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Generation of a Decision Support System to Enhance the Efficiency of Lean Manufacturing

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ABSTRACT

Lean manufacturing (LM) is an established process that employs an array of instruments to eradicate waste. A variety of methods have been applied (some more successfully than others) to enhance the effectiveness of this process. This study delves into the introduction of the Intelligent Lean Tools Simulation (iLeTS) to overcome the deficiencies in the LM process and reduce the failure ratio. Fabricated with the use of modelling software, the performance of iLeTS was enhanced by way of an amalgamation involving the visual basic application (VBA) and the multi agent system (MAS). This merging served to enhance the user friendliness of iLeTS, which in turn reduced the required period of usage. Face validity and a usability study were harnessed to evaluate the performance of iLeTS. While face validity was used to authenticate the multi-agent system flow in iLeTS; the usability study was engaged to determine the proficiency of iLeTS when it comes to managing a number of arbitrarily occurring incidents. Subsequent to a thorough examination of a wide range of simulation results (deriving from authentic data), we arrived at the conclusion that (a) the iLeTS is suitable for the automation of the manufacturing process, and (b) the iLeTS can be relied upon for making prompt and appropriate choices.

Keywords: Waste, Lean Manufacturing, Modeling, Simulation, Lean Practitioner, Intelligent Agent, Multi-Agent System, Decision Support System, Decision Support System

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1. INTRODUCTION

Developed by Eiji Toyoda and Taiichi Ohno of Toyota Motor Company, lean manufacturing (LM) made its debut at the close of the Second World War (Womack *et al.*, 1991). The LM system can be defined as one that employs an array of instruments to exclude non-beneficial tasks from the manufacturing process (Ghosh, 2012; Mahfouz *et al.*, 2011). According to Karim and Rahman (2012), this system promotes cost effectiveness, performance quality and output generation (Abdulmalek and Rajagopal, 2007). Pettersen (2009) opined that the LM system not only reduces manufacturing costs, but also the defects in the manufacturing process. While Ghosh (2012) stated that this system raises the quality of manufactured goods and makes certain their speedy delivery, Wahab *et al.* (2013) are convinced that the use of the LM system contributes towards a decrease in lead times.

A scrutiny of appraisals available in relevant literature validates the effectiveness of LM for enhancing productivity and performance. While the instruments and procedures for LM are readily available, its implementation calls for a comprehensive training process for the personnel involved. Simulation is deemed an effective training instrument for this purpose.

The use of LM instruments and the performance of simulation procedures can prove to be challenging. This is attributed to the lack of communication between modeller and client regarding progression from the hypothetical model to the process engineering phase (Williams and

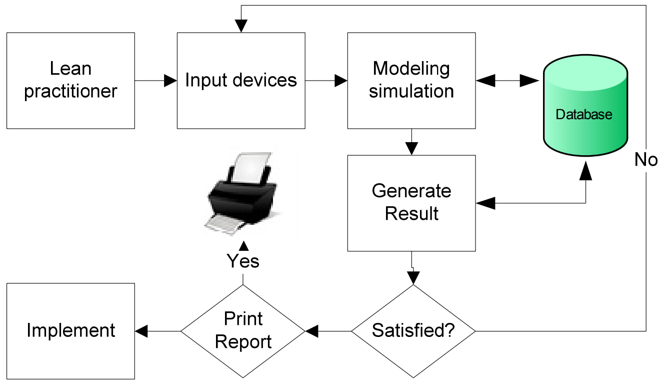


Figure 1. Existing implementation structure for online evaluation.

Ülgen, 2012; van der Zee, 2012). An added obstacle linked to these procedures is their inclination towards static simulation, whereas dynamic simulation would be more advantageous. Alzraiee *et al.* (2013) are of the viewpoint that headway in the context of on-line simulation is restricted to the field of specialists.

This endeavour delves into the development of an innovative decision support system for the implementation of LM. This is in response to the scarcity of investigations conducted in this area. The existing implementation structure for online evaluation is illustrated in Figure 1.

Figure 1 portrays the current process for LM tool implementation in accordance with previously conducted studies (Al-khafaji and Al-Rufaifi, 2012; Mohamad *et al.*, 2013; Senthiiland and Shirrushti, 2014; Anbumalar *et al.*, 2014; Mohamad *et al.*, 2016; Mohamad *et al.*, 2018). As can be observed, the lean practitioner (LP) utilizes input mechanisms (desktop, mouse and laptop) for the crafting of the model and for performing simulation to acquire the required data. The LP then interprets this data to ensure that a correct decision is arrived at. In a circumstance where the LP is dissatisfied with the result, the simulation can be repeated. On the other hand, if the result is deemed satisfactory, the following step would be to record the verification and confirm the intention of the team to carry out alterations. This platform is known as Intelligent Lean Tools Simulation (iLeTS). It is a platform developed through the utilization of visual basic application (VBA) and arena (Rockwell simulation) to reduce the impact of impediments, by way of an intelligent agent. This investigation represents an extension of the research carried out by Mohamad *et al.* (2017) and Mohamad *et al.* (2018).

2. INTELLIGENT LEAN TOOLS SIMULATION (ILETS)

iLeTS utilizes an intelligent agent for LM tool implementation. The development of iLeTS is based on feedback acquired from a usability study carried out on the existing structure. An amalgamation comprising the VBA, modelling software and intelligent agent served to (a) enhance efficiency during the evaluation stage, (b) boost the decision-making capacity of the lean practitioner, and (c) reduce the usage span between the user and the platform. Illustrations representing the structure of iLeTS can be observed in Table 1.

The realization of an all-inclusive iLeTS entails four main stages. Initially, an iLeTS structure is recommended (Stage 1). This structure is deemed an enhanced version of the existing structure. Subsequently, the platform is fashioned, and an intelligent agent that is in line with the objective of the platform is developed. This is followed by the designing and development of iLeTS (Stage 2). While VBA was utilized for the designing phase, modelling software (Arena Simulation) was harnessed to com-

Table 1. Depiction of iLeTS methodology

Platform	Step	Method used
iLeTS	Propose framework	From the usability study at LeTS, one framework had been proposed to enhance the effectiveness of the platform.
	Design Developed	Intelligent agent had been develop using Visual Basic Application (VBA)
		iLeTS had been developed using Modelling Simulation (Arena Simulation)
	Validate and verification	Face validation had been used to validate and verify the iLeTS. This step will involve the expert person to identify the flow of the intelligent agent in the platform. It's involve by five respondent.
	Usability study	The usability had been conduct and it's involve 20 respondent in Universiti Teknikal Malaysia Melaka (UTeM) from difference background of study and experience.

plete the development phase. The role of VBA in this situation is twofold. Other than the generation of an intelligent agent, VBA also raises the user-friendliness level of the environment. Upon the completion of designing and development, the iLeTS is subjected to validation and verification (Stage 3). Validation ensures that the performance of the platform is satisfactory, while the purpose of verification is to make certain that the platform complies with the needs of the client. And finally, a usability study is brought into the equation (Stage 4) to ensure that the platform is all-inclusive. If proven otherwise, repairs and updates in terms of the platform are in order.

iLeTS is the result of a merger involving modelling software, visual basic application and an intelligent agent. The results attained through a usability study uncovered that the LP faced difficulties when it came to the interpretation of results acquired from the simulation process. To overcome this impediment, an intelligent agent, which comes with the capacity to provide and decipher simulation results, was brought into play.

A scrutiny of data garnered from conference papers, paperbacks, periodicals and editorials found in Google Scholar, IEEE, Research Gate, Websites and Science Direct pointed to several setbacks in the current setup. Heading the list is the deficiency in user-friendliness. In an attempt to rectify this shortcoming, the new structure places emphasis on enhancing the decision support of LM implementation. Included in the new structure are multi-arena modelling (MAM), a multi-graphical user interface (MGUI) and an intelligent agent. The iLeTS structure is portrayed in Figure 2.

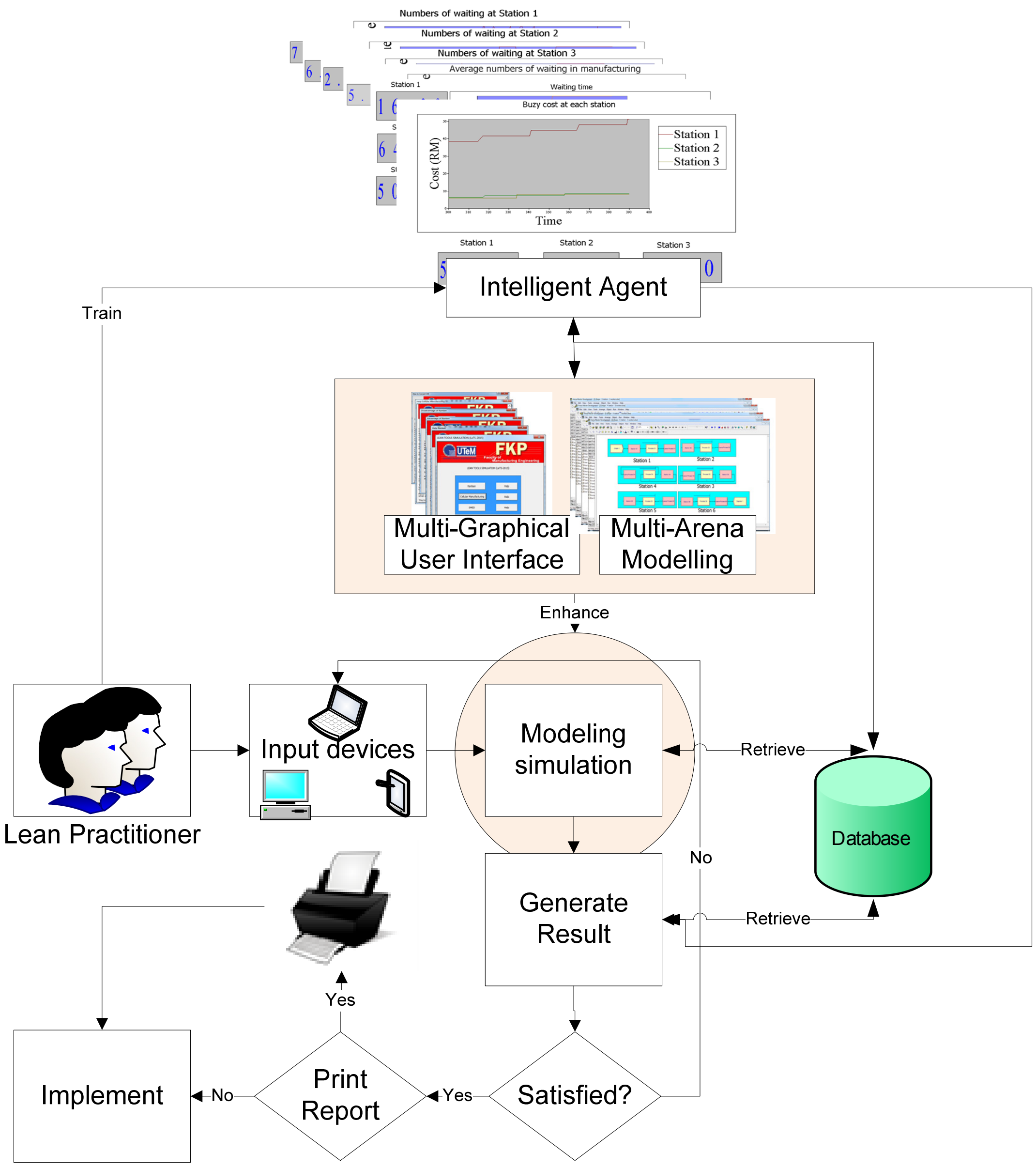


Figure 2. The iLeTS structure.

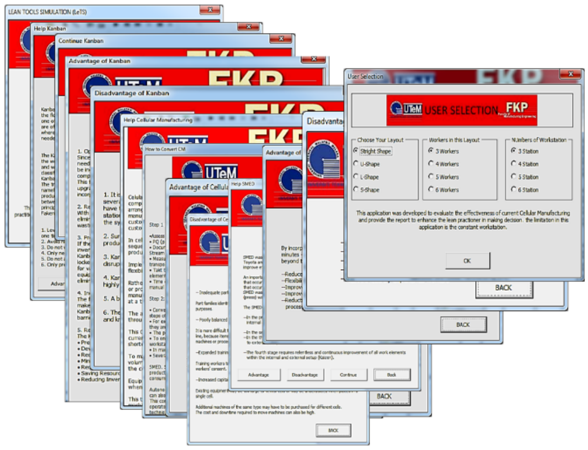


Figure 3a. Multi-Graphical-User-Interface (MGUI).

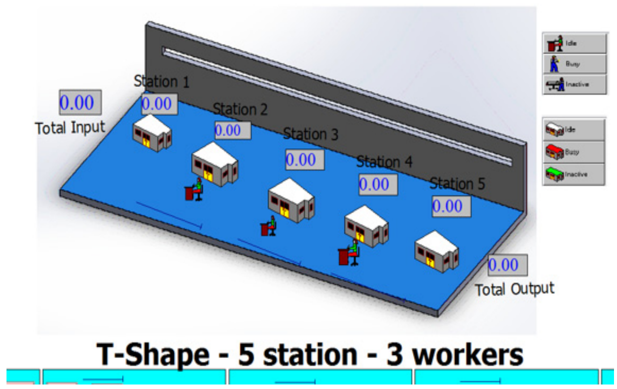


Figure 3b. Multi-Arena-Modelling (MAM).

While the MGUI platform comes with sixteen user interfaces to provide the user with a wide range of options (Figure 3a), MAM (Figure 3b) is equipped with seventeen interfaces to provide flexibility in the context of user selection. The integration of MAM and MGUI serves to raise the efficacy of the simulation process. Mechanisms such as a monitor and mouse are utilized by the LP to generate a simulation platform. This specifically designed platform does not call for the LP to be well-versed in the handling of lean tools. In accordance to the LP's selection, the modelling software employed initiates a one after another display of the MGUI. This serves to make things easier for the LPs during the evaluation process. An account of the results is acquired following the simulation process.

This account of results can be printed and used as support during tests and decision-making procedures. If the account of results is to the PA's satisfaction, the iLeTS structure is incorporated into the existing system. In a circumstance where the results are deemed unsatisfactory, simulation is replicated until an agreeable outcome is realized. The usability data indicates that in order to meet the expectations of the respondents, the existing platform's efficiency level needs to be elevated.

The LP uses an input mechanism to appraise the system and transmit the signal to the intelligent agent. The intelligent agent then plays its role by evaluating and interpreting the results before displaying them in a graphical design. This information is considered by the LP to determine the suitability of the result. In a situation where the result is deemed unsuitable, the LP can opt for an alternative among those available at the iLeTS. The realization of a suitable result is followed by a recommendation from the LP that the alternative be employed in the manufacturing scheme. A notable plus-point related to this structure is that it serves to expand the LP's store of data and raise the level of efficiency during the assessment of LM.

3. THE DESIGNING AND DEVELOPMENT OF iLeTS

Visual basic application and professional edition simulation software from Rockwell Automation are brought into play for the development of the platform. This software comes with the capacity for simulation procedures involving either a continuous or a discrete system. The Arena software was conceived for the intensive testing of business process models or other schemes. This software organizes the development process in a hierarchical flowchart, and employs data spreadsheets for the accumulation of information regarding the system. The base Arena language exercised is the SIMAN simulation language. The open architecture layout of Arena software allows the conveyance of data to other platforms. These platforms can then be integrated with visual basics prior to application (Banks *et al.*, 2005).

The development of this platform involved the use of three templates from the Arena software: basic process, advance process and block. Several modules, including the selection, create and dispose modules are utilized in the basic process. In the advance process, two modules i.e. the station and route modules are utilized. As for the block segment, the VBA block was utilized. The development of iLeTS is realized through an amalgamation involving these modules. Following the designing of the GUI and MAM, the platform is subjected to tests aimed at determining its operational proficiency. A satisfactory test result clears the way for the subsequent developmental stage, which entails the integration of the intelligent agent and the platform. This merging serves to improve the user's decision-making capacity. Following further tests to confirm its applicability, the platform can be employed by the LP for an improved decision-making process.

iLeTS merges intelligent agent-based techniques and the currently available structure to enhance the decision making process. An agent-based implementation entails two kinds of agents: the interface agent and the autonomous agent.

While the autonomous agent serves to upgrade the simulation model and enhance the decision making process, the interface agent elevates the system's level of user friendliness. A database is activated for accumulating and retrieving the simulation data. This data is required for the preparation of a statement justifying the alteration of the current structure. iLeTS can be utilized to ascertain the waiting time. For this purpose, six autonomous agents were brought into play (one autonomous agent representing each station). Essentially, these six autonomous agents represent the maximum number of iLeTS stations. The interaction that takes place between these autonomous agents serves to generate precise results. This interaction is portrayed in Figure 4. Subsequently, the data from each autonomous agent is dispatched to the simulation model, as well as to the database for storage and future reference.

As illustrated in Figure 5, the autonomous agent in iLeTS is separated into three sub-autonomous branches: the machine agent, the worker's agent and the product agent. A worker's agent (WA) is connected to each manufacturing cell. This agent is tasked with administering the cell to ensure that the required manoeuvre is executed. A machine agent (MA), which is deemed an intelligent unit, is connected to every workstation. The main purpose of the MA is to process the resource and elevate its level of efficiency to meet the requirements of the manufacturing cell. A product agent (PA) comes into being each time an additional part is enlisted into the system. The features and methods in relation to these agents are displayed in Table 2.

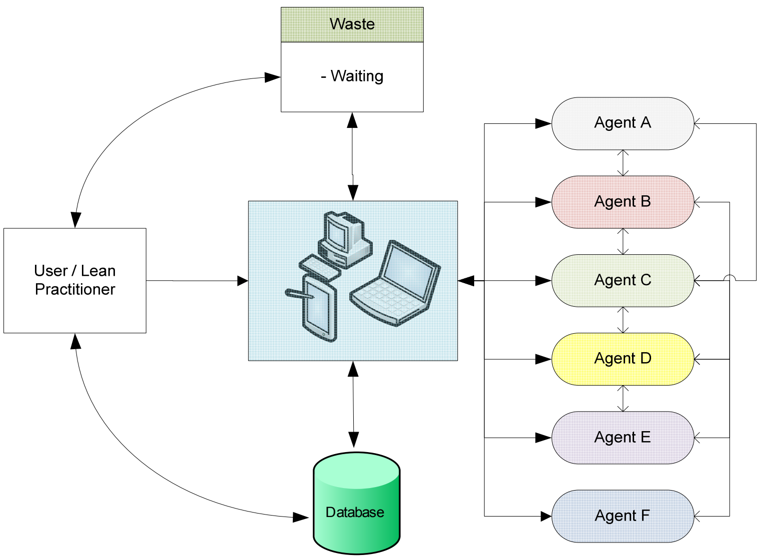
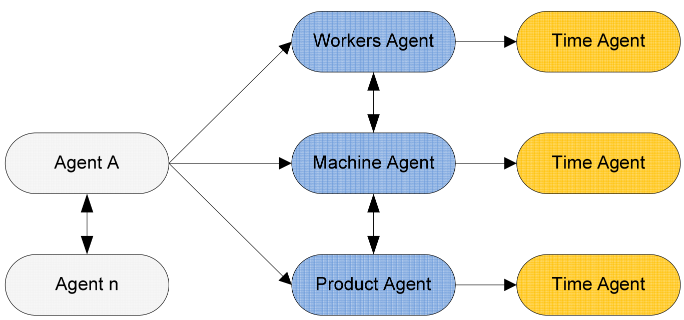


Figure 4. Automated waste identification by way of autonomous agents.

Table 2. Features of the autonomous agents

	Workers Agent	Machine Agent	Product Agent
Attribute	Name, gender, age, height, weight	Weight, size, brand, mechanism, power	Weight, size, packaging, shape
Method	Sick, rest, breakfast, lunch	Cleaning, maintenance, breakdown	Dropping, breaking, finishing, shaping



• *Time agent: Is the agent that measures the time cycle for each product (time taken by a product from entering the system to exit)*

Figure 5. iLeTS sub-agents.

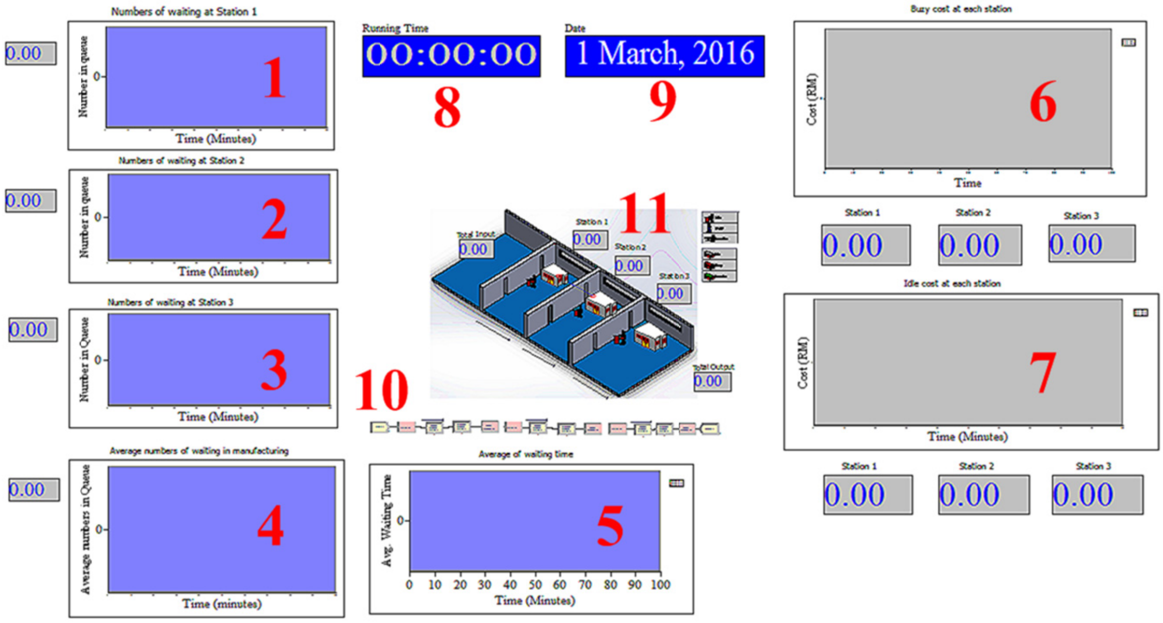


Figure 6. Intelligent agent indicator in iLeTS.

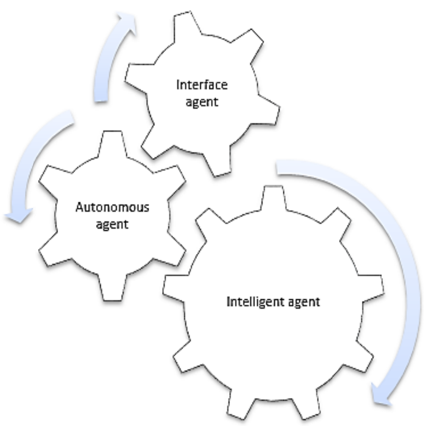


Figure 7a. Agent Interaction.

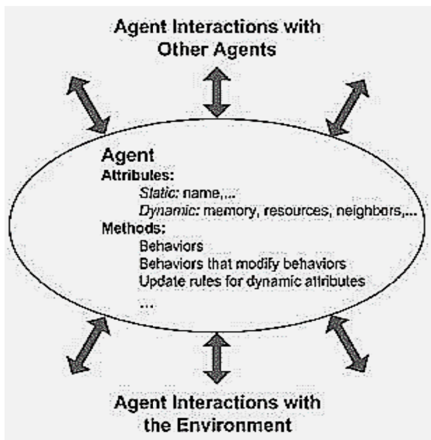


Figure 7b. Features of an agent.

Upon the close of simulation, the data acquired through the autonomous agent is stored in the database for the generation of graphs and future reference (Figure 6).

The LP can acquire information regarding the situation in a station (whether busy or idle) with the use of a graph. The graph will also disclose the quantity of goods waiting at each station (the stations are tagged 1, 2 and 3), the average quantity of goods in line (tagged 4), the average waiting period at each station (tagged 5), as well as the busy and idle expense at each station (tagged 6 and 7 correspondingly). Additionally, the production time is displayed under tag 8, the date is disclosed under tag 9, the modelling simulation is exhibited under tag 10, and the mimic production line can be observed under tag 11.

The efficiency and user-friendliness of iLeTS was enhanced with the application of thirty-seven interconnected interface agents. This interconnection of interface agents is illustrated in Figure 7a. As displayed in Figure 7b, each agent comes with its own distinguishing attributes and methods. While ‘attribute’ is in reference to the agent’s individuality, ‘method’ concerns its capability and perspective.

4. VERIFICATION AND VALIDATION OF iLeTS

The decision-making process, which is based on simulation models, can be made more precise through effective validation and verification techniques. While the decomposition model is used for the verification of each set of blocks, a simulation software equipped with a debugger is put into operation for the validation process. The decomposition procedure is exceptionally proficient at detecting inaccuracies, and for ensuring that the blocks are operating according to expectations. There are two main approaches for the gauging of validity: face validation and comparison testing. With face validation, a set of questionnaires is dispensed to twenty respondents. Comparison testing entails the weighing of the system output against the model output under identical input circumstances. The average percentage of deviation for this test is 15% (Mahfouz *et al*., 2011).

In a comparison testing exercise, the results from a case study are weighed against a computer simulation to assess the validity of the model. Table 3 exhibits the data used for this assessment. A summary of the case study results subsequent to the running of the model, as well as the actual results are provided in Table 4. The results derived from this comparison testing exercise clearly confirm the capacity of iLeTS for assessments on the system. The result shows that the number in (pcs) has been increased from 92.5 (case study) to 97 pieces through iLeTS. This indirectly indicates that the iLeTS is more efficient to calculate the maximum numbers of product entering to the system while numbers of product exiting from the system is 7 for both method (case study and iLeTS). In the comparison; there are three stations involve with different processing time (according to Table 3). The data has been gathered as tabulated in the Table 4 which shows that the confident interval of all the station above and nearly to the perfection. This can be put down to the fact that the confident interval of iLeTS was revealed to be above 90%. In the opinion of Mahfouz *et al.* (2011), the result from a comparison involving the system and model outputs under similar input conditions is acceptable provided the percentage of deviation is 15%. This declaration reinforces the conviction that iLeTS can be effectively employed for assessing the system.

Table 3. Case study

Types of Layout		T-Shape
Number of workstations		3 workstations
Number of workers		3 workers
Time between arrival		5 minutes
Entities per arrival		1
Station 1	Action	Seize delay release
	Processing time	15 min
Station 2	Action	Seize delay release
	Processing time	1 hour
Station 3	Action	Seize delay release
	Processing time	7 minutes
Number of replications		10
Replication length		8 hours
Hours per day		8 hours

Table 4. Case study results

	Case study	iLeTS	Confident interval
Numbers In (pcs)	92.5	97	97.6%
Numbers Out (pcs)	7	7	100%
Waiting Time			
Station 1	143.31	155.00	96%
Station 2	134.79	135.00	99.92%
Station 3	0	0	100%

5. USABILITY STUDY IN RELATION TO iLeTS

Two usability studies were carried out to evaluate the platform's capacity for lean manufacturing implementation. The initial usability study was aimed at assessing the existing structure, while the subsequent usability study was directed at assessing the performance of iLeTS. The usability study for the existing structure was carried out using the face validation procedure. This procedure is favoured by field specialists for examining the performance of a model (or platform), and making comparisons to arrive at a subjective opinion on its precision (Xiang *et al.*, 2005). Three colours (red, amber and green) were used to signify the status of the platform. A feature that is not a function is designated the colour red, a good feature is designated the colour amber, while an excellent feature is designated the colour green.

The usability of both modules was evaluated through a survey participated by twenty LP respondents. Prior to the distribution of questionnaires, the respondents were required to try out the existing platform. The questionnaire came with five segments: system capabilities, result, ease of use, satisfaction and perceived usefulness. In accordance with section 4.1 at ISO/IEC 25010:2011 (https://www.iso.org/obp/ui/#iso:std:iso-iec:25010:ed-1:v1:en), all the above mentioned segments were visited. For each segment, the specialist was obliged to respond to specific queries by selecting either of the two available options: clear/no/fast enough/reliable/likely or confused/yes/too slow/unreliable/unlikely. A summary of the data gathered through the usability study is displayed in Figure 8, where 'friendly and good' is indicated by the colour green; 'medium' is indicated by the colour amber and 'requires improvement' is indicated by the colour red.

The value of the five features in relation to the existing structure is portrayed in Figure 8. As can be observed, the value for segment 4 (which refers to 'result') leaves much to be desired. A substantial amount of fixing and improvements are in order here as respondents were obviously unimpressed by this feature. As such, intelligent agents were brought into the picture in a bid to rectify the weaknesses in this area. The merging of intelligent agents with the existing structure gave rise to iLeTS.

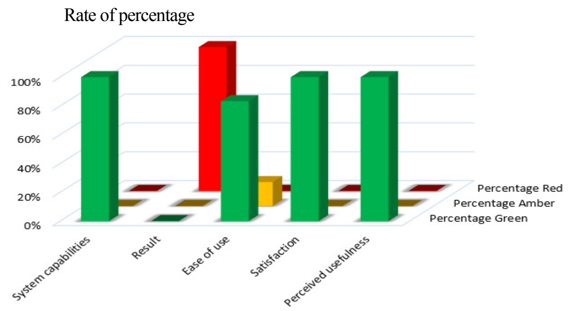


Figure 8. Results from usability study on existing structure.

While the verification process for the platform involved the monitoring of every product from their origination point to their clearance point, corroboration was realized by way of face validity. Face validity entails the employment of a questionnaire to elicit feedback relating to the result.

The applicability of iLeTS was determined through a usability study. The initial query for specialists who had tried out this platform concerned the reading of the result. According to the responses recorded in the questionnaires distributed, the respondents were in agreement that the result was easy to read. The next query sought to ascertain the difficulty (if any) respondents encountered in perceiving the waiting time (among the wastes in lean manufacturing) at the system on the whole (second question), and at each station (third question). The respondents were in accord that they did not encounter any difficulties in this area. Question 4 focused on the effectiveness of iLeTS in the context of enhancing the decision-making competency of the LP (or user). All respondents concurred that the platform efficiently enhanced the LP's (or users) decision-making capability.

Figure 9 provides a summary of the values deriving from the features of iLeTS. The various conditions of the segments are indicated by three colours: green for 'friendly and good', amber for 'medium', and red for 'have to improve'. Generally speaking, iLeTS can be described as an improved route towards the exposure of waste. According to feedback gathered through the survey conducted, all the features furnished exceptional results

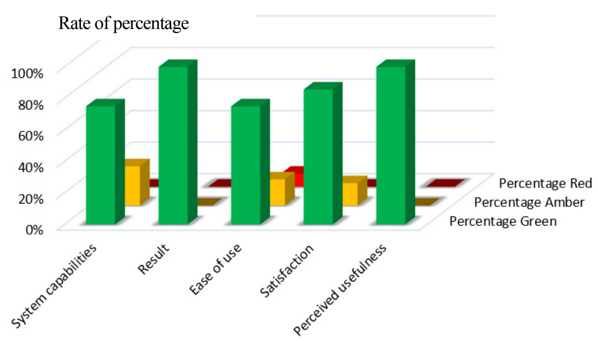


Figure 9. Results from usability study on iLeTS.

(green condition). As such, it can be surmised that the inclusion of an intelligent agent on the platform improves the efficiency of LM implementation, as well as that of the decision support system (DSS).

6. CONCLUSION AND SUGGESTIONS FOR FUTURE ENDEAVOURS

The development of iLeTS was directed at (a) raising the user friendliness level during LM implementation, and (b) altering the simulation mode from one that is static to one that is dynamic. While visual basic application was applied to improve user friendliness during LM implementation, the introduction of multi-arena modelling (MAM) and intelligent agents served to realize a dynamic simulation mode. The verification of iLeTS was achieved through a case study, while its reliability was determined by way of face validity. The usability study supported the applicability of iLeTS for enhancing the decision-making accuracy during LM operations. Undoubtedly iLeTS still have some limitation; one of them, its only can used to evaluate cellular layout and another is that it requires computer with Arena Software. Due to this limitation, we recommend that future investigations are to take place and further emphasis on the stated issues.

- The extension of this procedure to rope in a variety of other lean instruments. This can lower costs and save time as this procedure can then be used to manage a wider range of difficulties.
- The expansion of iLeTS through the engagement of Apple and Google Play applications. This can serve to increase the options available for assessments on the system.
- The increasing of iLeTS functions and the reduction of simulation restrictions in terms of workers and stations. This will render the platform more comprehensive during assessment exercises.

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REFERENCES

Abdulmalek, F. A. and Rajgopal, J. (2007), Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study, *International Journal of Production Economics*,

107(1), 223-236.

Al-khafaji, S. K. H. and Al-Rufaifi, H. M. R. (2012), A `case study of production improvement by using lean with simulation modeling, *Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management*, Istanbul, Turkey, 271-279.

Alzraiee, H., Zayed, T., and Moselhi, O. (2013), Assessment of construction operations productivity rate as computed by simulation models, *Proceedings of the 2013 Winter Simulation Conference*, IEEE, Washington, DC, USA, 3225-3236.

Anbumalar, V., Mayandy, R., and Arun prasath, K., and Sekar, M. R. C. K. (2014), Implementation of cellular manufacturing in process industry: A case study, *International Journal of Innovative Research in Science, Engineering and Technology*, **3**(3), 1144-1149.

Banks, J., Carson, J., and Nelson, B. (2005), *Discrete Event System Simulation*, Pearson.

Ghosh, M. (2012), Lean manufacturing performance in indian manufacturing plants, *Journal of Manufacturing Technology Management*, **24**(1), 113-122.

Karim, R. and Rahman, C. M. L. (2012), Application of lean manufacturing tools for performance analysis: A case study, *Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management*, Istanbul, Turkey, 1725-1734.

Mahfouz, A., Shea, J., and Arisha, A. (2011), Simulation based optimisation model for lean assessment in SME: A case study, *Proceedings of the Winter Simulation Conference*, Phoenix, Arizona, 2403-2413.

Mohamad, E. B., Ibrahim, M. A. B., Sukarma, L., Rahman, M. A. A., Shibghatullah, A. S. B., and Bin, M. R. (2017), Improved decision making in Lean manufacturing using simulation based approach, *International Journal of Agile System and Management*, **10**(1), 34-48.

Mohamad, E., Ibrahim, M. A., Shibghatullah, A. S., Rahman, M. A. A., Sulaiman, M. A., Rahman, A. A. A., Abdullah, S., and Salleh, M. R. (2016), Simulation based approach for lean manufacturing tools implementation: A review, *APRN Journal of Engineering and Applied Sciences*, **11**(5), 3400-3406.

Mohamad, E., Ito, T., and Yuniawan, D. (2013), Quantifying benefits of lean manufacturing tools implementation, *Journal of Human Capital Development*, **6**(2), 13-26.

Mohamad, E., Nawuiddin, S. R., Mohamad, N. A., Sulaiman, M. A., Salleh, M. R., Yuniawan, D., and Ito, T. (2018), Development of a simulation based kanban system for lean practitioners, *Proceedings of the Japan Society of Mechanical Engineers: The 28th Design Engineering System Division Lecture 2018*, Yomitan village, Okinawa Japan, 2202_1-2202_10.

Pettersen, J. (2009), Defining lean production: some conceptual and practical issues, *The TQM Journal*, **21**(2), 127-142.

Senthiiland, P. V. and Shirrushti, A. (2014), Productivity enhancement with lean concepts in belt driven compressor industry, *International Journal of Recent Advances in Multidisciplinary Research*, **1**(3), 51-55.

van der Zee, D. J. (2012), An integrated conceptual modeling framework for simulation-linking simulation modeling to the systems engineering process, *Proceedings of the 2012 Winter Simulation Conference*, Berlin, Germany, 1-12.

Wahab, A. N. A., Mukhtar, M., and Sulaiman, R. (2013), A conceptual model of lean manufacturing dimensions, *Procedia Technology*, **11**, 1292-1298.

Williams, E. J. and Ülgen, O. M. (2012), Pitfalls in managing a simulation project, *Proceedings of the 2012 Winter Simulation Conference (WSC)*, IEEE, Berlin, Germany, 1-8.

Womack, J. P., Jones, D. T., and Roos, D. (1991), *The Machine that Changed the World: The Story of Lean Production*, How Japan's Secret Weapon in the Global Auto Wars will Revolutionise Western Industry, New York, NY: *Harper Perennial.*

Xiang, X., Kennedy, R., Madey, G., and Cabaniss, S. (2005), Verification and validation of agent-based scientific simulation models, *Proceedings of the 2005 Agent-Directed Simulation Conference,* San Diego, CA, 47-55.