

QUANTIFYING BENEFITS OF LEAN MANUFACTURING TOOLS IMPLEMENTATION WITH SIMULATION IN COOLANT HOSE FACTORY

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ABSTRACT

Lean Manufacturing (LM) is 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 (CM), Standardised Work, Heijunka, and Poka Yoke. Although these tools could resolve many manufacturing issues, it is difficult to quantify the benefits of implementing LM before it is actually implemented. Therefore, this study focused on a process simulation approach to see the effectiveness of LM tools before their implementation. A process model of a coolant hose manufacturing (CHM) factory was designed and its simulation model was then implemented. Subsequently, this paper presents the implemented simulation model and shows how it could be used to see the effect of LM tools using an example of SMED LM tool and Cellular Manufacturing LM tool.

KEYWORDS: *Lean Manufacturing, Simulation, Key Performance Indicators*

1.0 INTRODUCTION

The lean concept was first introduced by Taiichi Ohno and Shingeo Shingo from Toyota Motor Company. Later, Womack *et.al.* (1990) introduced the term “lean manufacturing” (LM) in the book entitled *The Machine That Changed The World*. In recent years, LM has been widely used by discrete and process manufacturing companies in order to remain competitive. LM has been applied to various sectors including automotive, electronics, fabrication plants, and consumer product manufacturing to improve their productivity and to gain higher-quality products in shorter lead time at a reduced cost. Basically, LM is a philosophy aiming at detecting and eliminating waste throughout a product’s value stream by means of a set of synergistic tools and techniques (de Treville & Antonakis, 2006). Detailed explanation on concept, objectives, implications, structure, and tools of LM can be acquired from Kumar & Kumar (2012). Examples of LM tools and techniques are Single Minute Exchange of Die (SMED), Kanban, 5-S, Value Stream Mapping, Preventive Maintenance, Cellular Manufacturing (CM), Standardised Work, Heijunka, and Poka Yoke.

Most lean tools and techniques are based on “pencil and paper” technique involving analysis of static models (Sevillano *et.al.*, 2011). These tools are also available as computer software to apply in practical manufacturing lines. Even though these tools could resolve many manufacturing issues based on the tenets of LM, expected results by LM tools cannot be seen before their implementation (Ito *et.al.* 2013), leading to difficulties to convince the management team to implement LM. This is due to the lack of tools to quantify the effectiveness of LM implementation (Detty & Yingling, 2000). Oftentimes, the decisions to adopt LM have to be made based on faith in LM philosophy and experiences of other management teams (Abdulmalek & Rajgopal, 2007). A simulation-based approach is therefore needed to quantify various performance measures to enable management teams to make informed decisions before actually implementing LM tools (Standridge & Marvel, 2006).

This study focused on the process simulation approach to see the effectiveness of LM tools before their implementation. In this study, a sample process simulation model was designed and implemented based on the manufacturing process data of a coolant hose manufacturing (CHM) factory. Moreover, an idea of user understanding support was implemented in this study as several functions, which are layout function, zoom-in/zoom-out function, task status function, and KPI status function. This paper presents the simulation model based on the

CHM factory and shows how it could be used to see the effect of LM tools using an example of SMED and CM.

2.0 MANUFACTURER AND PRODUCT DESCRIPTION

The CHM factory produces four types of products including Coolant Hose 4 (CH4), CH6, CH8, and CH10. The factory floor consists of six sections (Section 1 to Section 6) as depicted in the flow diagram of CHM factory floor (Figure 1). Section 1 (S1) represents incoming warehouse, Section 2 (S2) represents crimping manufacturing line. Section 3 (S3) represents CH4 & CH6 manufacturing line. Section 4 (S4) represents CH8 & CH10 manufacturing line. Section 5 (S5) represents packaging line. Finally, Section 6 (S6) represents outgoing warehouse.

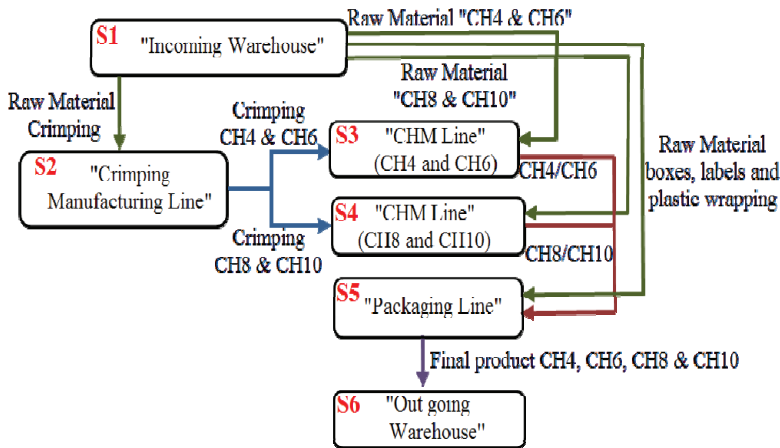


Figure 1: Flow diagram of CHM factory floor

S1 supplies raw materials to S2, S3, S4, and S5. Then, S2, S3, S4, and S5 supply their processed parts to S3/S4, S4, S5, and S6, respectively. Production capacity for each line is 150 units/day for 9 hrs. Materials' handling of parts in production lines is performed by either forklift or trolley. Table 1 shows these conditions.

Table 1: Manufacturing conditions

From	To	Material	Units	Material Handler (MH)
S1	S2	Raw Material Crimping CH4 & CH6 and CH8 & CH10	50	Forklift
	S3	Raw Material CH4 & CH6	50	Forklift
	S4	Raw Material CH8 & CH10	50	Forklift
	S5	Raw Material Wrapping/Packaging/Labelling	50	Forklift
S2	S3	Crimping CH4 & CH6	25	Trolley
	S4	Crimping CH8 & CH10	25	Trolley
S3	S5	CH4 & CH6	25	Trolley
S4	S5	CH8 & CH10	25	Trolley
S5	S6	Final Products	25	Trolley

The number of workstation (WS) in each section is three WSs in S2, five WSs in S3, six WSs in S4, and three WSs in S5, as shown in Table 2. Each of these WSs is operated by one operator. Table 2 also shows the task type of each WS and changeover (C/O) operation. Changeover operation is scheduled in S2, S3, and S4 because of die switches for product type change in the production line.

Table 2: Task conditions

Section	Task	No of Operator	C/O	Section	Task	No of Operator	C/O
S2	WS1 (Machining)	1	*	S4	WS1 (Machining)	1	*
	WS2 (Testing)	1			WS2 (Deburring)	1	
	WS3 (Marking)	1			WS3 (Crimping)	1	
S3	WS1 (Machining)	1	*		WS4 (Welding)	1	
	WS2 (Deburring)	1			WS5 (Testing)	1	
	WS3 (Crimping)	1			WS6 (Marking)	1	*
	WS4 (Testing)	1		S5	WS1 (Wrapping)	1	
WS5 (Marking)	1	*	WS2 (Packaging)		1		
			WS3 (Labelling)		1		

*Changeover (C/O): For product switch in production line.

3.0 MODEL DEVELOPMENT

A process model of CHM factory was developed in this study using Arena 12.0 simulation package (Kelton et al., 2010), based on the SIMAN language. Firstly, the layouts of all sections in CHM factory were created. From these layouts, model logics were created for all sections. For sections with scheduled C/O operation (S2, S3, and S4), submodels of the C/O process were also created. Example of layout

(Figure 2), model logic (Figure 3), and submodel of C/O process (Figure 4) are shown in this paper, using S4 as an example.

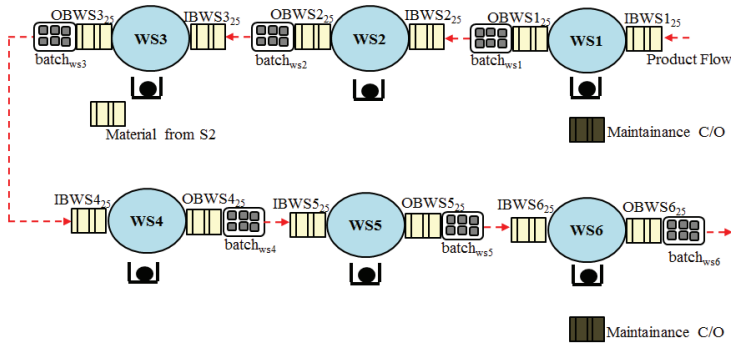


Figure 2: Layout of S4 in CHM Factory

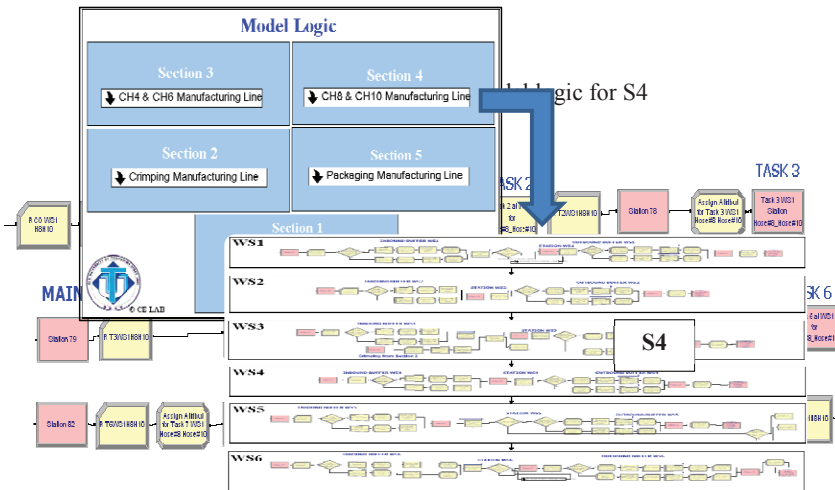


Figure 4: Submodel of C/O for WS1 at S4

Next, animation of CHM factory floor was developed to represent the model logic (Figure 5). Included in the animation are all the products produced by S2, S3, S4, and S5. Detailed information on the products is depicted in Figure 6 to Figure 9.

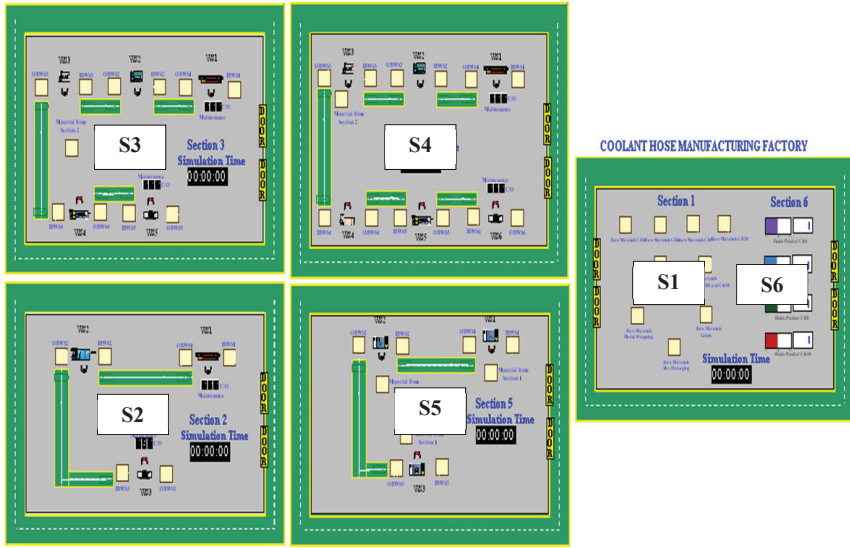


Figure 5: Snapshot of bird's-eye view of the CHM factory floor

Inbound Buffer	Workstation	Outbound Buffer	Inbound Buffer	Workstation	Outbound Buffer
	WS1 Machining			WS1 Machining	
	WS2 Testing			WS2 Testing	
	WS3 Marking			WS3 Marking	

Crimping CH4 & CH6 Crimping CH8 & CH10

Figure 6: Products of S2

Inbound Buffer	Workstation	Outbound Buffer	Inbound Buffer	Workstation	Outbound Buffer
	WS1 Machining			WS1 Machining	
	WS2 Deburring			WS2 Deburring	
	WS3 Crimping			WS 3 Crimping	
	WS4 Testing			WS 4 Testing	
	WS5 Marking			WS 5 Marking	

CH4 CH6

Figure 7: Products of S3

Inbound Buffer	Workstation	Outbound Buffer	Inbound Buffer	Workstation	Outbound Buffer
	WS1 Machining			WS1 Machining	
	WS2 Deburring			WS2 Deburring	
	WS3 Crimping			WS3 Crimping	
	WS4 Testing			WS4 Testing	
	WS5 Marking			WS5 Marking	
	WS6 Marking			WS6 Marking	

CH8 CH10

Figure 8: Products of S4

Inbound Buffer	Workstation	Outbound Buffer	
+	WS1 "Plastic Wrapping"		Wrapped CH4, CH6, CH8 & CH10
+	WS2 "Box Packaging"		Packed CH4, CH6, CH8 & CH10
+	WS3 Labelling		Labelled CH4, CH6, CH8 & CH10

Figure 9: Products of S5

Basically, animation was used to check the model logic in order to ensure that the model was error-free. Furthermore, the model logic was verified to ensure that the model closely approximated the real system. Verification was deployed by scrutinising all the products from the point of their creation (S1: Incoming warehouse) to the point of their disposal from the system (S6: Outgoing warehouse). Finally, the model was validated by means of comparison between simulation result and mathematical results.

Table 3: Validation of CHM factory model

Section	Simulation result (minute)	Mathematical calculation result (minute)	Similarity (%)	Confidence interval range 95%	Status
S2	385.59	380.02	98.56	342.13–519.58	Valid
S3	834.61	853.60	97.77	639.43–1001.3	Valid
S4	887.14	853.60	96.22	572.08–989.3	Valid
S5	118.89	111.40	93.70	91.36–203.70	Valid

3.1 Functions and features of CHM Factory Model

Considering the specific use for LM simulation, an idea of user understanding support was implemented in the CHM factory model, which provided several functions to help users understand how LM tools could improve the manufacturing process through an interactive use of process simulation. In other words, users could visualise production processes and quantify the effectiveness of LM tool implementation via the simulation model. This section presents some of these functions to clarify the features of the CHM factory model.

- i. **Layout function:** A bird’s-eye view of the whole CHM factory floor can be obtained by the user interface as shown in Figure 5. This shows how the manufacturing process of CHM runs with the flow of materials/products in the whole six sections of the factory.
- ii. **Zoom-in/zoom-out function:** For detailed view of each section of manufacturing processes, zoom-in function could be deployed. Figure 10 to 12 show the detailed view of all sections in CHM factory after deploying the zoom-in function.

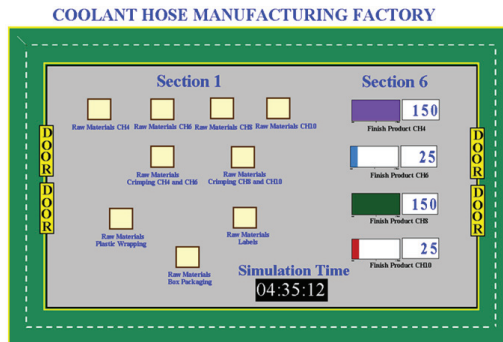


Figure 10: Snapshot of S1 and S6 using zoom-in function

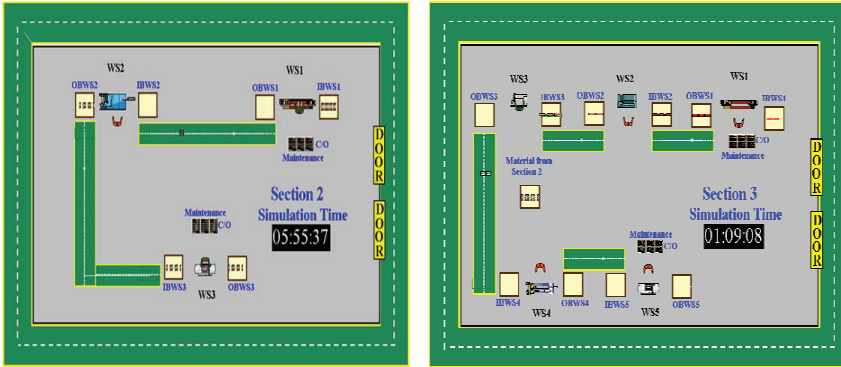


Figure 11: Snapshots of S2 and S3 using zoom-in function

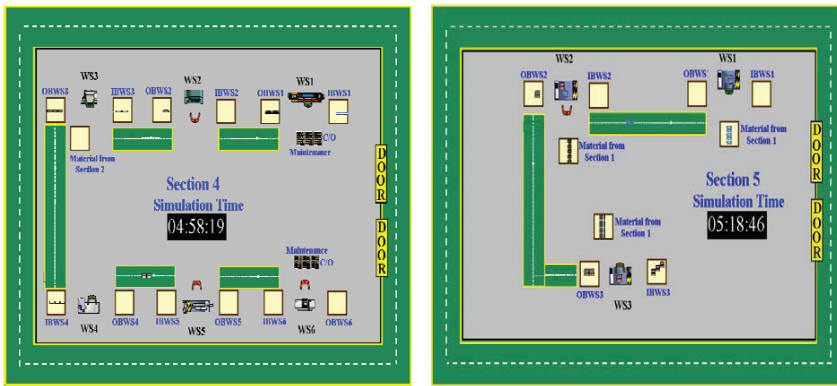


Figure 12: Snapshots of S4 and S5 using zoom-in function

- iii. **Task Status function:** For intuitive understanding of task status in each process, status illustrations are used in every WS. By doing so, user would be able to understand the changing task status in real time during the simulation runs. Figure 13 shows an example of status illustration to show the distinction in task status between busy, idle, and fail.

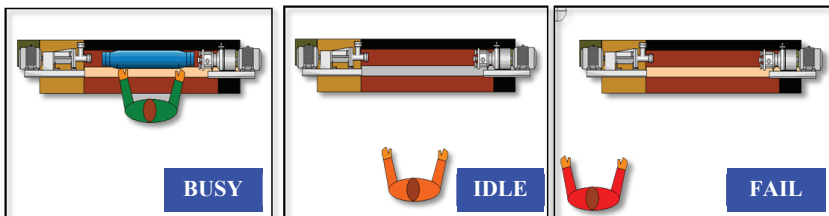


Figure 13: Task status illustration

iv. **KPI status function:** Key performance indicators (KPI), which include total production output, total production time, and C/O task time, are presented by means of KPI table and updated in real time during simulation. Snapshot of KPI table for S2, S3, S4, S5, and S6 is shown in Figure 14. To quantify the effectiveness of LM tool implementation (in this case, SMED and CM), users are prompted to observe the difference in KPI before and after LM tool implementation (using S4 as an example), as shown in Figure 15. The total production output after implementation of SMED and CM are 109 units/day and 105 units/day, respectively, compared to 100 units/day before implementation. It is also shown that the total production output increases to 110 units/day when SMED is implemented together with CM. These results, coupled with total production time results, justify that the benefit of implementing LM tools can be quantified using simulation methods.

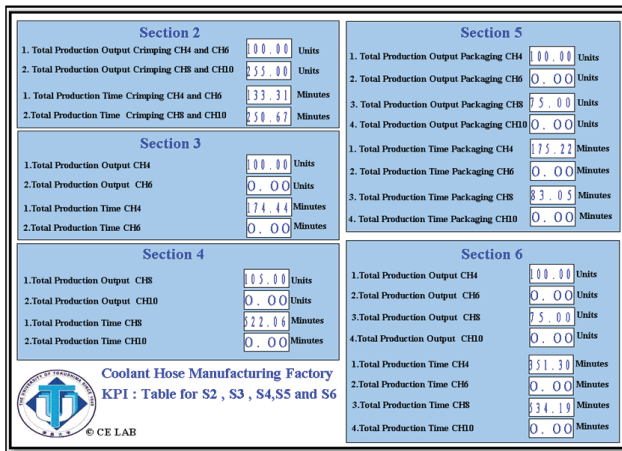


Figure 14: Snapshot of KPI table for S2, S3, S4, S5, and S6

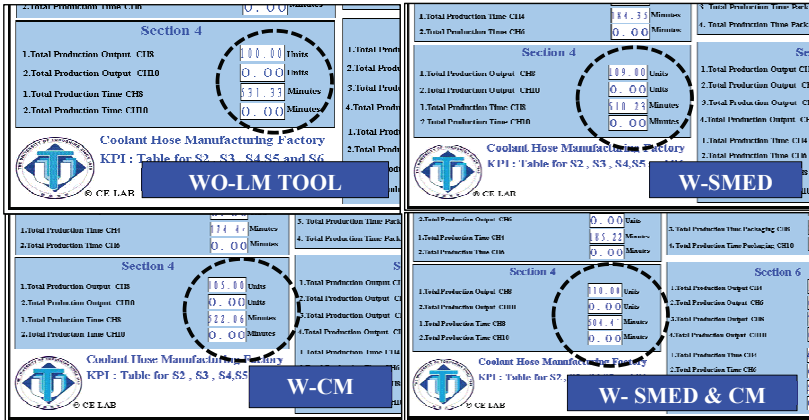


Figure 15: Snapshot of KPI table for S4 (WO-without, W-with)

For sections with C/O process, the KPI tables are as shown in Figure 16. An example is also provided using S4 to show the difference in C/O task time before and after SMED implementation (Figure 17).

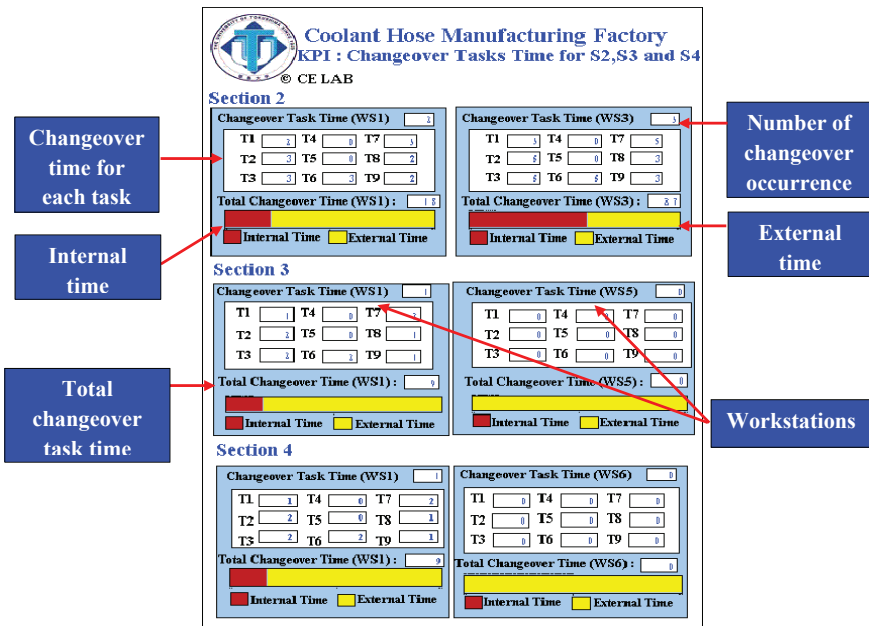


Figure 16: Snapshot of KPI table for S2, S3, and S4 for C/O task time

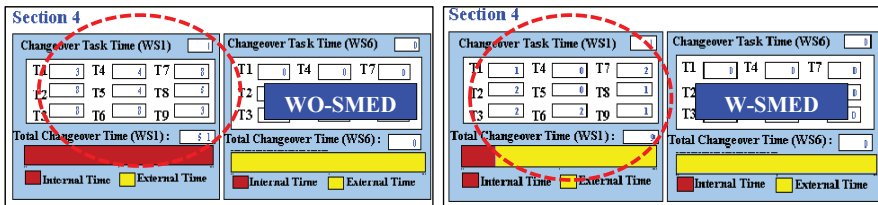


Figure 17: Snapshot of KPI table for S4 showing C/O task time WO-SMED and W-SMED implementation

As mentioned before, KPI values in this simulation model are generated and updated in real time during simulation. This way, users could understand the effectiveness of LM tools by a trial-and-error use of simulation and by conducting what-if analysis. In addition, for visual understanding of KPI, bar charts of KPI table are also available during simulation (Figure 18). Similarly, a sample of KPI graph that represents the KPIs with and without LM tools implementation is shown in Figure 19.

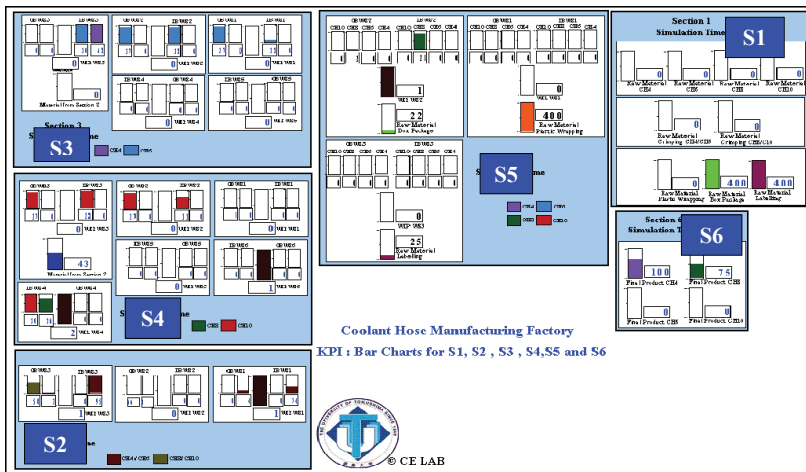


Figure 18: Snapshot of KPI graph (bar charts) for all sections of CHM factory

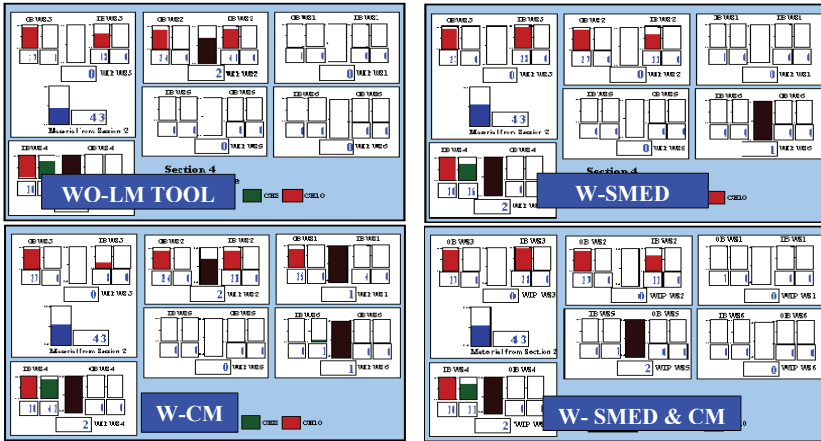


Figure 19: Snapshot of KPI graph for S4 with and without LM tools implementation

4.0 CONCLUSIONS AND FUTURE WORK

By deploying a process simulation model of CHM factory, the impact of LM tools on the process performance of the factory could be quantified. This provides the management team of the factory a basis for decision making whether or not to implement a particular LM 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. This study picked up SMED and CM tool and implemented its simulation in the models. Future work includes considering the role of intelligent agent to provide decision support functionality to management teams in pursuing LM implementation. The agent would act as an expert assistant to the user in using LM tool implementation software. The design and development of an agent-based system will be presented in a separate paper.

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