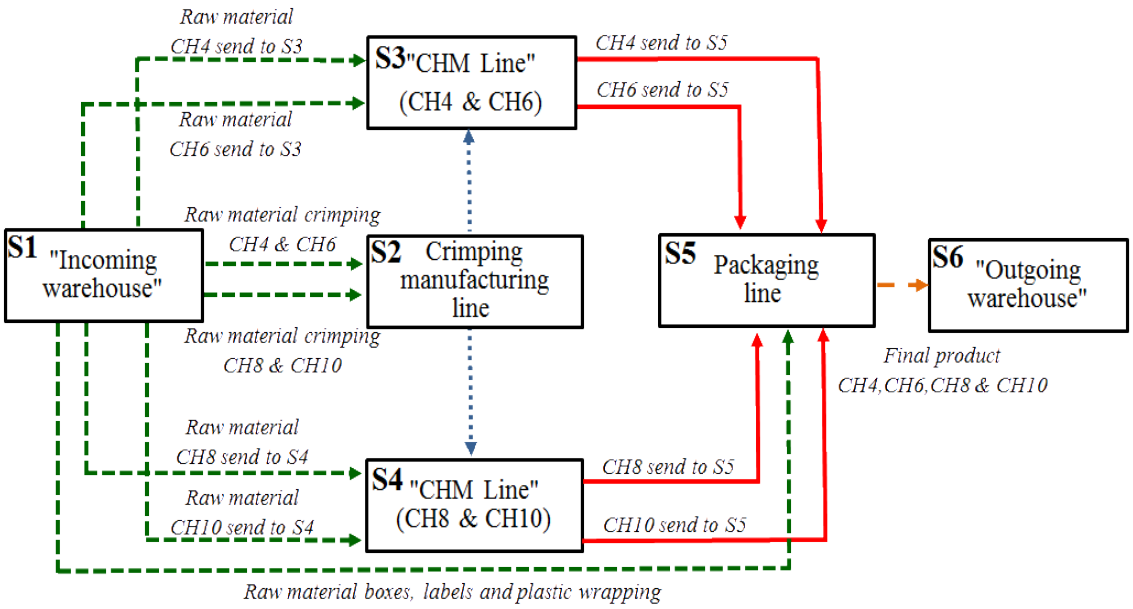


Figure 4-10: Process model of CHM factory floor

S1 is the incoming warehouse which stores raw materials to be supplied to S2, S3, S4 and S5. Raw material crimping CH4&CH6 and raw material CH8&CH10 will be sent to S2. S1 also supplies raw material CH4&CH6 to S3 and raw material CH8&CH10 to S4. Raw materials for wrapping, packaging and labelling will be supplied to packaging line (S5). Figure 4-11 shows the model layout of S1.

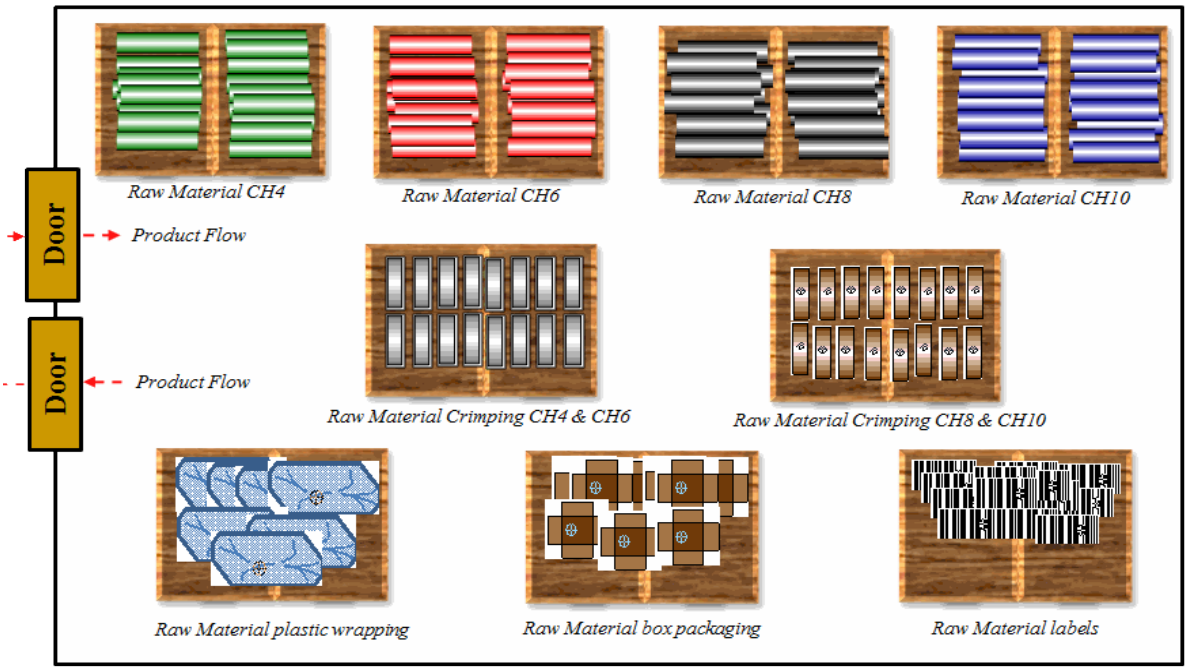
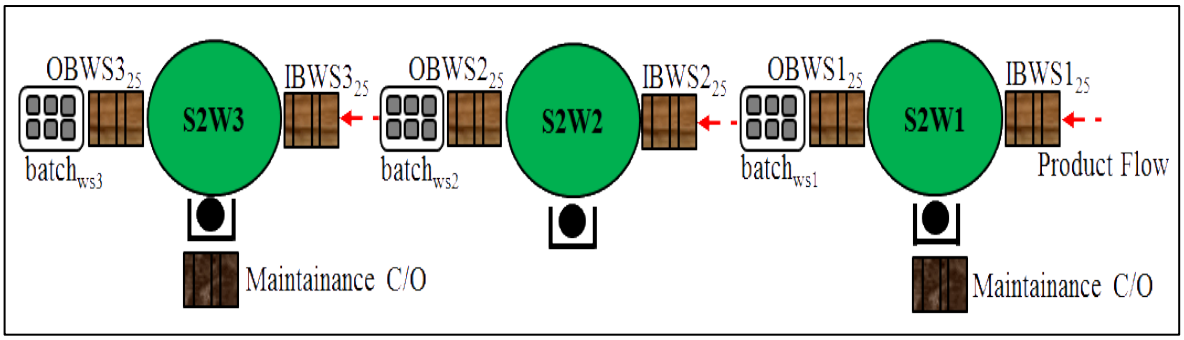


Figure 4-11: Model layout of S1 (Incoming warehouse)

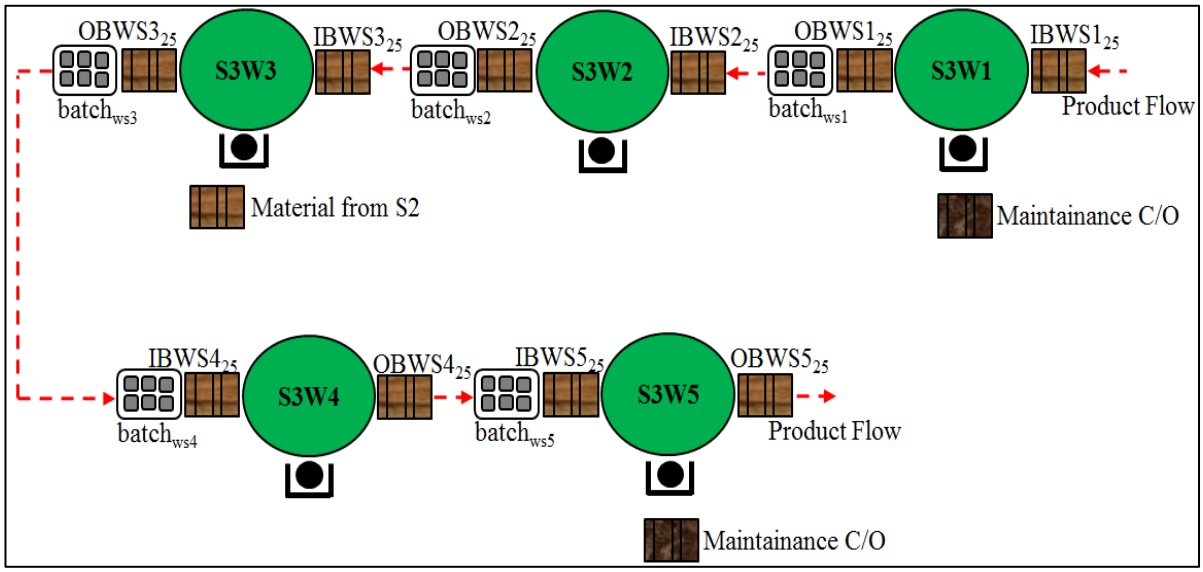
S2 is the crimping manufacturing line which consists of three workstations (WS) namely S2W1 (machining), S2W2 (testing) and S2W3 (marking). Each WS is operated by one operator as shown in Figure 4-12. Based on triangular distribution, the process time for S2W1 is TRIA (0.5, 1, and 1.5); S2W2 TRIA (0.5, 0.75, 1) and S2W3 TRIA (1, 1.25, 1.5). S2 produces two types of products namely crimping CH4&CH6 and crimping CH8&CH10. Changeover (CO) process occurs in S2W1 and S2W3 for product switch in the production line. CO in S2W1 requires 40 minutes while the CO in S2W3 requires 24 minutes to be completed. The batch capacity of each WS in S3 is 5 units and the buffer capacity for inbound and outbound is 25 units. Crimping CH4&CH6 will be sent to S4 (CH8&CH10 manufacturing line).



**Changeover (CO): for product switch in production line*

Figure 4-12: Model layout of S2 (Crimping Manufacturing Line)

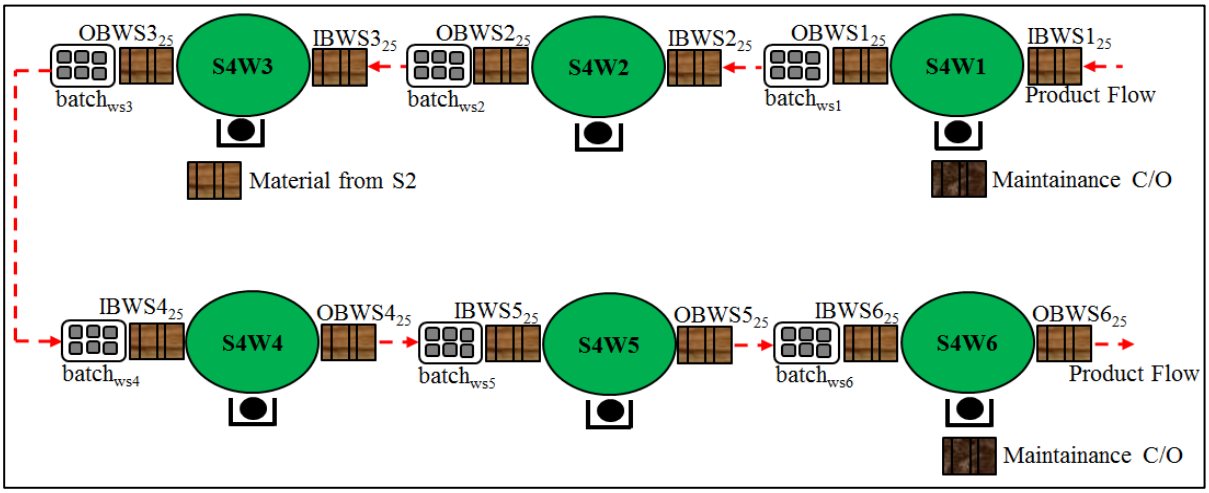
As seen in Figure 4-13, S3 (CH4&CH6 manufacturing line) consists of five WS namely S3W1 (machining), S3W2 (deburring), S3W3 (crimping), S3W4 (testing) and S3W5 (marking). Similar to S2, each WS in S3 is operated by one operator. Based on triangular distribution, the process time for S3W1 is TRIA (0.5, 1, 1.5); S3W2 TRIA (0.25, 0.5, 0.75); S3W3 TRIA (0.5, 1, 1.5); S3W4 TRIA (0.5, 0.75, 1) and S3W5 TRIA (1, 1.25, 1.5). S3 produces two types of products namely CH4 and CH6. CO process occurs in S3W1 and S3W5 which requires 51 minutes and 24 minutes to be completed respectively. The batch capacity of each WS in S3 is 5 units and the buffer capacity for inbound and outbound is 25 units. CH4 and CH6 produced by S3 are sent to S5 (packaging line).



**Changeover (CO): for product switch in production line*

Figure 4-13: Model layout of S3 (CH4&CH6 manufacturing line)

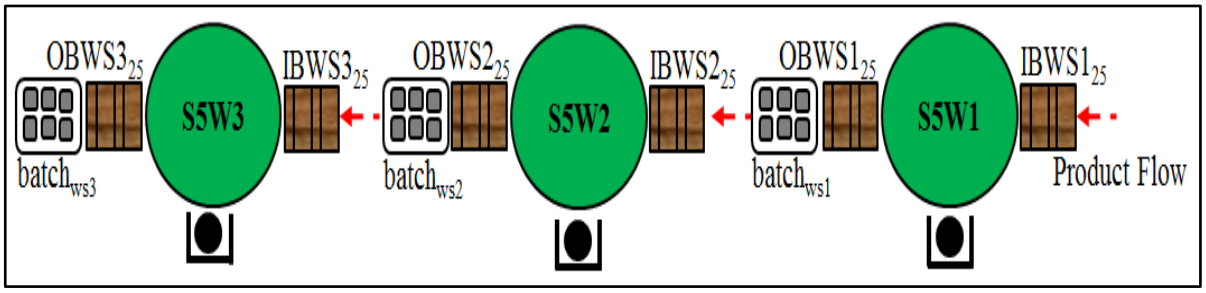
The next section in CHM factory is S4 which is CH6&CH8 manufacturing line (Figure 4-14). S4 consists of six WS namely S4W1 (machining), S4W2 (deburring), S4W3 (crimping), S4W4 (welding), S4W5 (testing) and S4W6 (marking). Similar to S2 and S3, each WS in S4 is operated by one operator. Based on triangular distribution, the process time for S4W1 is TRIA (0.5, 1 , 1.5); S4W2 TRIA (0.25, 0.5 , 0.75); S4W3 TRIA (0.5, 1 , 1.5); S4W4 TRIA (2, 3 ,4); S4W5 TRIA(0.5, 0.75 , 1) and S4W6 TRIA(1, 1.25 , 1.5). S4 produces two types of products namely CH8 and CH10. CO process occurs in S4W1 and S4W6 that requires 51 minutes and 24 minutes to be completed respectively. The batch capacity of each WS in S3 is 5 units and the buffer capacity for inbound and outbound is 25 units. CH8 and CH10 produced by S4 are sent to S5 (packaging line).



**Changeover (CO): for product switch in production line*

Figure 4-14: Model layout of S4 (CH6&CH8 manufacturing line)

The packaging line (S5) includes three WS namely S5W1 (wrapping), S5W2 (box packaging) and S5W3 (labelling) as shown in Figure 4-15. Each WS in S5 is operated by one operator and no CO process occurs in this section. Based on triangular distribution, the process time for S5W1 is TRIA (0.5, 1 , 1.5); S5W2 TRIA (1, 2 , 3) and S5W3 TRIA (0.25, 0.5, 0.75). The batch capacity of each WS in S5 is 5 units and the buffer capacity for inbound and outbound is 25 units. The final products of S5 (CH4, CH6, CH8 and CH10) are sent to S6 (outgoing warehouse) (Figure 4-16).



**Changeover (CO): for product switch in production line*

Figure 4-15: Model layout of S5 (Packaging line)

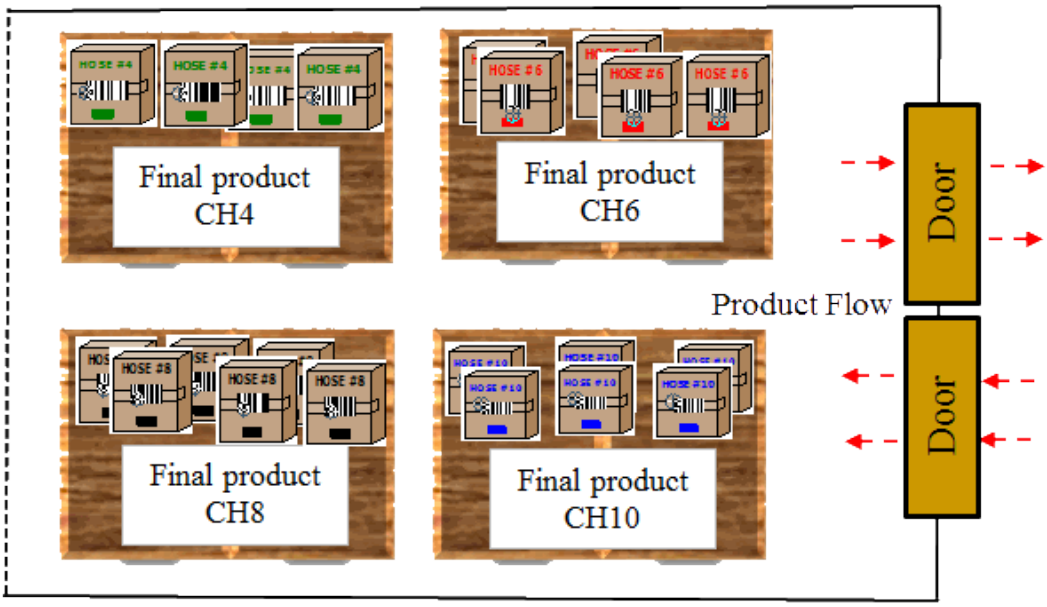


Figure 4-16: Model layout of S6 (Outgoing warehouse)

4.4 CHM factory simulation model

Arena 12.0 Professional Edition simulation package is used for developing CHM factory simulation model (Altiok & Melamed, 2007). Based on the model layout of each section of CHM factory, model logics are created for each section. For sections with CO process (S2, S3 and S4), sub models of the CO process are also created. The simulation model is predicated upon certain assumptions. The assumptions are all workstations operate at full capacity, all workstations have triangular distribution process time, product arrival time is based on a deterministic arrival pattern and all results are reported at a confidence interval level of 95%.

Generally, simulation model of each section of CHM factory is created using a set of simulation modules (model logic). Each module is used for different purposes. Batch Module and Separate Module are used for managing batch of product in the production lines while Process Module is used for processing the products. Inbound and outbound buffer in the production line are represented by Hold Module. The details regarding all modules used to develop the CHM factory simulation model are as follows:

i. **Create Module:** This module is the source of product creation in the simulation model. It provides time distribution and quantity of product arrival.

ii. **Batch Module:** This module is used to manage batch of product. The batch capacity for each WS in this factory may vary. However for most WS in CHM factory simulation model, the batch capacity is 5 units.

iii. **Separate Module**: This module is used to separate products from batch form.

iv. **Hold Module**: This module is used to manage buffer in CHM factory model based on certain inferred conditions. An example of inferred condition for buffer release is:
"NQ (Seize Operator WS1 Hose#8_Hose#10.Queue) == 0 && NQ (Outbound buffer Hose#8 at WS1.Queue) <= 25".

v. **Process Module**: This module is used to represent the processing of products in WS. The module includes information on resources and process time of the products. In CHM

factory simulation model, process time is in the form of triangular distribution and operators are the resources.

vi. **Station Module**: This module is used to represent certain landmark in the CHM factory simulation model.

vii. **Route Module**: This module is used together with Station Module to transfer product from one station to another.

viii. **Assign Module**: This module is used to customize product with attribute, variable, product type and picture following the requirement of the production line.

ix. **Decide Module:** This module is used to decide on production processes based on inferred condition. For example, in CO process, Decide Module is used to determine the time for die switch for product type change in the production lines.

x. **Match Module:** This module is used as a main controller of the queue of products. This module is paired with Hold Module in order to manage the queue accordingly.

The model logics and sub-models logic of S1, S2, S3, S4, S5 and S6 of CHM factory are shown in Figure 4-17 to Figure 4-25 as follows:

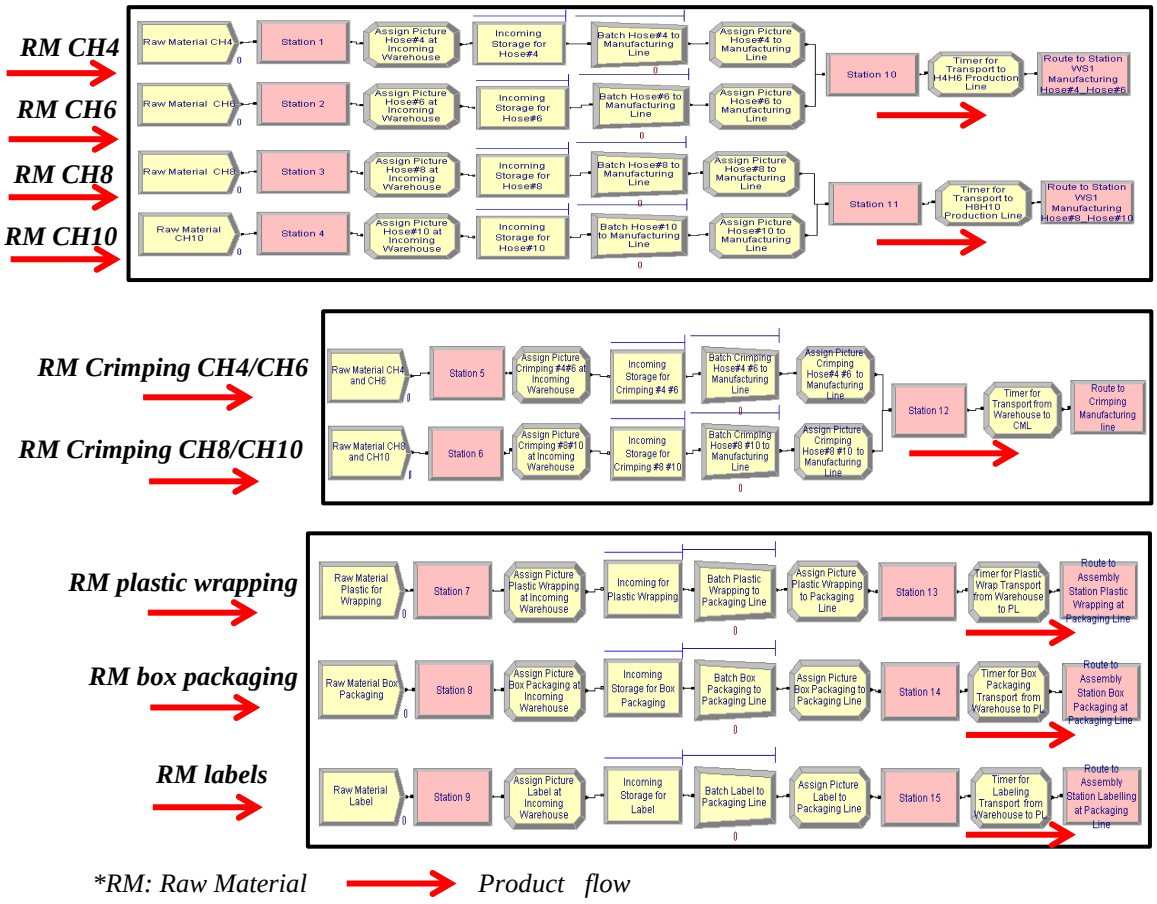


Figure 4-17: Model logic of S1 (Incoming warehouse)

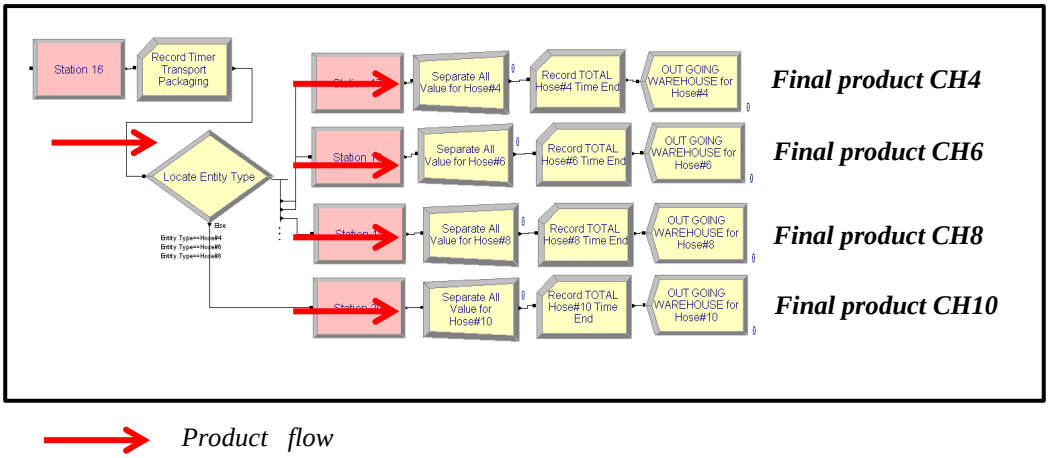


Figure 4-18: Model logic of S6 (Outgoing warehouse)

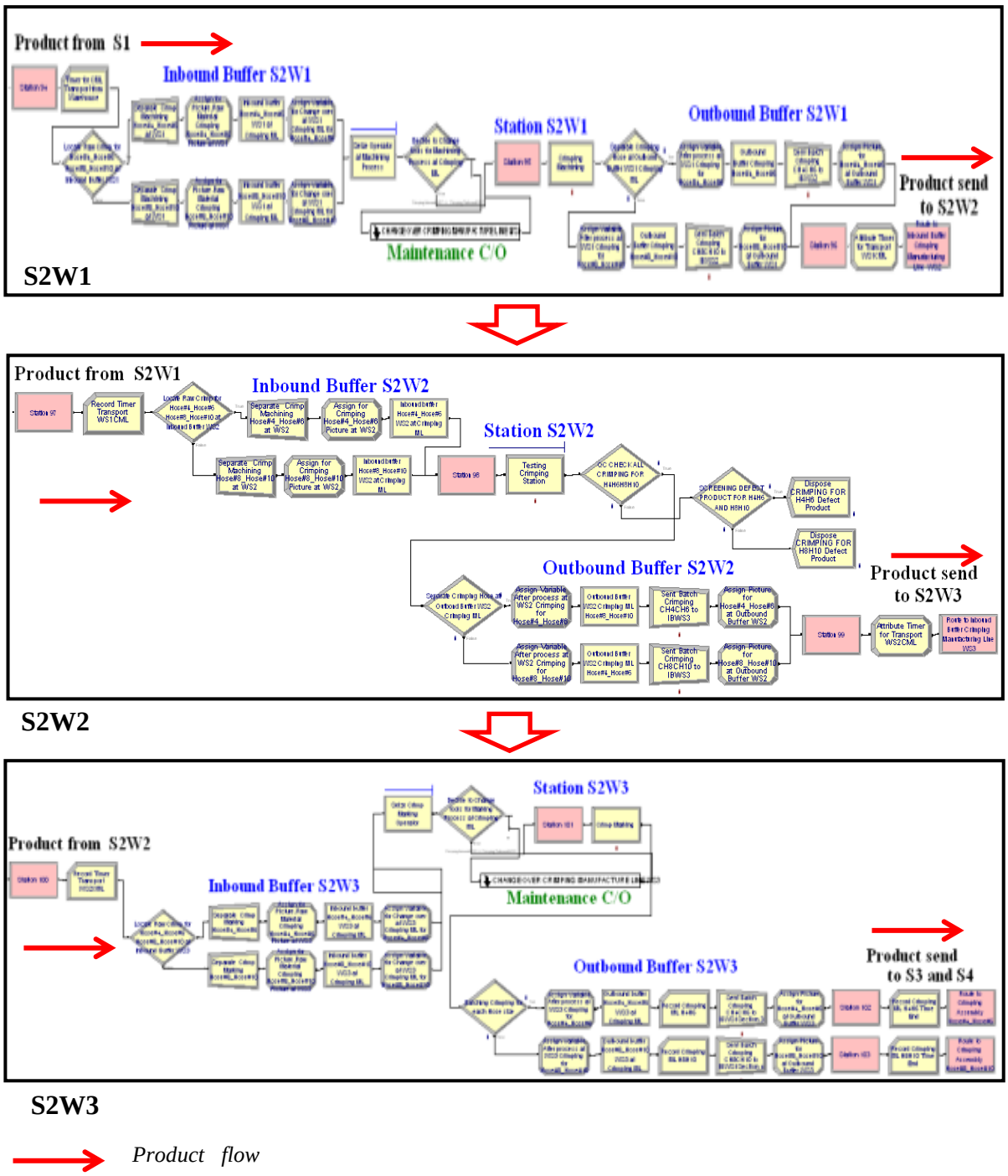


Figure 4-19: Model logic of S2 (Crimping manufacturing line)

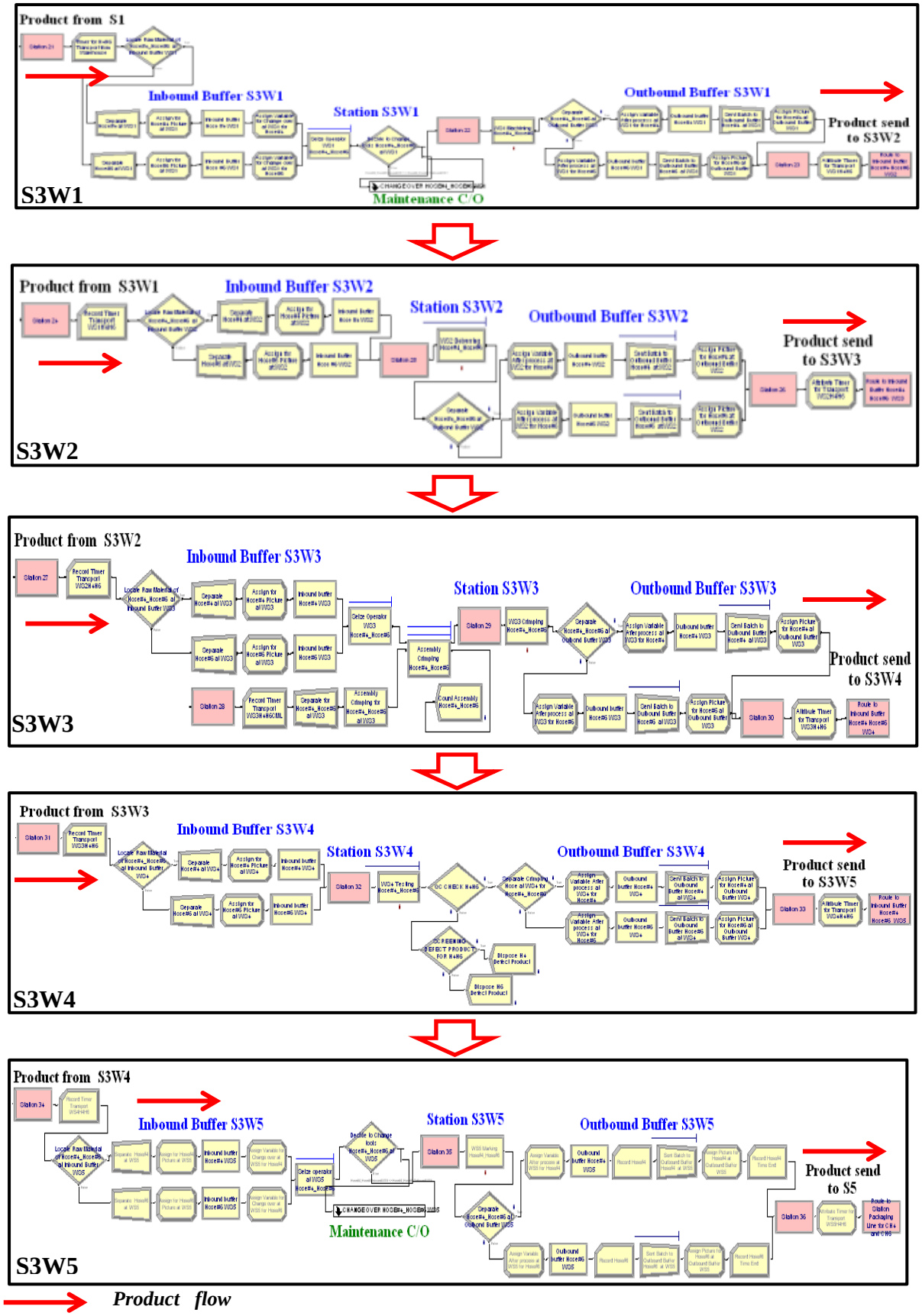


Figure 4-20: Model logic of S3 (CH4 & CH6 manufacturing line)

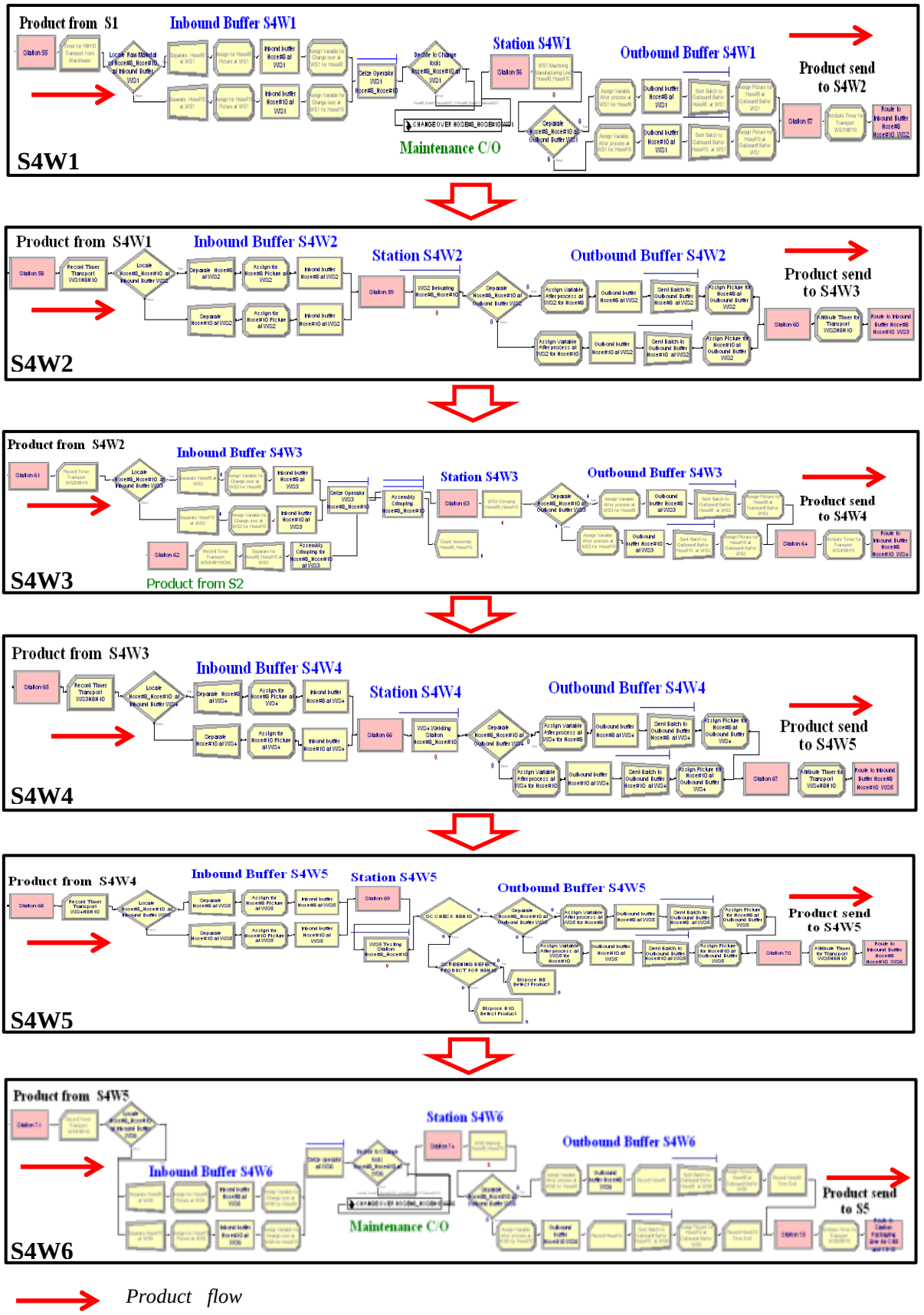
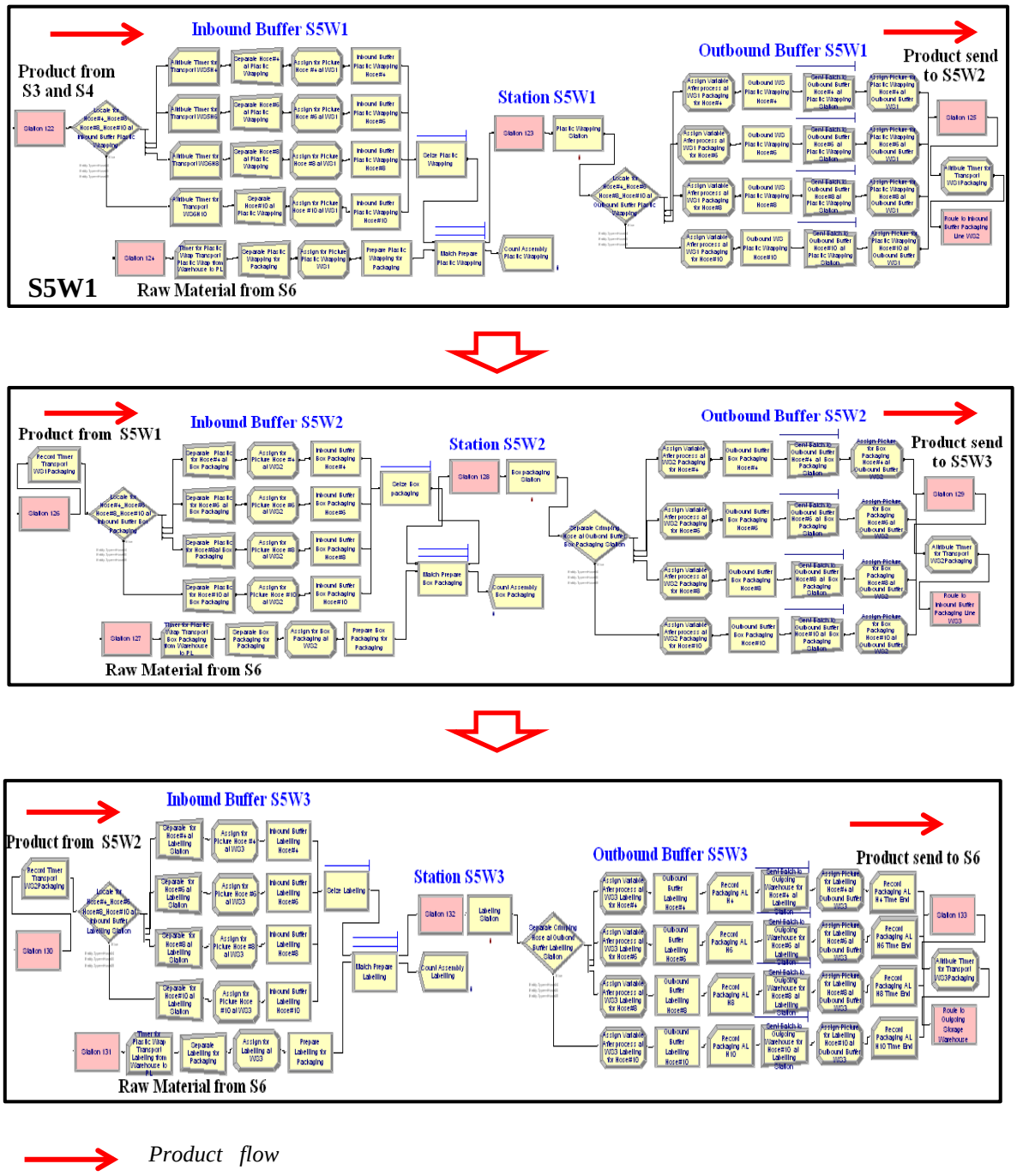
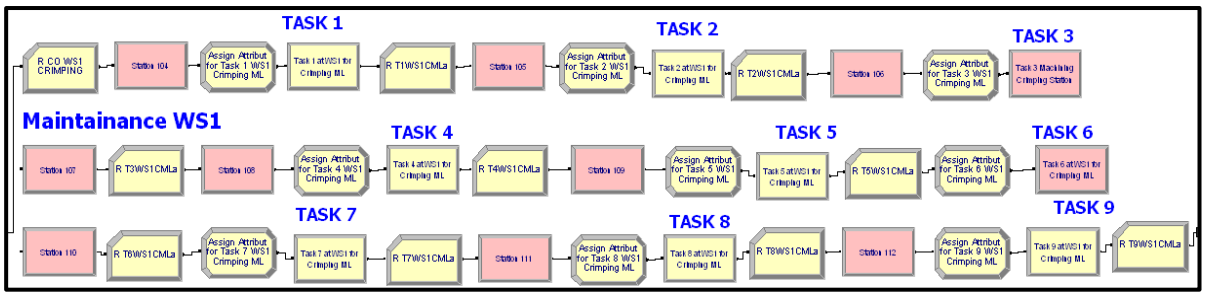


Figure 4-21: Model logic of S4 (CH6 & CH8 manufacturing line)

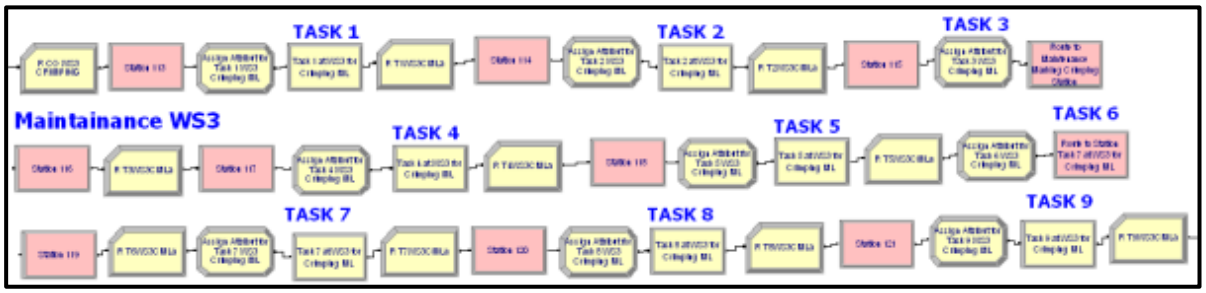


Product flow

Figure 4-22: Model logic of S5 (Packaging line)

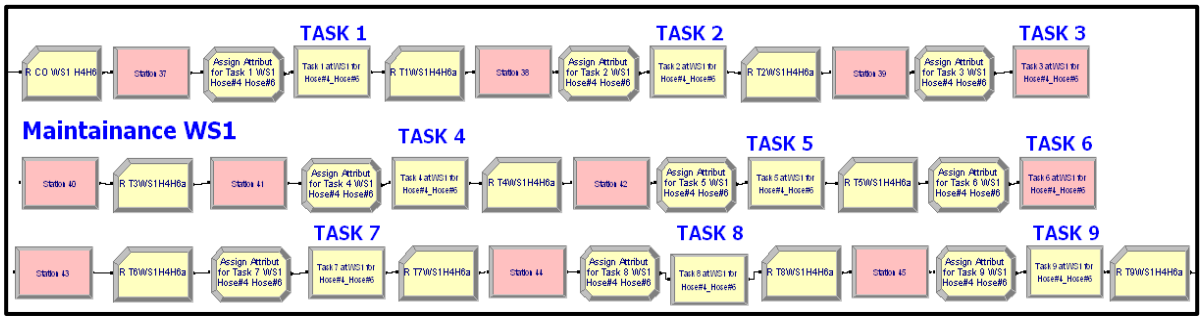


Changeover S2W1

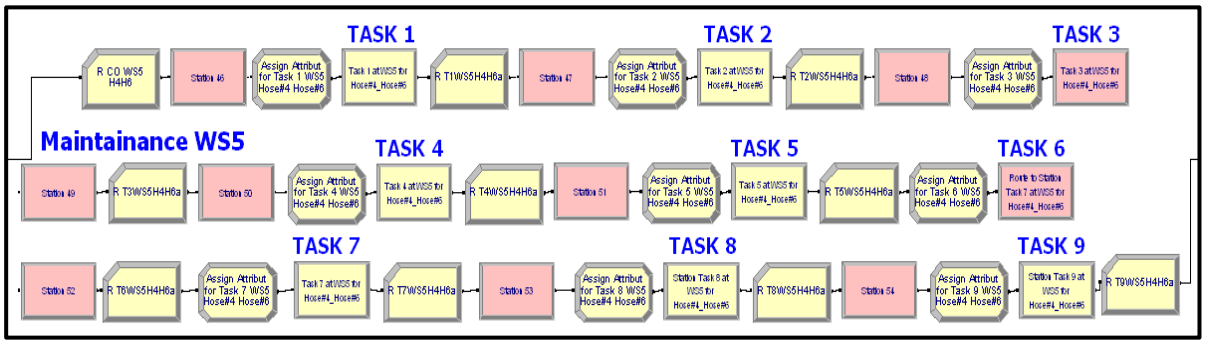


Changeover S2W3

Figure 4-23: Sub-model of changeover for S2W1 and S2W3 at S2

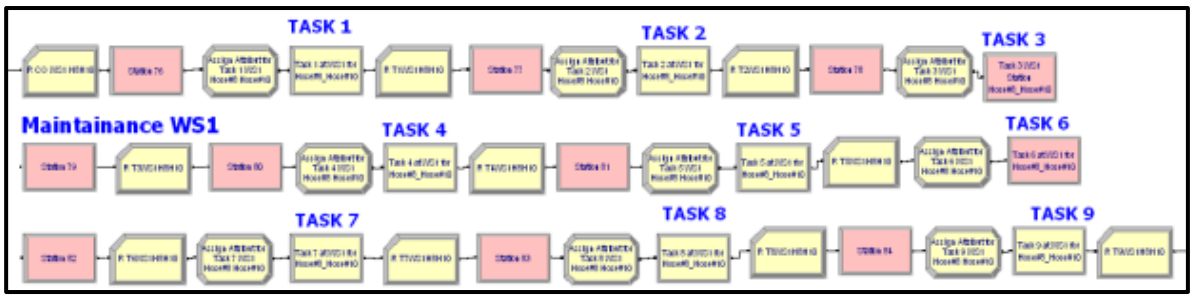


Changeover S3W1

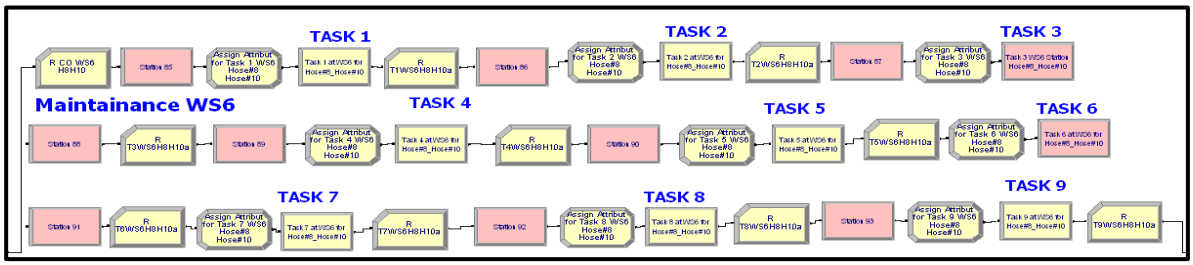


Changeover S3W5

Figure 4-24: Sub-model of changeover for S3W1 and S3W5 at S3



Changeover S4W1



Changeover S4W6

Figure 4-25: Sub-model of changeover for S4W1 and S4W6 at S4

4.4.1 Animation of CHM factory simulation model

Following the creation of model logics, animation of CHM factory simulation model is developed. To develop the animation, images representing each product of CHM factory are created first and placed in a CHM library (CHM factory product.plb) as exemplified in Figure 4-26. The images of products before and after process are shown in Table 4-1 to Table 4-4.

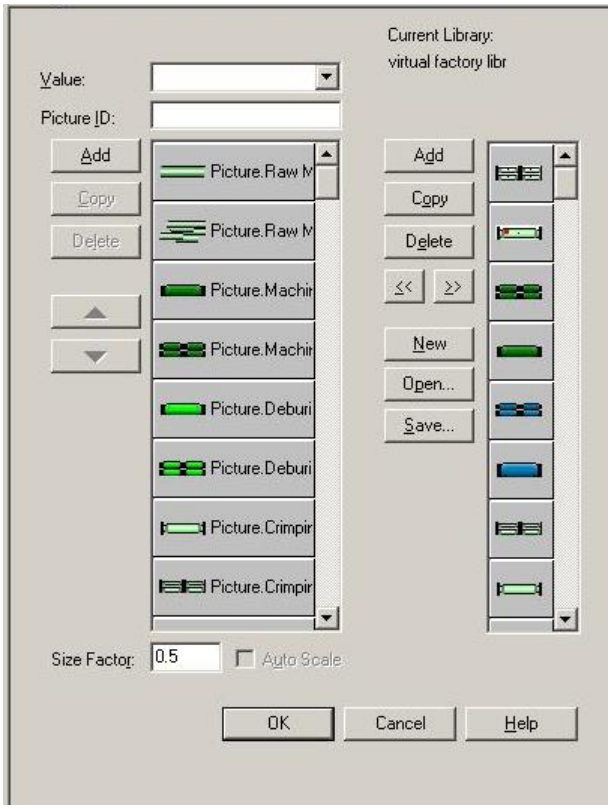
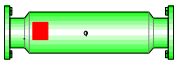
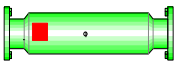
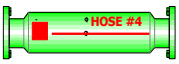


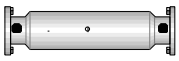
Figure 4-26: Snapshot of CHM library

Table 4-1: Product of S3 (CH4 & CH6 manufacturing line)

Before Process	Workstation	After Process	Before Process	Workstation	After Process
	S3W1			S3W1	
	S3W2			S3W2	
	S3W3			S3W3	
	S3W4			S3W4	
	S3W5			S3W5	

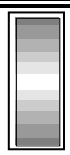
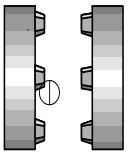
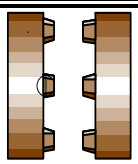
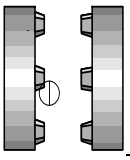
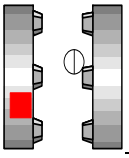
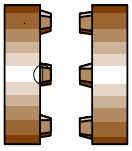
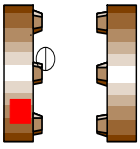
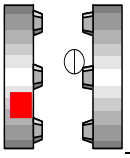
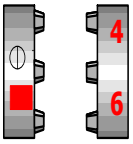
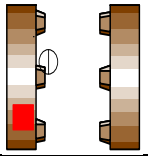
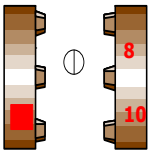
Product CH4 Product CH6

Table 4-2: Product of S4 (CH8 & CH10 manufacturing line)

Before Process	Workstation	After Process	Before Process	Workstation	After Process
	S4W1			S4W1	
	S4W2			S4W2	
	S4W3			S4W3	
	S4W4			S4W4	
	S4W5			S4W5	
	S4W6			S4W6	

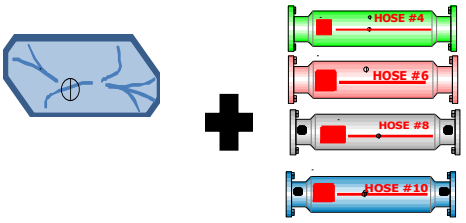
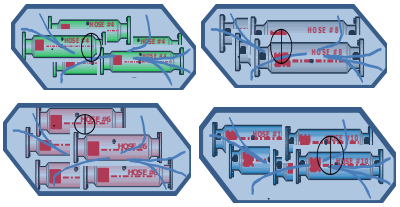
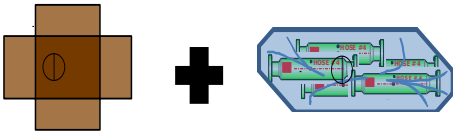
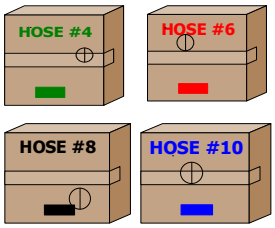
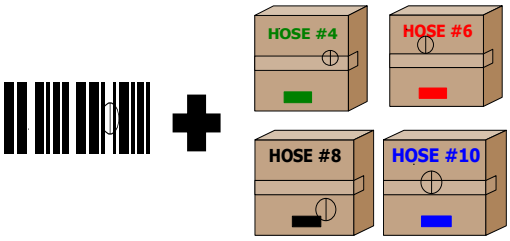
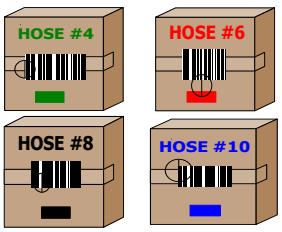
Product CH8 Product CH10

Table 4-3: Product of S2 (Crimping manufacturing line)

Before Process	Workstation	After Process	Before Process	Workstation	After Process
	S2W1			S2W1	
	S2W3			S2W3	
	S2W3			S2W3	

Product crimping CH4 and CH6 Product crimping CH8 and CH10

Table 4-4: Product of S5 (Packaging line)

Before Process	Workstation	After Process
	S5W1	
	S5W2	
	S5W3	

Based on model layouts and model logics of all sections of CHM factory, and using the product images in CHM library, animations of CHM factory simulation model are generated as shown in Figure 4-27 to Figure 4-31. To ensure that the animation of simulation models mimic the real system, verification and validation of the simulation model are executed.

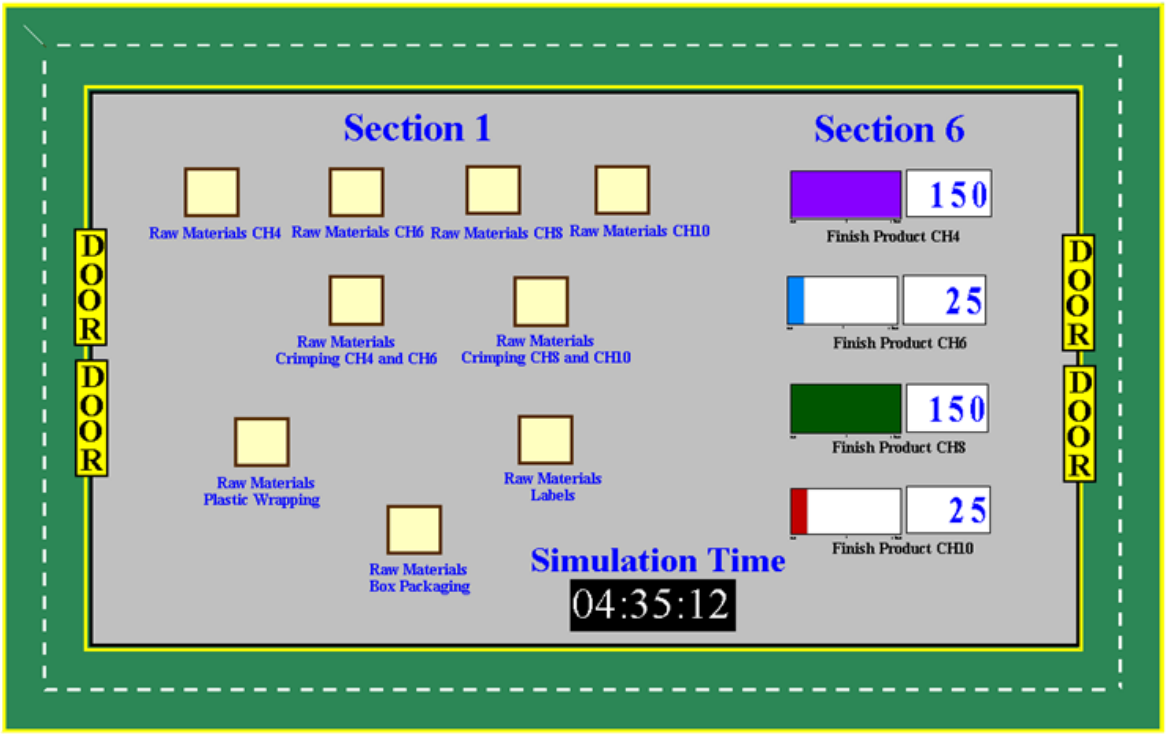


Figure 4-27: Snapshot of animation of S1 and S6

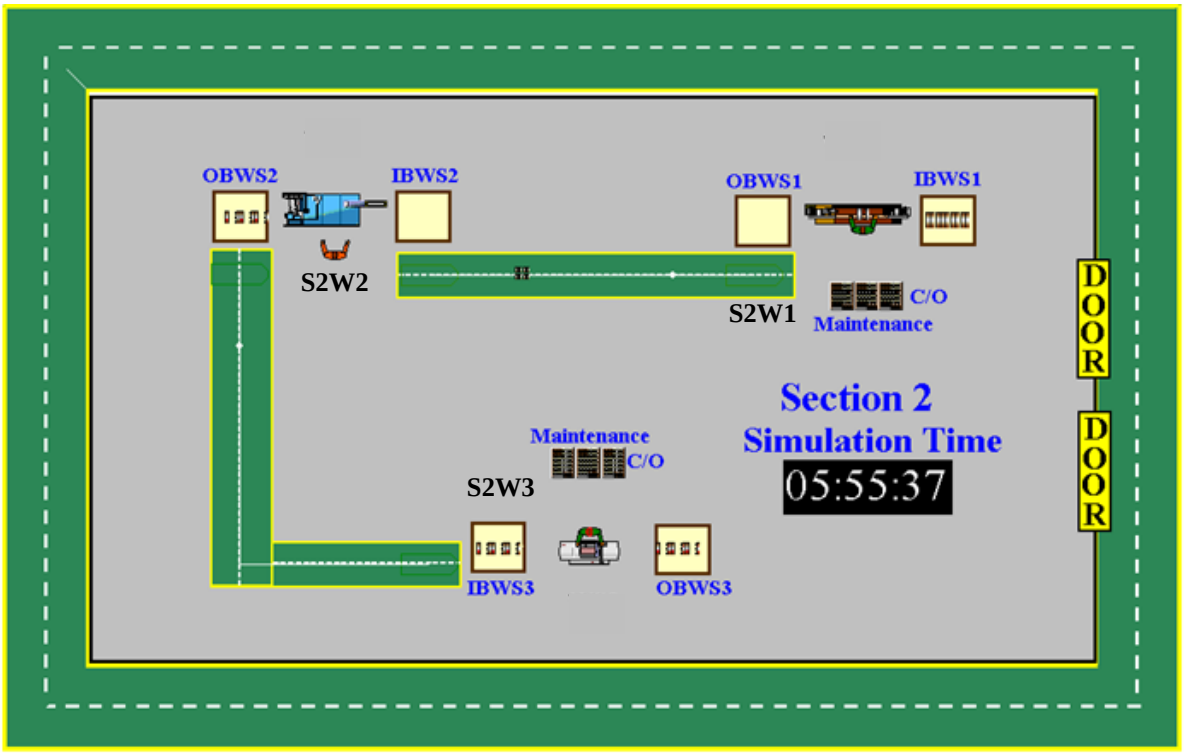


Figure 4-28: Snapshot of animation of S2

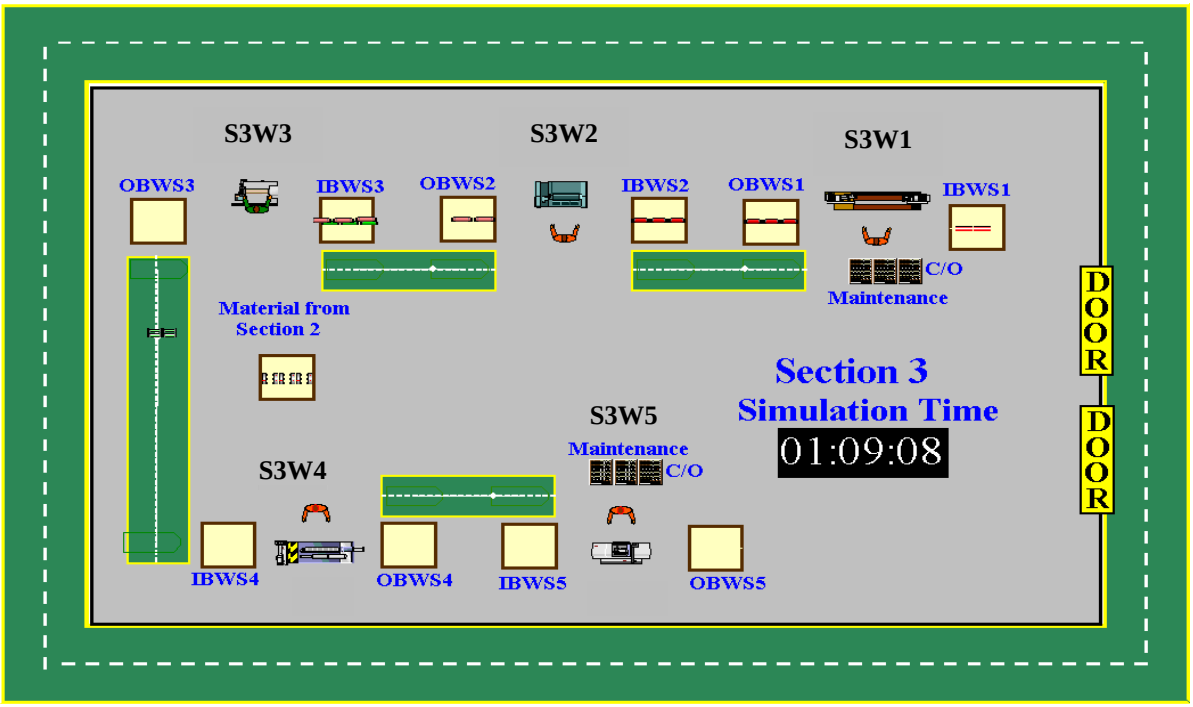


Figure 4-29: Snapshot of animation of S3

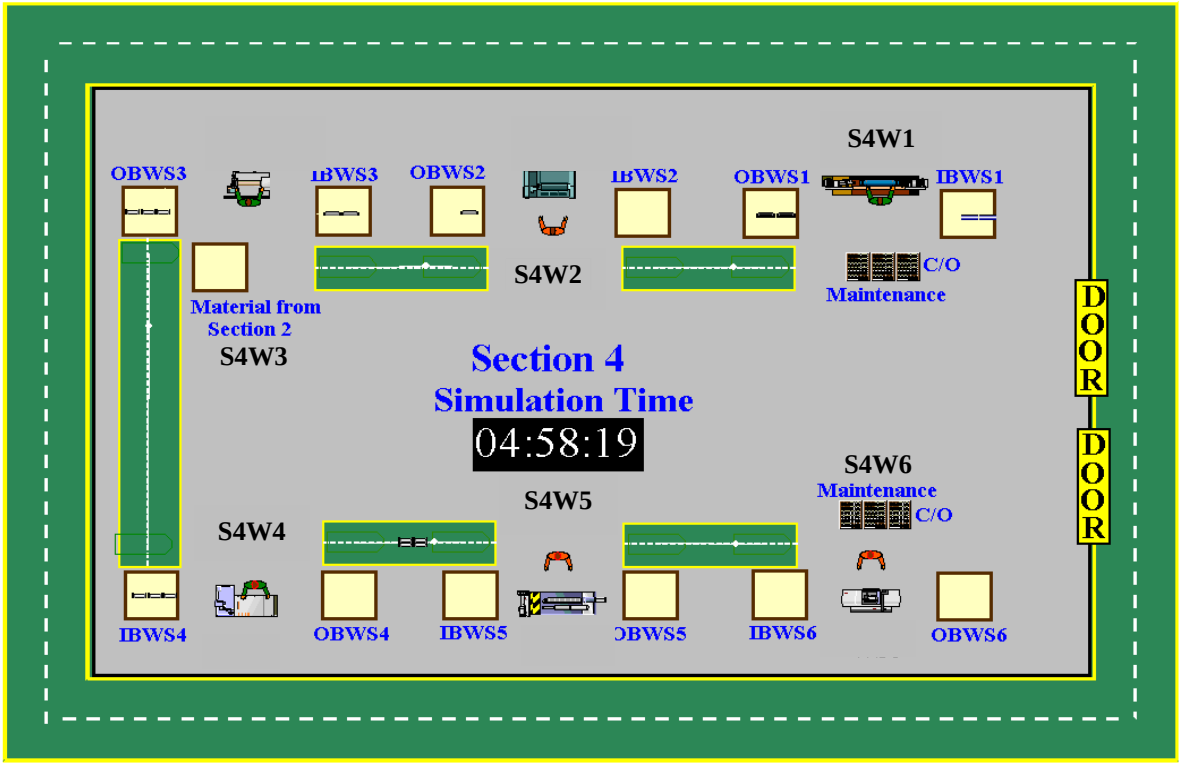


Figure 4-30: Snapshot of animation of S4

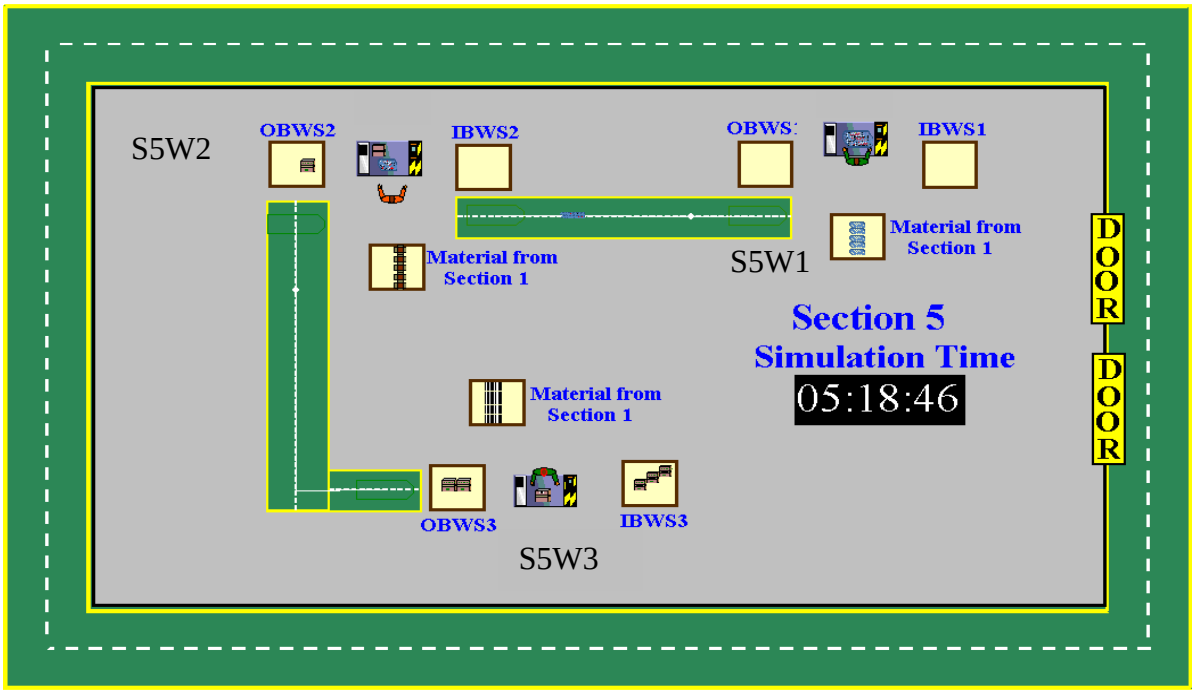


Figure 4-31: Snapshot of animation of S5

4.5 Verification and validation of CHM factory simulation model

Verification of CHM factory simulation model is proved by tracing all the products from the point of their creation (S1: Incoming warehouse) to the point of their disposal from the system (S6: Outgoing warehouse). Validation of the model is conducted by comparing the output of simulation (total production time) with its mathematical calculation results by applying Little's Law equation (Rooda & Vervoort, 2007). Total production time is obtained from WS with the longest $\boldsymbol{\varphi_{tot}}$ (total mean flow time) in the production line.

In this study, $\boldsymbol{\varphi_{tot}}$ is calculated by considering the buffer, batch size, process time and route time for each WS.

$$\varphi_{tot} = \varphi_B + \varphi_{Bq} + \varphi_{Bk} + t_0 + t_{route} \tag{9}$$

Whereby,

$\boldsymbol{t_{route}}$: route time between workstation (in time unit)

$\boldsymbol{t_0}$: process time for workstation (in time unit)

$\boldsymbol{\varphi_B}$: mean flow time for waiting in buffer (in time unit)

$\boldsymbol{\varphi_{Bq}}$: mean flow time for queuing on the inter-arrival of a batch (in time unit)

$\boldsymbol{\varphi_{Bk}}$: mean flow time for wait-to-batch time (in time unit)

The mean flow time for waiting in buffer is calculated using this formula:

$$\boldsymbol{\varphi_B} = \frac{c_a^2 + c_0^2}{2} \cdot \frac{u}{1-u} \cdot t_0 \tag{10}$$

Whereas the formula for queuing time on the inter-arrival time of a batch $\boldsymbol{\varphi_{Bq}}$ is:

$$\boldsymbol{\varphi_{Bq}} = \frac{c_{a,b}^2 + c_0^2}{2} \cdot \frac{u}{1-u} \cdot t_0 \tag{11}$$

For calculation of wait-to-batch time, this formula is used:

$$\boldsymbol{\varphi_{Bk}} = \frac{k-1}{2} \cdot t_a \tag{12}$$

Where, [for equation (10) to (12)]:

$\boldsymbol{\varphi_B}$: The mean waiting time in buffer (in time units)

$\boldsymbol{c_a^2}$: The squared coefficient of variation of inter arrival time

$\boldsymbol{c_0^2}$: The squared coefficient of variation of process time

$\boldsymbol{t_0}$: Process time at WS (in time units/unit product)

$\boldsymbol{k}$: number of units in a batch (in unit product)

$\boldsymbol{u}$: The utilization of workstation

$\boldsymbol{t_a}$: Inter arrival time (in time units)

$\boldsymbol{c_{a,b}^2}$: The squared coefficients of variation of inter arrival time of a batch

Utilization $\boldsymbol{u}$ is calculated using this formula:

$$\boldsymbol{u} = \frac{T_{non\ idle}}{T_{total}} = \frac{t_a}{k.t_0} \tag{13}$$

Whereby:

$\boldsymbol{T_{non\ idle}}$: The time the machine is not idle during a total time frame (in time units)

$\boldsymbol{T_{total}}$: total time frame (in time units)

$\boldsymbol{c_a^2}$ & $\boldsymbol{c_0^2}$ is obtained from calculation of variant of its data divided by its squared time:

$$\boldsymbol{c_0^2} = \frac{s_0^2}{t_0^2} \tag{14}$$

$$\boldsymbol{c_a^2} = \frac{s_a^2}{t_a^2} \tag{15}$$

Whereby

$\boldsymbol{s_0^2}$ & $\boldsymbol{s_a^2}$ originates from variant equation:

$$\boldsymbol{s_a^2} = \boldsymbol{s_0^2} = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2 \tag{16}$$

However in this study, triangular distribution is applied for the entire simulation model. Therefore, the variant equation is as below:

$$\boldsymbol{s_a^2} = \frac{1}{18}(a^2 + b^2 + c^2 - ab - ac - bc) \tag{17}$$

$$\boldsymbol{t_0} = \frac{1}{3}(a+b+c) \tag{18}$$

Whereby:

a : minimum value of time range (in time units)

b : mode of time range (in time units)

c : maximum value of time range (in time units)

For the squared coefficients of variation of inter arrival time of a batch $\boldsymbol{c^2_{a,b}}$:

$$\boldsymbol{c^2_{a,b}} = \frac{s_a^2}{t_a^2} = \frac{k.s_a^2}{(k.t_a)^2} = \frac{1.s_a^2}{k.t_a^2} = \frac{c_a^2}{k} \tag{19}$$

To distinguish between the notations of coefficient of variation for buffer process to that of batch process, we consider $\boldsymbol{c^2_a} = \boldsymbol{c^2_{a,\,l}}$. For coefficient of variation of the batch leaving the machine and entering the next machine for a batch,$\boldsymbol{c^2_d}$, (for the next workstation, $\boldsymbol{c^2_d}$ is also a coefficient of variation for inter arrival $\boldsymbol{c^2_{a,\,l}}$):

$$\boldsymbol{c^2_d} = u^2.c_0^2 + (1-u^2).c_a^2 \tag{20}$$

To calculate total production time, this formula is used:

$$\textit{Total production time} = \boldsymbol{\varphi_{tot}} \;.\; \textit{Total demand /no of batch} \tag{21}$$

The total production time with this formula is compared with total production time acquired using simulation. As can be seen in Table 4-5, the similarity of both results is above 93% and within the range of 95% confidence interval level. Therefore the CHM factory simulation model was validated.

Table 4-5: Total production time for CHM factory simulation model

Section	Total production time by simulation (minute)	Total production time by mathematical calculation (minute)	Confidence interval range 95%	Status
2	430.86	380.02	368.12-493.59	Valid
3	820.37	853.60	692.43-948.31	Valid
4	780.70	853.60	633.18-928.22	Valid
5	147.56	148.53	107.82-187.30	Valid

4.6 Feasibility study of SDSS

A lean practitioner with experience in the traditional method of implementing LM tools is chosen. For the purpose of this feasibility study the lean practitioner selects S4 of CHM factory simulation model. By using zoom in/zoom out function and task status function (Figure 4-32 and Figure 4-33) of SDSS, the lean practitioner observed bottleneck in S4W1 and prolonged idle status of operators in WS4, WS5 and WS6.

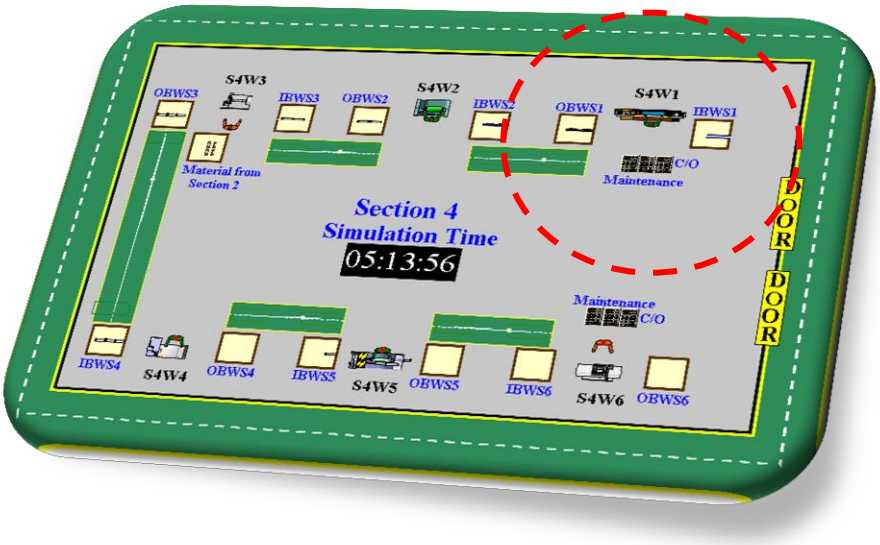


Figure 4- 32. Zoom-in/zoom-out function of S4

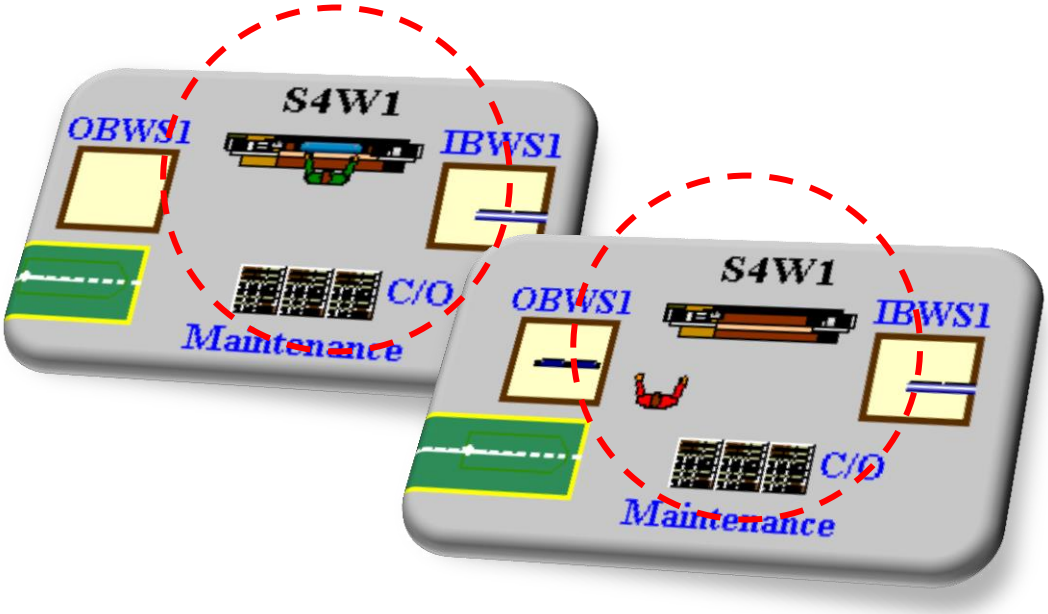


Figure 4- 33. Task status function of S4

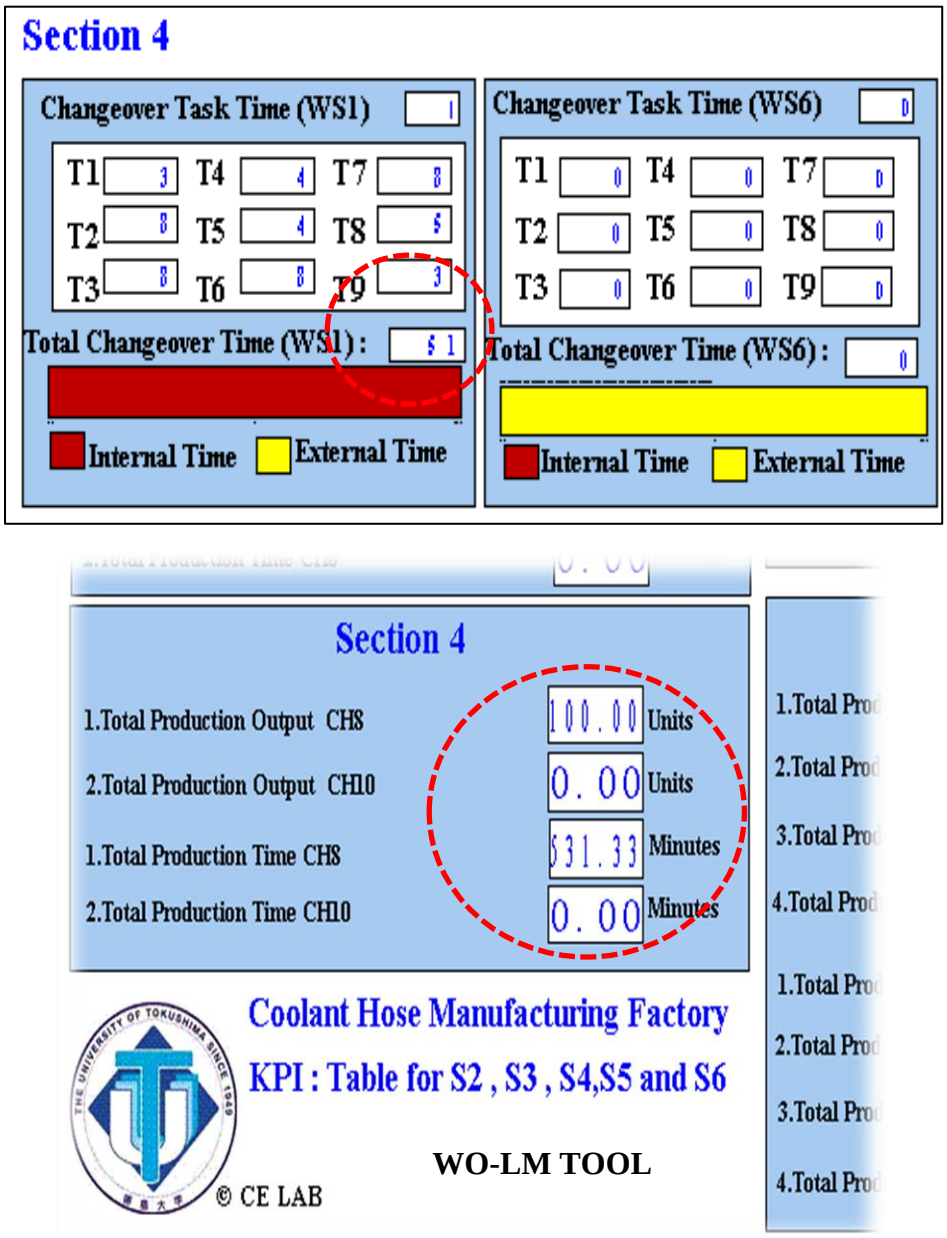


Figure 4-34. Snapshot of KPI status function for S4

The reason for this bottleneck situation is acquired from the KPI status function which showed high changeover time (51 minutes) (Figure 4-34). The high CO time causes a low total production output (100 units/day) and high total production time (531.33minutes).

To react to these problems, the lean practitioner conducted what-if analysis as follows:

a) What-if SMED is implemented at S4?

Table 4-6 shows the values of changeover task time which is incorporated into the simulation model to observe the improvement by SMED implementation. Figure 4-35 shows snapshot of S4 with SMED implementation. Following SMED implementation, the lean practitioner observes an increment of 9% in the total production output and decrement of 4% in the total production time from the KPI table of S4 (Figure 4-36).

Table 4-6: SMED implementation at S4 for WS1 and WS6

Changeover (CO) Tasks Time	**WS1**		**WS6**	
	Before SMED	After SMED	Before SMED	After SMED
a. Task 1 (Minutes)	3	1	2	1
b. Task 2 (Minutes)	8	1.5	2	1.5
c. Task 3 (Minutes)	8	1.5	5	1.5
d. Task 4 (Minutes)	4	0	2	0
e. Task 5 (Minutes)	4	0	2	0
f. Task 6 (Minutes)	8	1.5	5	1.5
g. Task 7 (Minutes)	8	1.5	2	1.5
h. Task 8 (Minutes)	5	1	2	1
i. Task 9 (Minutes)	3	1	2	1
Total CO Task Time (Minutes)	51	9	24	9

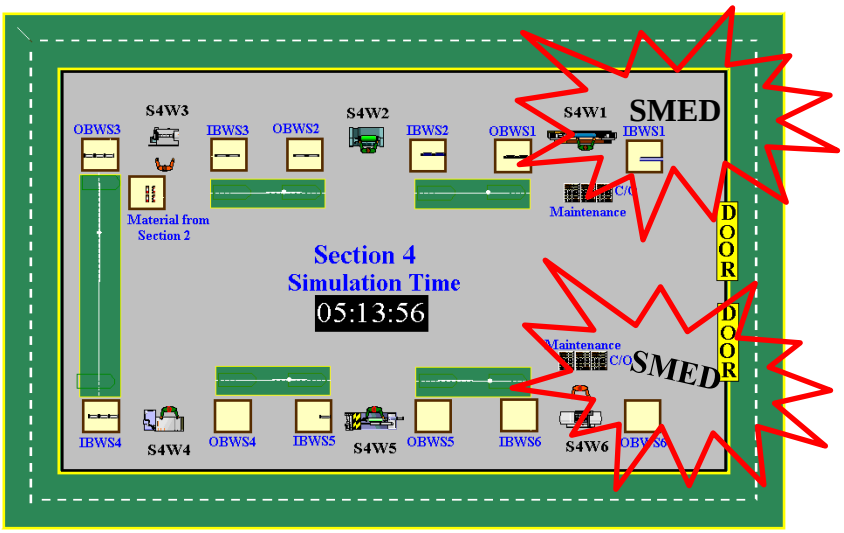


Figure 4-35. Snapshot of S4 with SMED implementation

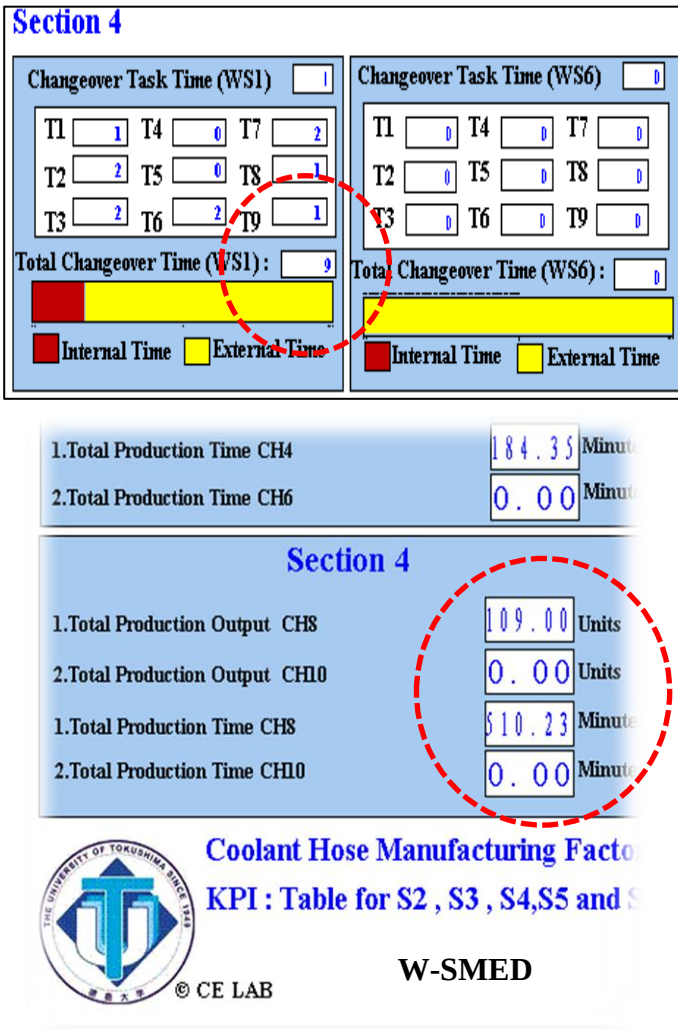


Figure 4-36. Snapshot of KPI table for S4 (With-SMED)

b) What-if Cellular Manufacturing (CM) is implemented at S4?

By observing the task status function continuously during simulation runs, another problem detected in S4 is prolonged idle status of operators in WS4, WS5 and WS6. By implementing CM, the total production output is increased by 5% while the total production time is reduced by 1.74% as seen in Figure 4-37 and Figure 4-38. Despite the minor improvements, the number of operator has been reduced by 33.33% (from six to four people).

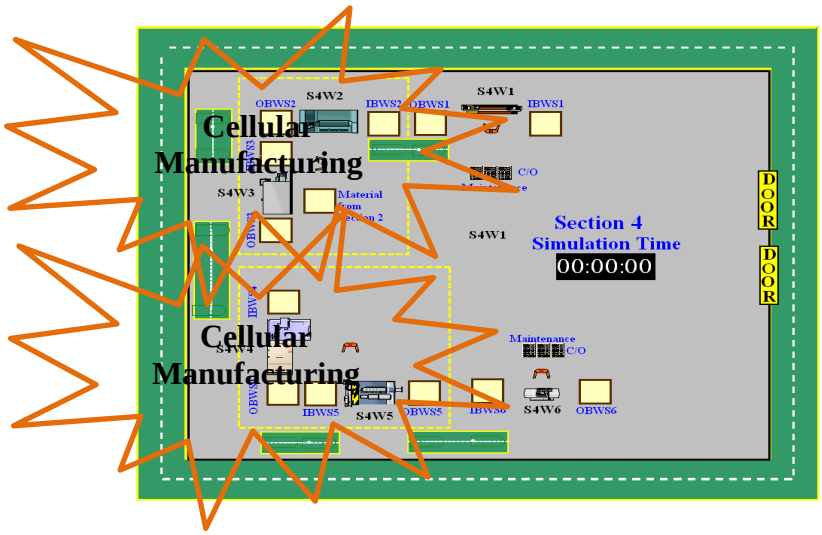


Figure 4-37. S4 with Cellular Manufacturing implementation

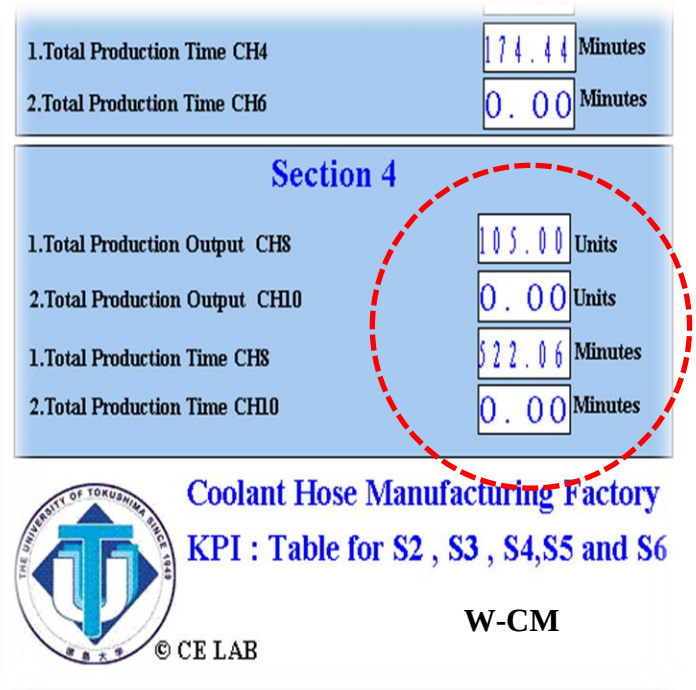


Figure 4-38. Snapshot of KPI table for S4 (Cellular Manufacturing)

c) What-if SMED is implemented together with CM at S4?

By implementing SMED and CM concurrently (Figure 4-39), the total production output is increased by 10% while total production time is reduced by 5.06 %(Figure 4-40). The number of operator is also reduced by 33.33% (from six to four people).

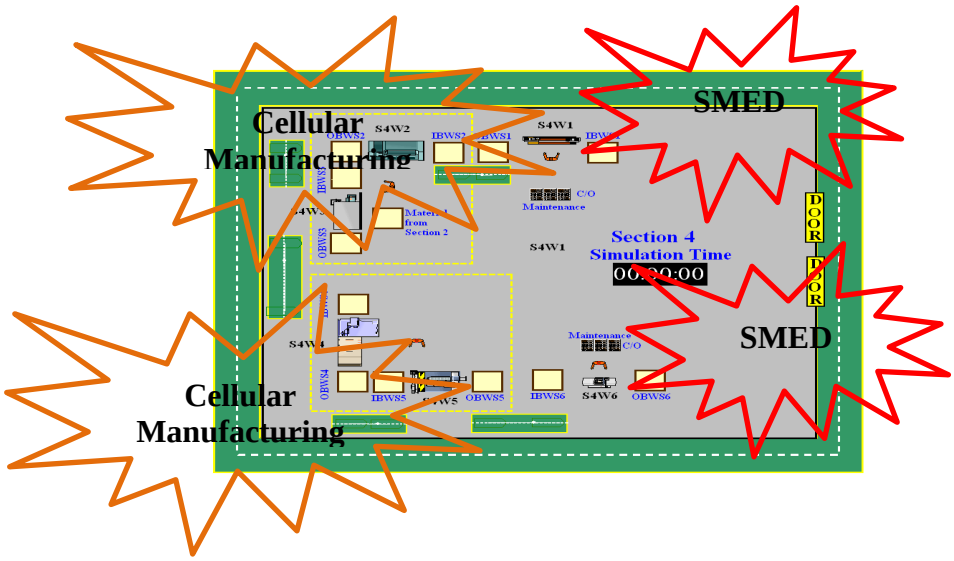


Figure 4-39. S4 with SMED and Cellular Manufacturing implementation

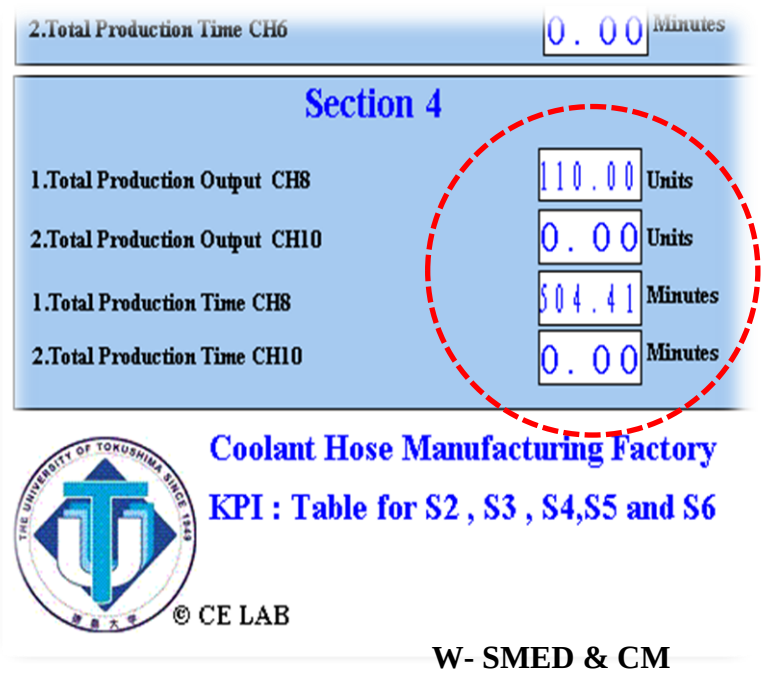


Figure 4-40. Snapshot of KPI table for S4 (SMED and Cellular Manufacturing)

By utilising the specific functions of SDSS and comparing the difference in results before and after LM tool implementation, the effectiveness of LM tool implementation (in this case, SMED and CM) is quantified by the lean practitioner. This feasibility study showed that SDSS is a suitable decision support system for lean practitioners because it increases the literacy in simulation among lean practitioners by providing a structured approach of using

simulation software tool. Moreover, the idea of user understanding support, which was implemented in the model as several functions, also assists users in visualising the production processes and simulation outputs.

4.7 Conclusion

The proposal of SDSS in this study is motivated by the need to address the gap between lean practitioners and simulation-based approaches, in terms of expertise in utilising simulation software tools and to develop a system capable of supporting operational (real time) decision making in LM implementation.

By deploying a process simulation model and providing four functions, namely layout, zoom-in/zoom-out, task status and Key Performance Indicators (KPI) status, SDSS enables lean practitioners to assess current and future state of manufacturing process, perform what-if analysis and measure impact of improvement after LM tool implementation. Therefore, lean practitioners could choose a suitable LM tool to implement at the right time and on the right place.

This study reveals the extent of benefits accrued by the proposed decision support system. SDSS is able to address the complex interdependent input parameters in manufacturing line and provides lean practitioners with time to react to emerging problems, evaluate potential solutions and decide on LM implementation. SDSS could also be used not only to improve lean system but also to support decision-making in replacing an existing manufacturing process with a lean system.

The future scopes of this study include extending the scope of SDSS to cover strategic decision making in LM implementation, validating the results acquired in this study over a range of case study application and considering the role of intelligent agent to provide decision support functionality to lean practitioners and management teams in pursuing LM implementation. The agent would act as an expert assistant to the user in using LM tool software. The design and development of an agent-based system will be presented in the next chapter.

Chapter V

Quantifying waste in manufacturing simulation by intelligent agent-based approach

5.1 Introduction

One of the biggest obstacles in successful LM implementation is lack of expertise in selecting appropriate LM tool for each specific situation. Another reason is lack of extensive knowledge and experience required to implement LM tools (Achanga et al., 1998).

Furthermore, LM tools are basically applied in a deterministic way based on analysis of a static model, which is not always applicable to the dynamic real production system (Sevillano, 2011). Difficulty in quantifying benefits expected by LM implementation is another problem that makes it hard to convince management team to apply LM tools (Abdulmalek & Rajgobal, 2007; Detty & Yingling, 2000). Because of these reasons, implementation of LM does not always succeed.

Simulation-based approaches are proposed to solve these implementation issues in LM and their effectiveness has been reported. Nevertheless, simulation study in lean projects is usually managed by simulation engineers who know how to design the simulation model from scratch, build or analyse the simulation model, and integrate it to LM software (Janca & Gilbert, 1998). In fact, real-time updating of simulation model is mostly performed by simulation engineers (Gourdeau, 1997). These approaches are not suitable for other domain experts in the lean project (process engineer, mechanical engineer, quality engineer, production engineer, materials engineer, marketing executive, and finance executive) who are familiar with neither simulation software nor LM tool software (Figure 5-1). Misunderstanding between simulation engineers and other domain experts may lead to development of a biased simulation model (West et al., 2000). Therefore, some appropriate niche techniques to bridge the gap between domain experts (less-computer-literate users) and simulation-based approaches are expected to support LM implementation.

In this chapter, an intelligent agent called Muda Indicator (MI) is proposed as a solution to the above mentioned gap issue. MI agent acts as an expert assistant to lean practitioners in using LM tool software. MI agent also supports the decision making made by the lean practitioners by quantifying waste in manufacturing simulation. Quantifying waste is chosen as the expertise of the agent because it is the most important aspect to be considered in decision-making process (Tuček & Dlabač, 2012a).

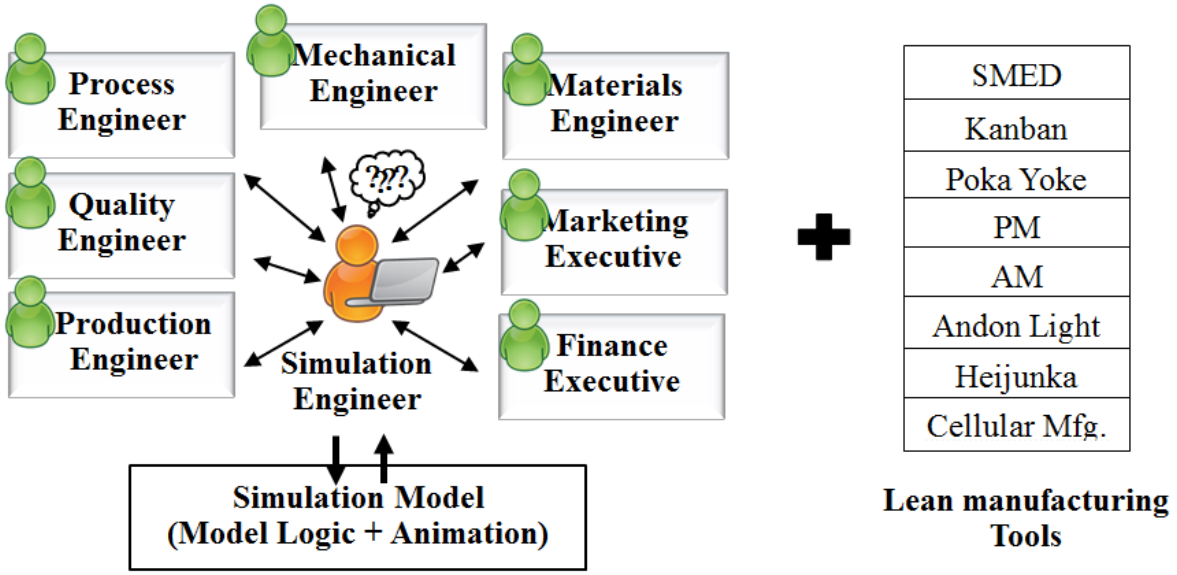


Figure 5-1: Traditional simulation approach in LM implementation

5.2 Muda Indicator (MI) agent

The expertise of MI agent developed in this study is to quantify waste (waiting, overproduction, over-processing, high inventory, defects, motion, and transportation) in a simulated production line (Figure 5-2). Unlike other closed self-contained agent-enabled application, MI agent is designed to be an independent agent. In other words, MI agent could be incorporated freely in the simulation model of manufacturing production line. Prior to that, users have to set a rule for MI in terms of type of waste to be detected and quantified. The rules could have inferred conditions. Once incorporated, MI agent will learn about the rules and adapt its action accordingly. In this study, MI agent continuously monitors the status of

Muda during simulation runs and provides Muda level indication by means of R.A.G (Red, Amber, Green) status.

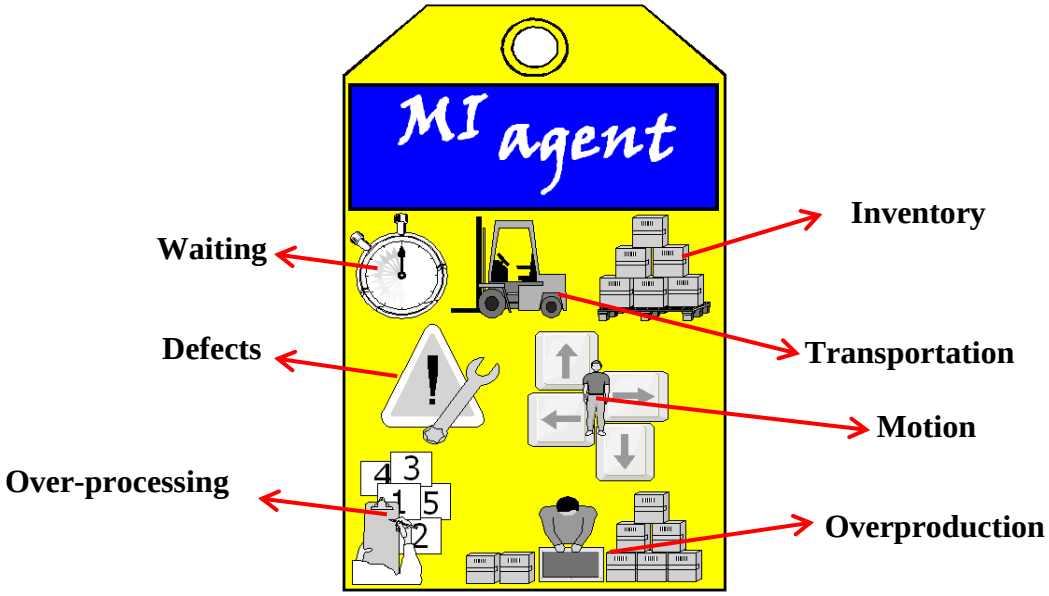


Figure 5-2: Muda Indicator (MI) agent

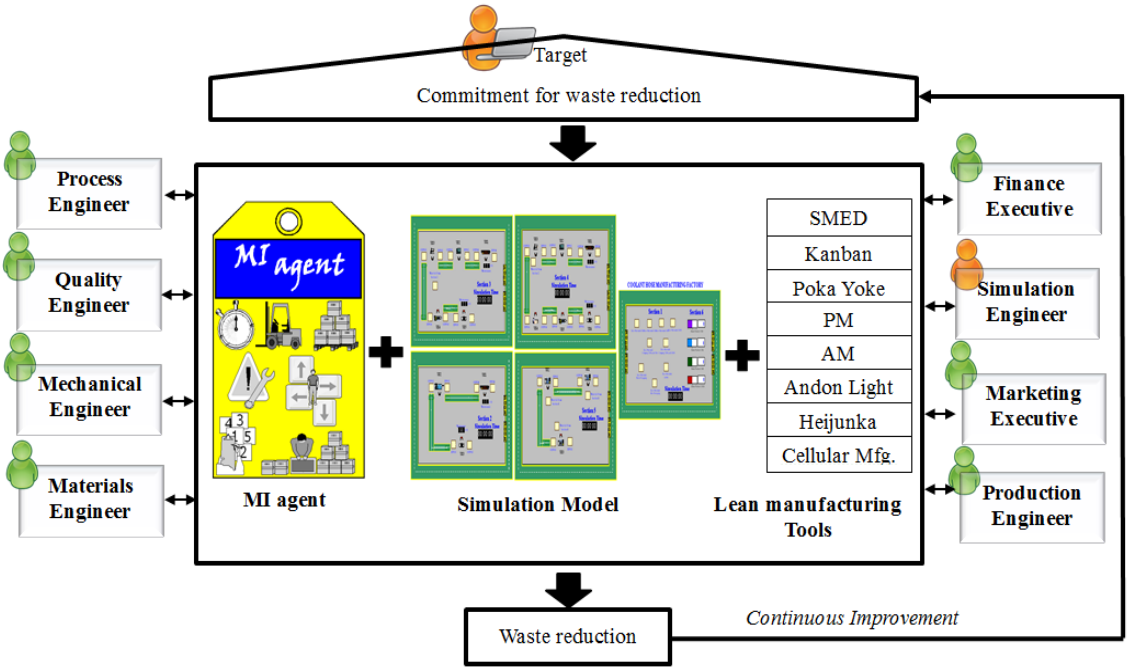


Figure 5-3: Intelligent agent-based approach in LM implementation

This agent-based approach is expected to increase domain experts' understanding on simulation results and enhance communication between domain experts and simulation engineers. With MI agent, simulation model provides quantitative information regarding Muda level, which is readily interpreted. Therefore, the lean team could make timely decisions on manufacturing process requirement (waste elimination) or the need for remedial actions (implementing the correct LM tool) (Figure 5-3). With this approach, developmental effort could be reduced while at the same time increase production efficiency.

5.2.1 Definition of Muda level in simulation model

This section provides the definition of Muda (waiting, overproduction, over-processing, high inventory, defects, motion, and transportation) in this study. Waiting is defined as operator waiting for the next production step or idle status of operator due to starvation of parts or materials and high changeover task time in workstation. Modelling resources of idle operator evolve as a result of variability in interconnected processes. As mentioned before, MI agent continuously monitors the status of Muda during simulation runs and provides Muda with level indication by means of R.A.G status. What each R.A.G status indicates for "waiting" Muda is shown in Table 5-1.

Table 5-1: Definition of Muda level in "Waiting"

Muda level with "R.A.G status" indicator	Definition of Muda level in "Waiting"
 **Red**	Red status indicates that Muda (prolonged idle status of operator) is beyond the acceptable limits.
 **Amber**	Amber status indicates that Muda (prolonged idle status of operator) exists but is still within acceptable limits and warrants attention.
 **Green**	Green status indicates that Muda (prolonged idle status of operator) is not present.

Overproduction in this study is defined as production output ahead of demand. By monitoring the variability and balance between demand and production output, MI agent indicates the Muda level by means of R.A.G status as exemplified in Table 5-2.

Table 5-2: Definition of Muda level in "Overproduction"

Muda level with "R.A.G status" indicator	Definition of Muda level in " Overproduction "
 **Red**	Red status indicates that Muda (total production output ahead of demand) is beyond the acceptable limits.
 **Amber**	Amber status indicates that Muda (production output ahead of demand) exists but is still within acceptable limits and warrants attention.
 **Green**	Green status indicates that Muda (production output ahead of demand) is not present.

The definition of over-processing in this study is non-value added task, for example changeover procedures resulting from poor tool or product design. By monitoring the process flow and measuring utilisation of resources and process, MI agent indicates the Muda level in over-processing by means of R.A.G status as shown in Table 5-3.

Table 5-3: Definition of Muda level in “Over-processing”

Muda level with “R.A.G status” indicator	Definition of Muda level in “Over-processing”
 **Red**	Red status indicates that Muda (non-value added task/ changeover procedure) is beyond the acceptable limits.
 **Amber**	Amber status indicates that Muda (non-value added task/ changeover procedure) exists but is still within acceptable limits and warrants attention.
 **Green**	Green status indicates that Muda (non-value added task/ changeover procedure) is not present.

Table 5-4: Definition of Muda level in “High Inventory”

Muda level with “R.A.G status” indicator	Definition of Muda level in “High Inventory”
 **Red**	Red status indicates that Muda high (high number of queues in buffer) beyond the acceptable limits.
 **Amber**	Amber status indicates that Muda (high number of queues in buffer) but is still within acceptable limits and warrants attention.
 **Green**	Green status indicates that Muda (high number of queues in buffer) is not present.

High inventory in this study refers to all components, work in progress, and products that are not processed in each workstation or high number of queues in buffer. MI agent monitors the queues in buffer in each workstation and indicates Muda level by means of R.A.G status as shown in Table 5-4.

In this study, defects are defined as rework due to producing defective product as a result of poor preventive quality system. By recognising product failure or machine failure, MI agent monitors rework or defects incidence in the process flow (Table 5-5).

Table 5-5: Definition of Muda level in "Defects"

Muda level with "R.A.G status" indicator	Definition of Muda level in "Defects"
 **Red**	Red status indicates that Muda (rework or defects incidence) is beyond the acceptable limits.
 **Amber**	Amber status indicates that Muda (rework or defects incidence) exists but is still within acceptable limits and warrants attention.
 **Green**	Green status indicates that Muda (rework or defects incidence) is not present.

Motion is defined as unnecessary movement of people or equipment to perform a process. MI agent monitors the interconnection between people, equipment, and process and indicates the Muda level by R.A.G status as shown in Table 5-6.

Table 5-6: Definition of Muda level in “Motion”

Muda level with “R.A.G status” indicator	Definition of Muda level in “Motion”
 **Red**	Red status indicates that Muda (unnecessary movement of people or equipment) is beyond the acceptable limits.
 **Amber**	Amber status indicates that Muda (unnecessary movement of people or equipment) exists but is still within acceptable limits and warrants attention.
 **Green**	Green status indicates that Muda (unnecessary movement of people or equipment) is not present.

Transportation in this study refers to unnecessary product or transportation movement to perform a process. MI agent monitors the process flow and transportation time depending on velocity and distance. Then, it provides Muda level by means of R.A.G status as depicted in Table 5-7.

Table 5-7: Definition of Muda level in “Transportation”

Muda level with “R.A.G status” indicator	Definition of Muda level in “Transportation”
 **Red**	Red status indicates that Muda (unneeded product or transportation movement) is beyond the acceptable limits.
 **Amber**	Amber status indicates that Muda (unneeded product or transportation movement) exists but is still within acceptable limits and warrants attention.
 **Green**	Green status indicates that Muda (unneeded product or transportation movement) is not present.

5.3 MI agent: How it works

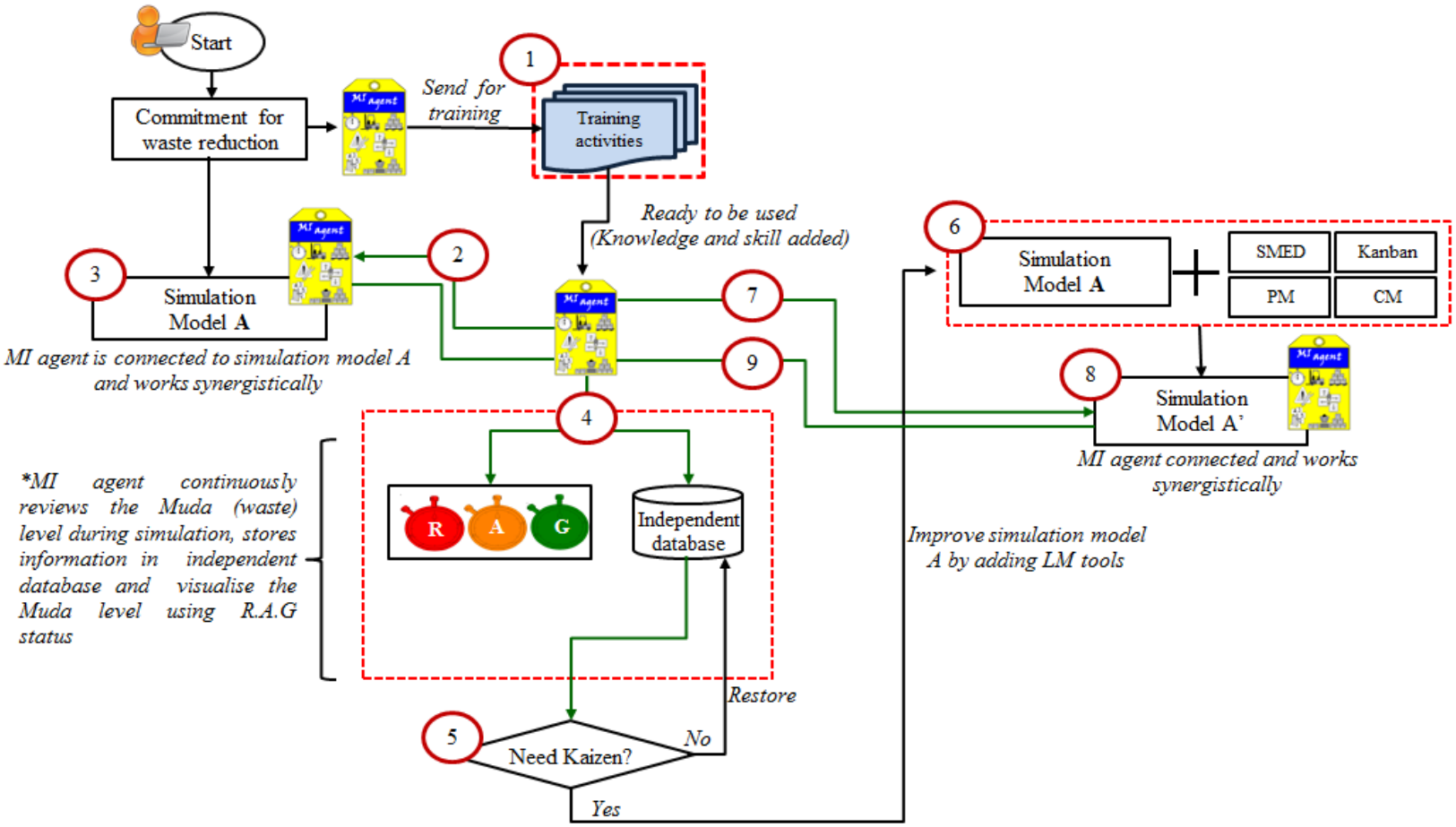


Figure 5-4: MI architecture

This section presents the architecture of MI agent (Figure 5-4), which depicts how an MI agent works. The architecture is explained following the steps below:

i. Step 1 : Before an MI agent can be used to quantify waste in a simulated production line, it has been sent for training. The details on training activities and procedures will be further elaborated in the next section. After the training, MI agent with added knowledge and skills is ready to be used.

ii. Step 2 : MI agent is sent to simulation model.

iii. Step 3 : MI agent is connected to simulation model A to work synergistically with simulation model A to quantify waste.

iv. Step 4 : MI agent continuously reviews the Muda (waste) level during simulation, stores information in independent database, and visualises the Muda level using R.A.G status.

v. Step 5 : User determines the need for kaizen based on quantified waste. If kaizen is not required, the data will be kept in independent database for future reference.

vi. Step 6 : If kaizen is required, LM tool is added to simulation model A to address the Muda problem.

vii. Step 7 : After improvement of simulation model A by LM tool, MI agent is sent to simulation model A'.

viii. Step 8 : MI agent is connected again to simulation model A' and works synergistically to quantify waste.

ix. Step 9 : MI agent continuously reviews the Muda (waste) level simulation model A', stores information in independent database, and visualises the Muda level using R.A.G status. This process is followed by kaizen assessment and repetition of the cycle until the desired results are achieved.

5.3.1 MI agent training activities procedure

This section presents the details on MI agent training activities and procedures. As shown in Figure 5-5, four steps are involved in the training procedure of MI agent (Step a until Step d). Detailed explanations of each step are as follows:

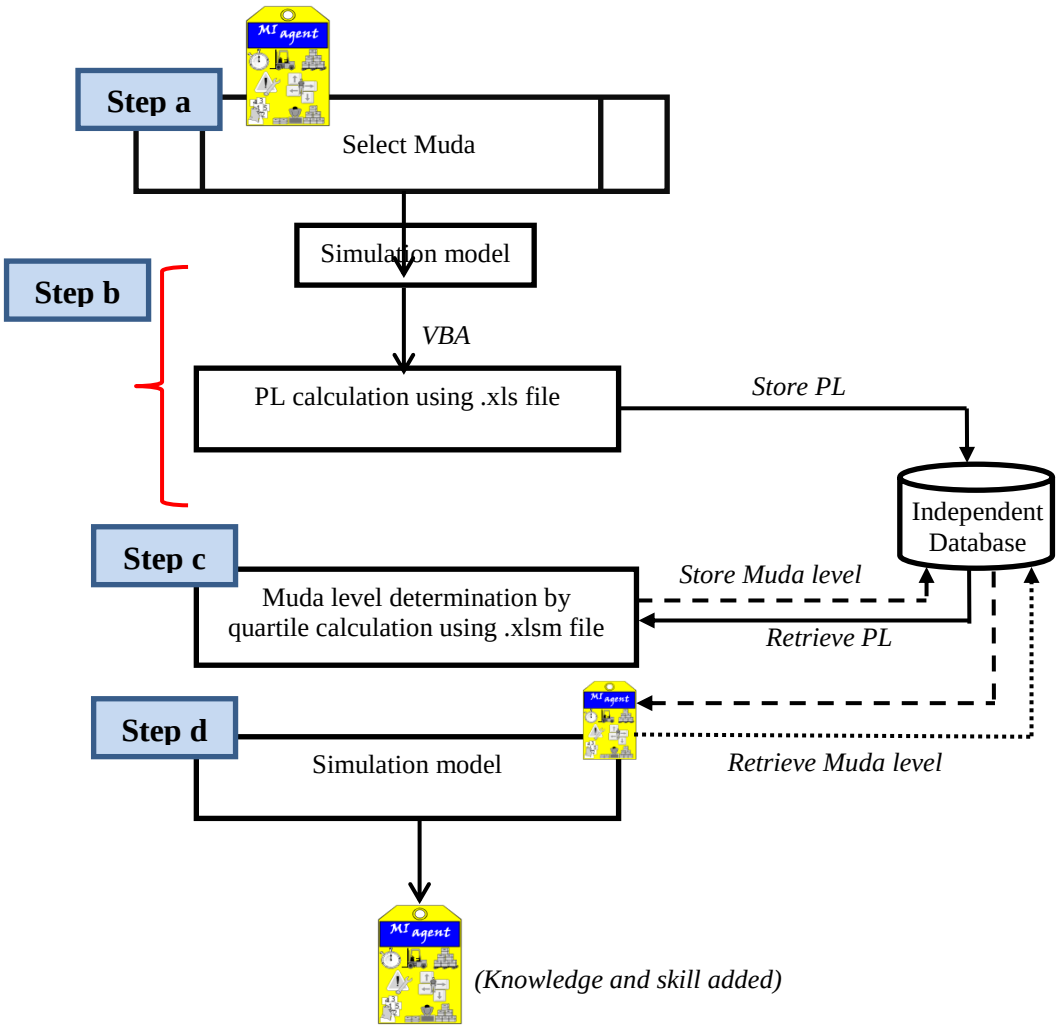


Figure 5-5: MI agent training procedure

A. Step a: Select a type of Muda to be monitored by MI agent in the simulation model. In this study, waiting Muda is selected. Waiting muda is used as an example in this study because waiting is the easiest waste to be noticed in a production line (Japan Management Association, 1986). Rule is set for MI agent to monitor the idle status of operator in the production line.

B. Step b: After setting the rule for MI agent, the next step for MI agent training is as depicted in Figure 5-6.

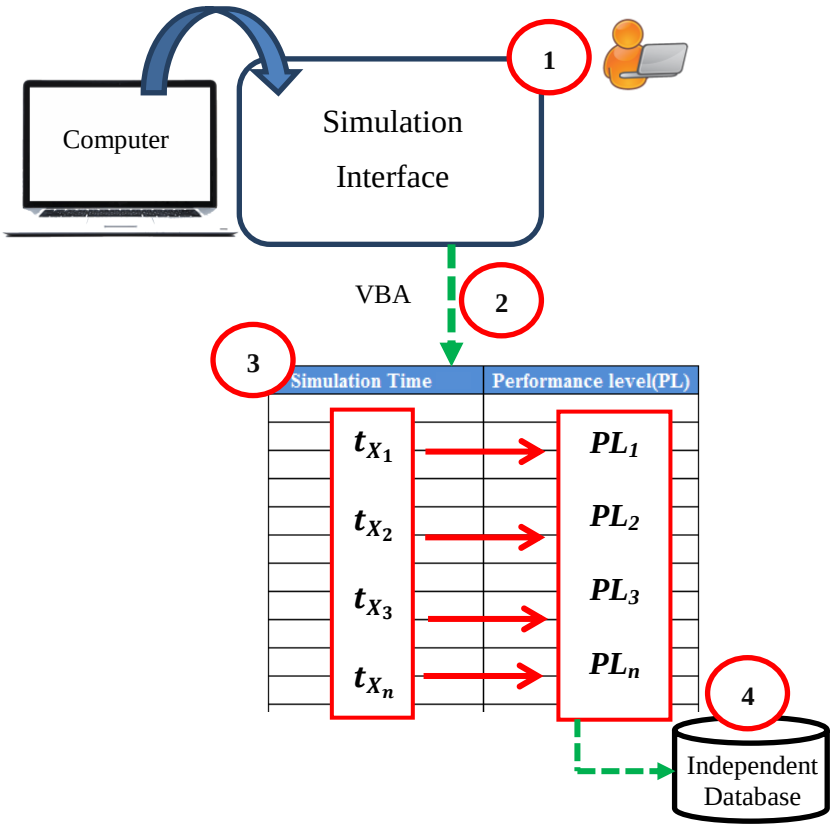


Figure 5-6: Flow of Step b of MI agent training

x. Step 1 : The simulation model is run to collect observation data.

xi. Step 2 : These observation data are automatically uploaded through Visual Basic Application (VBA) into *PL calculation for training MI agent.xls*

xii. Step 3 : The performance level (***PL***) is calculated automatically using the formula below :

$$\boldsymbol{PL} = \left({}^{X_n}/_{t_{X_n}}\right) \tag{22}$$

where,

$\boldsymbol{X_n}$ = *Output data of simulation* $(X_1, X_2, X_3, X_4, X_5, \ldots X_n)$ *minutes*

$\boldsymbol{t_{X_n}}$ = *Simulation time* $(t_{X_1}, t_{X_2} t_{X_3} t_{X_4} t_{X_5} \ldots t_{X_n})$ *minutes*

To calculate the Performance Level (PL), the collection output data of simulation are based on a series of simulation while each of simulation times will run for R replications.

$$\boldsymbol{PL} = \left(\overline{(X_n)} \Big/ t_{X_n} \right) \tag{23}$$

where,

$*$ $\overline{(\boldsymbol{X_n})}$ = *Output data of simulation on each replication (minutes)*

$\boldsymbol{t_{X_n}}$ = *Simulation time* $(t_{X_1}, t_{X_2} t_{X_3} t_{X_4} t_{X_5} \ldots t_{X_n})$ *minutes*

Average of output data of simulation ($\overline{\boldsymbol{X_n}}$):

= *Total no. of output data of simulation on each replication/Number of replications*

$$(\overline{\boldsymbol{X_n}}) = (X_{1a}, X_{1b}, X_{1c}, X_{1d}, X_{1e}, X_{1f}, X_{1g}, X_{1h}, X_{1i}, X_{1j})/R_n \tag{24}$$

R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_n
X_{1a}	X_{1b}	X_{1c}	X_{1d}	X_{1e}	X_{1f}	X_{1g}	X_{1h}	X_{1i}	X_{1j}

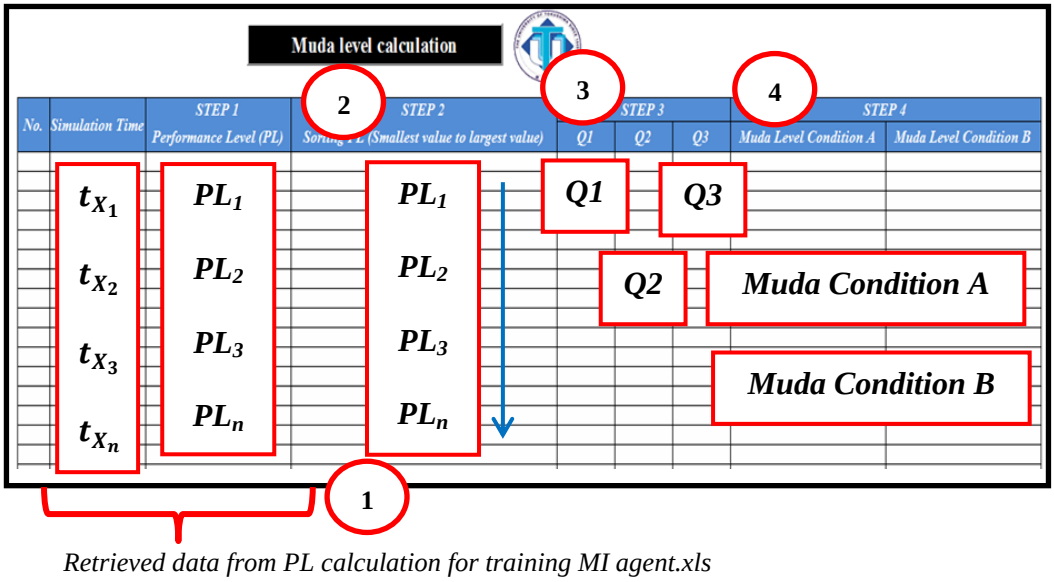
where,

$\boldsymbol{R_n}$ = *Number of Replications (unit)*

$\boldsymbol{X_n}$ = *Output data of simulation on each replication (minutes)*

xiii. Step 4 : The *PL calculation for training MI agent.xls* file is then stored in an independent data base. The *PL calculation for training MI agent.xls* file consists of table of simulation time ($\boldsymbol{t_{X_n}}$) and performance level (***PL***).

C. Step c: After going through performance level (***PL***) calculation, MI agent is trained to determine Muda level, which is the status of waste in a manufacturing line. Firstly, the *Muda level calculation for training MI agent.xlsm* file is opened (Figure 5-7). Next, the training procedures are as follows :



Retrieved data from PL calculation for training MI agent.xls

Figure 5-7: *Muda level calculation for training MI agent.xlsm* file

i. Step 1 : The file is run and data on performance level (***PL***) and simulation time (t_{X_n}) will be automatically retrieved from the independent data base (from Step b) through VBA.

ii. Step 2 : Next, the distribution pattern of performance level (***PL***) is assessed. This is done by automatic sorting of performance level (***PL***) values in ascending order of magnitude and this proceeds with quartile calculation automatically.

iii. Step 3 : Quartile calculation is done to attain Q1, Q2, and Q3. Method for Quartile calculation as follows :

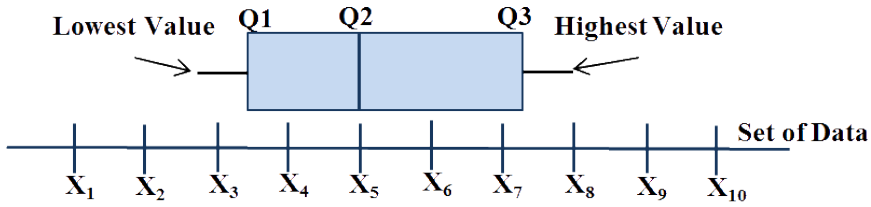


Figure 5-8 Quartile range

A set of data from each WS is arranged in ascending order of magnitude ($X_1, X_2, X_3, X_4, X_5, \ldots X_n$) (Figure 5-8). Then, the median is obtained by picking out the middle value of the data (Chatfield, 1983). This is followed by quartile calculation for even and odd sample size (*n*), respectively. The method of quartile calculation is mentioned below:

a. For even sample size (*n*),

Q2 (Second quartile) $= [x_{(n/2)} + x_{\left(\frac{n}{2}+1\right)}]/2$ (25)

Q1 (First quartile) $=$ *median of* $x_{(1),\ldots\ldots,}x_{(n/2)}$ (26)

Q3 (Third quartile) $=$ *median of* $x_{\left(\frac{n}{2}+1\right),\ldots\ldots,}x_{(n)}$ (27)

b. For odd sample size (*n*),

Q2 (Second quartile) $= x_{((n+1)/2))}$ (28)

Q1 (First quartile) $=$ *median of* $x_{(1),\ldots\ldots,}x_{\left(\frac{(n+1)}{2}-1\right)}$ (29)

Q3 (Third quartile) $=$ *median of* $x_{\left(\frac{n+1}{2}+1\right),\ldots\ldots,}x_n$ (30)

iv. Step 4 : After *Q1*, *Q2*, and *Q3* have been determined, Muda level is set depending on the condition of the manufacturing line. A green status indicates that Muda is not present. Amber status indicates that Muda exists but is still within acceptable limits and warrants attention. Red status indicates that Muda is beyond the acceptable limits. Table 5-8 exemplifies two conditions of waste in manufacturing line in relation to Muda level. User can make decision to pick up what types of condition, depending on the situation.

Table 5-8: Muda level for different conditions of waste

Muda Level	Condition A	Condition B
R (Red)	PL ≤ Q1	PL ≥ Q3
A (Amber)	Q1 < PL < Q3	Q1 < PL < Q3
G (Green)	PL ≥ Q3	PL ≤ Q1

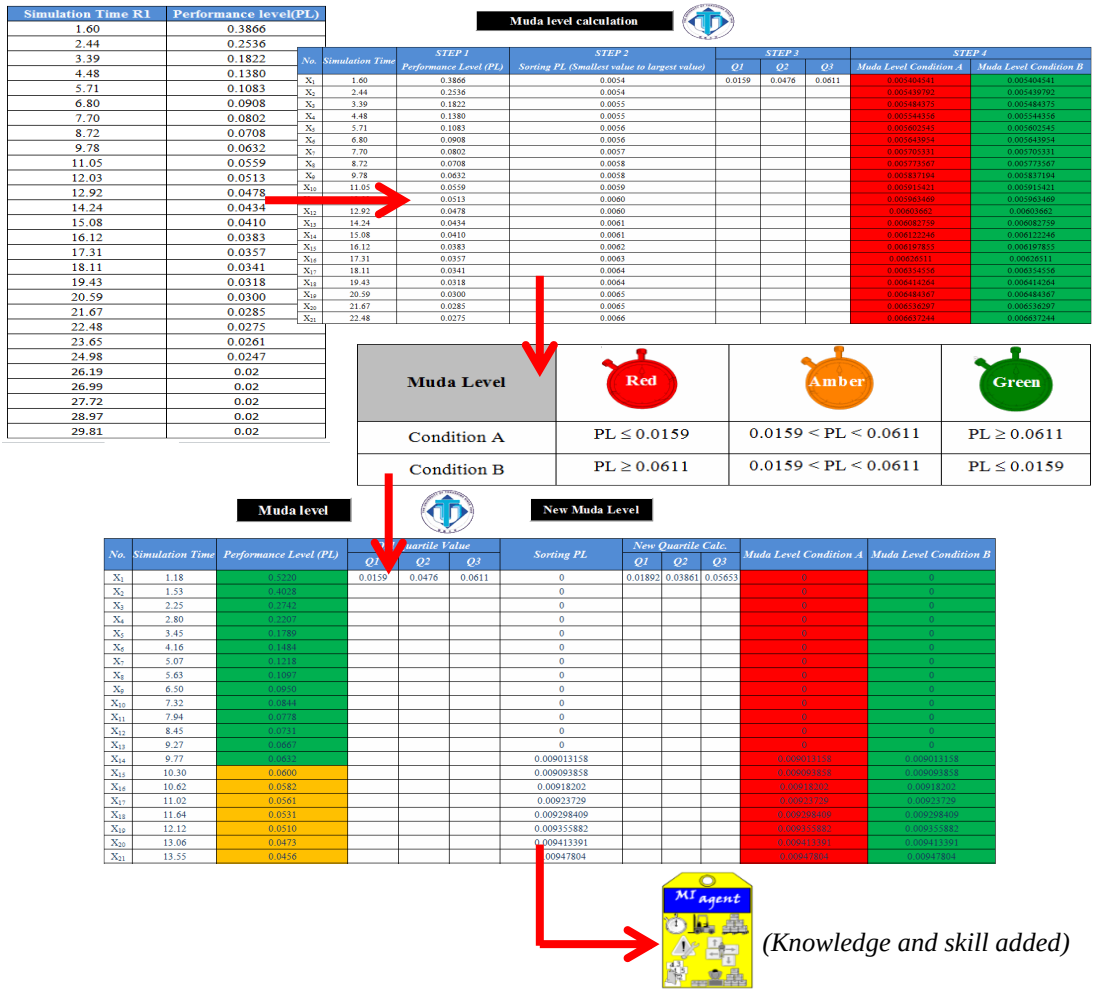
After the 4th procedure of Step c, the *Muda level calculation for training MI agent.xlsm* file is stored in an independent database.

D. Step d: MI agent is connected to a manufacturing simulation model. When the simulation runs, MI agent continuously monitors status of waste (Muda level) in the simulation model and learns the status automatically. Then, the MI agent presents Muda level in the form of graphical image of R.A.G status.

5.4 Feasibility studies of MI agent in CHM Factory Model

5.4.1 Feasibility study 1

Feasibility study of MI agent is conducted using a simulation model of coolant hose manufacturing (CHM) factory. The design and development of CHM factory simulation model is elaborated in details in Chapter IV. For this feasibility study, a practising engineer with a few years' experience in industry is chosen. Guided by author, the practising engineer selects WS1 of S4 simulation model to test the feasibility of MI agent. S4 of CHM factory consists of 6 WSs and produces two types of products, CH8 and CH10. Waiting Muda, or M4 (Table 2-1), is chosen to show how MI agent works in simulation. Waiting Muda is defined as idle status of operator, which causes high changeover task time in WSs, due to starvation of parts/materials.



Simulation Time R1	Performance level(PL)
1.60	0.3866
2.44	0.2536
3.39	0.1822
4.48	0.1380
5.71	0.1083
6.80	0.0908
7.70	0.0802
8.72	0.0708
9.78	0.0632
11.05	0.0559
12.03	0.0513
12.92	0.0478
14.24	0.0434
15.08	0.0410
16.12	0.0383
17.31	0.0357
18.11	0.0341
19.43	0.0318
20.59	0.0300
21.67	0.0285
22.48	0.0275
23.65	0.0261
24.98	0.0247
26.19	0.02
26.99	0.02
27.72	0.02
28.97	0.02
29.81	0.02

Muda level calculation

No.	Simulation Time	STEP 1 Performance Level (PL)	STEP 2 Sorting PL (Smallest value to largest value)	STEP 3 Q1	Q2	Q3	STEP 4 Muda Level Condition A	Muda Level Condition B
X_1	1.60	0.3866	0.0054	0.0159	0.0476	0.0611	0.005404541	0.005404541
X_2	2.44	0.2536	0.0054				0.005439792	0.005439792
X_3	3.39	0.1822	0.0055				0.005484375	0.005484375
X_4	4.48	0.1380	0.0055				0.005544356	0.005544356
X_5	5.71	0.1083	0.0056				0.005602545	0.005602545
X_6	6.80	0.0908	0.0056				0.005643954	0.005643954
X_7	7.70	0.0802	0.0057				0.005705331	0.005705331
X_8	8.72	0.0708	0.0058				0.005773567	0.005773567
X_9	9.78	0.0632	0.0058				0.005837194	0.005837194
X_{10}	11.05	0.0559	0.0059				0.005915421	0.005915421
		0.0513	0.0060				0.005963469	0.005963469
X_{12}	12.92	0.0478	0.0060				0.00603662	0.00603662
X_{13}	14.24	0.0434	0.0061				0.006082759	0.006082759
X_{14}	15.08	0.0410	0.0061				0.006122246	0.006122246
X_{15}	16.12	0.0383	0.0062				0.006197855	0.006197855
X_{16}	17.31	0.0357	0.0063				0.00626511	0.00626511
X_{17}	18.11	0.0341	0.0064				0.006354556	0.006354556
X_{18}	19.43	0.0318	0.0064				0.006414264	0.006414264
X_{19}	20.59	0.0300	0.0065				0.006484367	0.006484367
X_{20}	21.67	0.0285	0.0065				0.006536297	0.006536297
X_{21}	22.48	0.0275	0.0066				0.006637244	0.006637244

Muda Level	Red	Amber	Green
Condition A	PL ≤ 0.0159	0.0159 < PL < 0.0611	PL ≥ 0.0611
Condition B	PL ≥ 0.0611	0.0159 < PL < 0.0611	PL ≤ 0.0159

Muda level

New Muda Level

No.	Simulation Time	Performance Level (PL)	Quartile Value Q1	Q2	Q3	Sorting PL	New Quartile Calc. Q1	Q2	Q3	Muda Level Condition A	Muda Level Condition B
X_1	1.18	0.5220	0.0159	0.0476	0.0611	0	0.01892	0.03861	0.05653	0	0
X_2	1.53	0.4028				0				0	0
X_3	2.25	0.2742				0				0	0
X_4	2.80	0.2207				0				0	0
X_5	3.45	0.1789				0				0	0
X_6	4.16	0.1484				0				0	0
X_7	5.07	0.1218				0				0	0
X_8	5.63	0.1097				0				0	0
X_9	6.50	0.0950				0				0	0
X_{10}	7.32	0.0844				0				0	0
X_{11}	7.94	0.0778				0				0	0
X_{12}	8.45	0.0731				0				0	0
X_{13}	9.27	0.0667				0				0	0
X_{14}	9.77	0.0632				0.009013158				0.009013158	0.009013158
X_{15}	10.30	0.0600				0.009093858				0.009093858	0.009093858
X_{16}	10.62	0.0582				0.00918202				0.00918202	0.00918202
X_{17}	11.02	0.0561				0.00923729				0.00923729	0.00923729
X_{18}	11.64	0.0531				0.009298409				0.009298409	0.009298409
X_{19}	12.12	0.0510				0.009355882				0.009355882	0.009355882
X_{20}	13.06	0.0473				0.009413391				0.009413391	0.009413391
X_{21}	13.55	0.0456				0.00947804				0.00947804	0.00947804

(Knowledge and skill added)

Figure 5-9: MI agent training using Section 4 of CHM factory simulation model

Next, MI agent is trained in S4 following the procedures described in the earlier part of this chapter (Figure 5-9). The trained MI agent is then ready to be used. In this case, the practising engineer aims to quantify waste in WS1of S4 in two days (Friday and Monday). Using triangular distribution, the practising engineer sets the process time for Friday as TRIA (0.5, 1, 1.5) minute and Monday as TRIA (0.3, 0.5, 1.0) minute. Then, the simulation model of WS1 of S4 is run. Snapshot MI agent implementation in WS1 of S4 is shown in Figure 5-10.

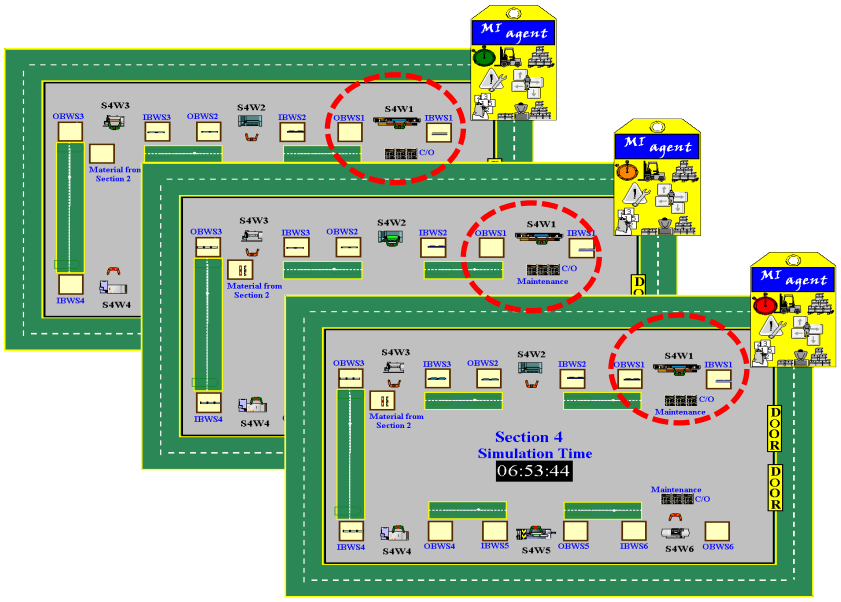


Figure 5-10: Snapshot MI agent implementation in WS1 of S4

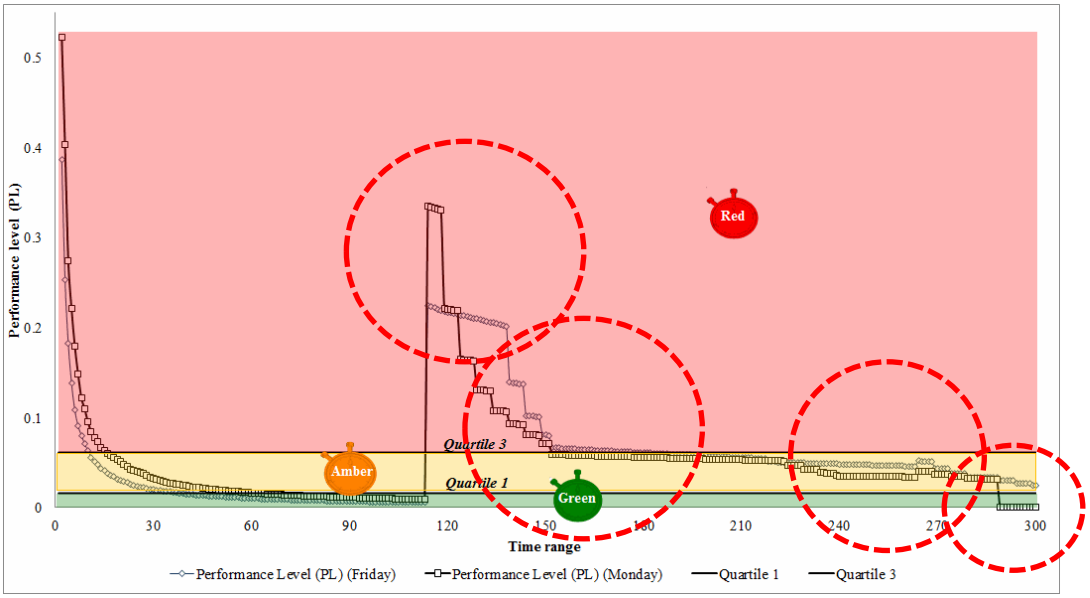


Figure 5-11: Performance level of WS1 of S4

A graph of Performance Level (PL) of WS1 is acquired from the simulation run as depicted in Figure 5-11. As can be seen from the graph, the PL is lower on Monday as compared to PL on Friday from t_{120} to t_{150} and t_{240} to t_{300}. This means that the idle status of operators is shorter during this time on Monday compared to Friday. The ability of MI agent to provide this result indicates that MI agent could detect process improvement autonomously and proves that the process improvement is successfully achieved.

5.4.2 Feasibility study 2

A lean practitioner is chosen for the purpose of this feasibility study. Similarly, the lean practitioner selects S4 of CHM factory simulation model to test the feasibility MI agent. The MI agent is placed in simulation model of WS1 of S4. Next, a series of simulation runs are conducted from t_{30} to t_{540}. Table 5-9 shows PL values calculated by MI agent in this simulation.

Table 5-9: PL for S4W1 within Time Range t_{30} to t_{540}

Time Range	t_{30}	t_{60}	t_{90}	t_{120}	t_{150}	t_{180}	t_{210}	t_{240}	t_{270}
PL	0.0207	0.0103	0.0069	0.0348	0.1279	0.1899	0.2199	0.1015	0.0757
Time Range	t_{300}	t_{330}	t_{360}	t_{390}	t_{420}	t_{450}	t_{480}	t_{510}	t_{540}
PL	0.0681	0.0619	0.0568	0.0524	0.0487	0.0426	0.0502	0.0500	0.0370

Table 5-10: Ascending order of PL for WS1

No	PL (WS1)
X_1	0.0069
X_2	0.0103
X_3	0.0207
X_4	0.0348
X_5	0.0370
X_6	0.0426
X_7	0.0487
X_8	0.0500
X_9	0.0502
X_{10}	0.0524
X_{11}	0.0568
X_{12}	0.0619
X_{13}	0.0681
X_{14}	0.0757
X_{15}	0.1015
X_{16}	0.1279
X_{17}	0.1899
X_{18}	0.2199

Q1 (First quartile)

Q2 (Second quartile)

Q3 (Third quartile)

According to the quartile calculation by MI agent, Q1, Q2, and Q3 are calculated as 0.0370, 0.0513, and 0.0750, respectively, for WS1 with sample size (n=18) as shown in Table 5-10. Based on Q1, Q2, and Q3 values, MI agent determines Muda level using condition B (please refer to Table 5-8). MI agent reviews the waiting Muda level and the results are presented in real-time in the form of R.A.G status as shown in Table 5-11.

Table 5-11: Muda Level of WS1

Muda Level			
Range for Muda level (S4W1)	PL ≥ 0.0757	0.0370 < PL < 0.0757	PL ≤0.0370

Next, the lean practitioner is prompted to conduct what-if analysis as follows:

a) What if SMED is implemented at S4?

Firstly, the lean practitioner incorporates the changeover task time for before and after SMED implementation into the simulation model (Table 5-12). Then, simulation run is conducted (Figure 5-12) and performance levels of WS1 with and without SMED implementation is shown in Table 5-13 and Figure 5-13.

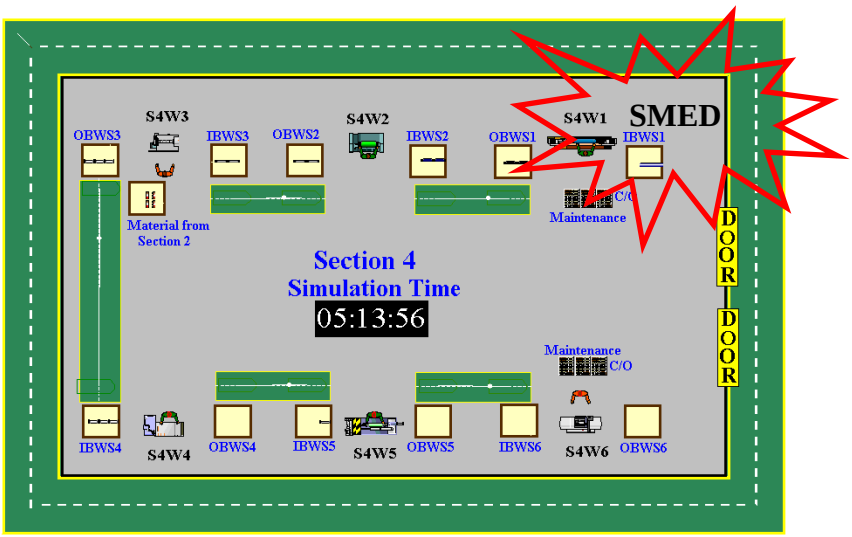


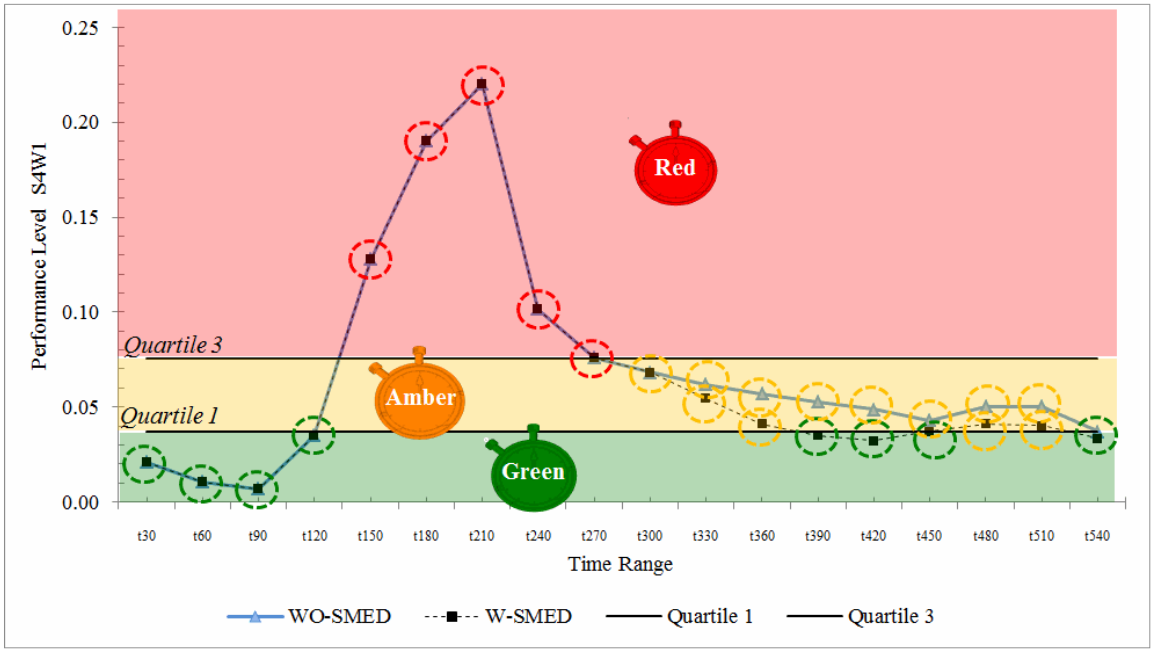
Figure 5-12. Snapshot of S4 with SMED implementation

Table 5- 12: SMED implementation at S4 for WS1

Changeover (CO) Tasks Time	**WS1**	
	Before SMED (minutes)	After SMED (minutes)
a. Task 1	3	1
b. Task 2	8	1.5
c. Task 3	8	1.5
d. Task 4	4	0
e. Task 5	4	0
f. Task 6	8	1.5
g. Task 7	8	1.5
h. Task 8	5	1
i. Task 9	3	1
Total CO Tasks Time (minutes)	51	9

MI agent autonomously copes with the dynamic nature of manufacturing process in WS1 and updates the performance level during simulation from t_{30} to t_{540}. Figure 5-13 shows that MI agent does not reveal any difference in PL values from t_{30} to t_{300}. This is because no CO process takes place in WS1 from the t_{30} to t_{300}. However, MI agent shows significant decrease in PL value from amber to green at the t_{390} when SMED is implemented and the green colour continues until the t_{450}. This behaviour of MI indicates that MI agent autonomously detects the process improvement by SMED LM tool and proves that the process improvement has been successfully achieved.

Table 5-13 shows the quantitative results of performance level calculated by MI agent. This quantitative information on the percentage of PL improvement is designed to provide pro-active assistance to LM practitioner so that selection of LM tool could be appropriately achieved.



 # W-SMED (with SMED); WO-SMED (without SMED)

Figure 5-13: Performance level of WS1 W-SMED and WO-SMED

Table 5-13: PL improvement of WS1 W-SMED and WO-SMED

Time Range			t_{30}	t_{60}	t_{90}	t_{120}	t_{150}	t_{180}	t_{210}	t_{240}	t_{270}
S4W1	PL	WO-SMED	0.0207	0.0103	0.0069	0.0348	0.1279	0.1899	0.2199	0.1015	0.0757
		W-SMED	0.0207	0.0103	0.0069	0.0348	0.1279	0.1899	0.2199	0.1015	0.0757
	Improvement	(%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Time Range			t_{300}	t_{330}	t_{360}	t_{390}	t_{420}	t_{450}	t_{480}	t_{510}	t_{540}
S4W1	PL	WO-SMED	0.0681	0.0619	0.0568	0.0524	0.0487	0.0426	0.0502	0.0500	0.0370
		W-SMED	0.0681	0.0543	0.0410	0.0349	0.0322	0.0370	0.0412	0.0401	0.0334
	Improvement	(%)	0.00%	12.30%	27.74%	33.34%	33.85%	13.20%	18.02%	19.77%	9.74%

 # W-SMED (with SMED); WO-SMED (without SMED)

5.5 Conclusion

This study proposes an agent-based approach to LM implementation, where MI agent plays a critical role to support LM practitioners for their decision making in selection of LM tools. MI agent focuses on user's perspective unlike other models that focus on the application and require user to adapt to the application.

Feasibility study shows that MI agent handles the dynamic nature of manufacturing processes

autonomously and pro-actively translates the results of waste detection and quantification by means of R.A.G status during simulation, which is easily understood by the user.

Future works include enhancement of MI agent function to cover the remaining types of Muda in manufacturing processes, design/implementation of various manufacturing processes to apply MI agent for further feasibility study, usability experiments to evaluate MI agent, and web-based implementation of MI agent to apply for practical use.

CHAPTER VI
Conclusion and future works

Lean Manufacturing has emerged as the preferred way for improvement activities because of its capability to increase productivity and profitability. However, despite its widening dissemination within the manufacturing community, the impediments of LM tools and techniques and current UTP for LM tools motivate the need for integration of simulation and modelling approach to lean manufacturing. This research is motivated by the need to fill these gaps.

In this research, the researcher has developed a training framework that integrates e-learning and simulation to current user training program (UTP) of LM tools. This effort is motivated by the need to address the gap between attending UTP for LM tools and confidently applying the LM tools in real production floor. The gap exists due to the redundancy of the current UTP for LM tools and the inability of LM tools to demonstrate and convince the users on the impact of implementing LM tool on a production floor before they actually apply the tools. Thus, users will have to conduct pilot studies and other experiments in the production floor post-UTP to observe the impact of applying those LM tools to their manufacturing process.

This research proposes a training framework that integrates Lean Manufacturing Tools Training System (LMTTS) with the current UTP for LM tools to support LM implementation. LMTTS assists users in knowing the basic concept of LM tools implementation through its e-learning module and improves users' understanding by providing a dynamic illustration of simulation models via S-module. By providing a learner-centric orientation of learning, users' comprehension and confidence levels towards LM tools are increased and the overall training results of the LM tools are enhanced. Most importantly, LMTTS provides a dynamic and flexible learning environment for users to study the LM tools. Users could experiment with the simulation models using input parameters from their production floor and immediately see the effects of the changes. This way, the time spent in garnering possible solutions to problems within their production floor would be reduced. In this research, the designs of the

e-learning module and S-module are highlighted as well as the procedure in using each of these modules, using SMED LM tool as an example. The future scopes of this research include developing LMTTS for other LM tools (i.e., Kanban, Poka Yoke, Preventive Maintenance, Autonomous Maintenance, Andon Light, Heijunka, and Cellular Manufacturing).

Next, the researcher also proposes a simulation-based decision support system (SDSS) in this research. This proposal is motivated by the need to address the gap between lean practitioners and simulation-based approaches in terms of expertise in utilising simulation software tools and in developing a system capable of supporting operational (real-time) decision making in LM implementation.

By deploying a process simulation model and providing four functions namely layout, zoom-in/zoom-out, task status, and Key Performance Indicators (KPI) status, SDSS enables lean practitioners to assess current and future state of manufacturing process, perform "what-if" analysis, and measure impact of improvement after LM tool implementation. Therefore, lean practitioners could choose a suitable LM tool to implement at the right time and place. This research chooses SMED and CM tool and implements its simulation in the models.

Feasibility study of SDSS using a manufacturing process model of CHM factory shows that by utilising specific functions of SDSS and comparing the difference in results before and after SMED/CM implementation, the effectiveness of LM tool implementation can be quantified by the lean practitioners. This feasibility study also shows that SDSS is a suitable decision support system for lean practitioners because it increases the literacy in simulation among lean practitioners by providing a structured approach of using simulation software tool. Moreover, the idea of user understanding support, which is implemented in the model as several functions, also assists users in visualising the production processes and simulation outputs.

The future scopes of this study include extending the scope of SDSS to cover strategic decision-making in LM implementation, broadening the function of SDSS to support other LM tools, validating the results acquired in this study over a range of case study applications,

and considering the role of intelligent agent to provide decision support functionality to lean practitioners and management teams in pursuing LM implementation.

The role of intelligent agent to provide decision support functionality to lean practitioners in pursuing LM implementation is discussed in chapter V of this research. The intelligent agent named Muda Indicator (MI) agent acts as an expert assistant to lean practitioners in using LM tool software and in quantifying waste to support the decision made by the lean practitioners in selecting LM tools. Quantifying waste is chosen as the expertise of the agent because it is the most important aspect to be considered in decision-making process. MI agent continuously monitors the status of waiting Muda during simulation runs and provides Muda level indication by means of RAG status. Feasibility study of MI agent using a manufacturing process model of coolant hose manufacturing (CHM) factory shows that the MI agent handles the dynamic nature of manufacturing processes autonomously and pro-actively provided RAG status during simulation. MI agent also shows transition of quantifying wastes during simulation in a dynamic manner. Future works for this intelligent agent-based approach to lean manufacturing include enhancing the function of MI agent to cover the remaining types of Muda in manufacturing processes, designing various manufacturing processes to apply MI agent for further feasibility study, conducting usability experiments to evaluate MI agent, and developing web-based implementation of MI agent to apply for practical use.

In a nutshell, this research has provided important insights into a simulation and modelling approach to lean manufacturing as well as highlighted some associated issues. The benefits from integration of LMTTS with current UTP for LM tools, simulation-based approach to decision support for lean practitioners (SDSS), and waste quantification by using intelligent agent (Muda Indicator) may open more research opportunities regarding usage of simulation and modelling in lean manufacturing implementation.

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