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CASE STUDY: LEAN-RFID BASED WASTE IDENTIFICATION SYSTEM ON EXAMPLE OF SMALL-MEDIUM MANUFACTURING INDUSTRIES

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Abstract
The purpose of this research is to develop a Lean-RFID based waste identification system (LRWIS) for small-medium manufacturing companies. The specific objective of this research is to develop and implement the LRWIS from integrating the appropriate lean tools and advanced technologies for wastes reduction and inventory management. Subsequently, the framework was converted into a system for a small-medium sized wood processing manufacturer in Malaysia and integrated into a computerized program. The LRWIS can monitor real-time inventory and production status so the manufacturer can optimise the quantity of the primary products and deliver them on time as per the RFID information of each container. The manufacturer can also make decision instantly for controlling and changing different products in the production progress. The system provides simple constructed framework under a low cost infrastructure, yet it is of practical value in reducing the wastes and also optimising the production process.

Keywords
lean manufacturing, lean management, pull production, waste identification system.

Introduction

Manufacturing process involves various material-handling operations. Improvement of production efficiency is always a focal point for any manufacturers. The improvement can be achieved through its common operational tasks such as picking, checking, counting, moving, and delivering of products, which can be implemented at the better timing for the right material in the right quantity at the right workstation [1, 2]. Lean is well-received and recognised principle in the manufacturing process, which is originated from principles of Toyota Production System [3]. The primary goal of lean thinking is to eliminate waste [4, 5]. Lean also can improve productivity, performance, and commitment of culture for continuous improvement in process [6]. Appropriate lean tools and other logistic knowledge can be implemented for the reduction of wastes through its lean management system [7].

Recent studies of lean manufacturing tend to focus on the impact and adoption of lean practices in performance improvement, for example, increasing the quality in the process industries including common outcomes in reduction in wastes, cost and inventories [8, 9]; balancing flexible workforce in the assembly line [10] and improving efficiency of warehousing and routing operations [11]. Some advanced technologies have been incorporated with lean principles such as the Internet of Things (IoT) with lean for designers [12, 13]; radio frequency identification (RFID) with lean manufacturing for real-time cost tracking [14] and production [15]; and building information modelling (BIM) with lean principles for construction and operation management [16]. However, from the perspective of actual implementation of lean manufacturing on small and medium manufacturing companies, their management are lack of awareness in lean about the importance of RFID.

As part of logistics system, inventory control system gives some vital functions. As an integration element in logistics chain, it can make sure the flow of material is smooth without delay [17]. Secondly, as an aid of customer service expansion because the company can provide immediate response to customer requests and consumes shorter time to send out the items. Thirdly, the movement of the materials and inventory system of an organisation will help decrease the inventory level and increase the inventory turnover [18]. Next, it can balance the different directions of material movement and also control the delivery time of item, production and consumption [19]. Last but not least, it can be used as a buffer when unexpected events occurred. For example, delay of delivery, lost of items and others. Those vital functions can be related to the goal of lean management, which means the inventory can be maintained at optimum point, smallest wastes and highest value. The environment nowadays is getting competitive and it gives pressure to companies especially to cut costs and expenses. In order to achieve the objective, companies need to reduce waste in the transformation process [20]. In this case, inventories are known as the waste which gives impacts on the business. Therefore, it is important to introduce inventory control system to lean management [21].

Hence, this research aims to develop a Lean-RFID based waste identification system (LRWIS) for small-medium manufacturing companies. The specific objective of this research is to develop and implement the LRWIS from integrating the appropriate lean tools and advanced technologies for wastes reduction and inventory management. Deductive reasoning approach was adopted to develop the framework of the LRWIS, and subsequently the LRWIS was programmed and implemented into a small-medium wood processing manufacturer as the case study of the research. Since small-medium manufacturers lack of knowledge and awareness about lean manufacturing, the LRWIS will generate simulation results according to the situation of the companies before further proceed to fully implementation.

Related literatures

Toyota has created the lean concept so that the companies can achieve their objective without large human effort, time or cost [6]. Nowadays, the lean concept is commonly used in a lot of industrial sectors, especially manufacturing. Lean concept becomes popular because it can reduce cost, increase quality and improve efficiency [22]. By using lean tools and techniques, the company can achieve the improvement that they desire. However, the lean concept does not have a specific definition. This makes the lean management become vague and difficult to persistently conduct the lean ideas towards the goals. On the other hand, the people who continues the lean concept with strong commitment will further enhance their supply chain in terms of lean principles [23].

A supply chain consists of facilities and activities which executes the duty of developing of products, ordering of raw material, manufacturing of products and goods delivery to consumers. There are four members in the supply chain which are supplier, manufacturer, distributor and end customer. The concern on lean application is within shop floor of each organization but not beyond the whole supply chain. Majority of big companies agree that it is insufficient to improve performance in an organisation. Lean management benefits the organisation as it increases the efficiency of supply chain management. As a result, companies prefer to adopt lean management to merge the supply chain members and activities. When lean is operated in the whole supply chain, the supply chain is known as lean supply chain (LSC) [23] and further application of it will lead to lean manufacturing.

Lean manufacturing is to use a set of techniques and tools to reduce or eliminate the seven wastes (MUDA) in Toyota as proposed by Taiichi Ohno [24, 25]. There are two core principles in Toyota Production System: Just in Time (JIT) and Jidoka. In terms of quantity control, JIT always serves as the main concept of inventory control for supplying the exact quantity at the right time and place. The waste from poor inventory management can bring significant cost implication from over-production items and waiting work-in-progress (WIP). With the clear knowledge and philosophy of lean manufacturing, the companies will focus on the value-added activities for saving capital and time. It also can contribute to waste elimination, optimization, process control, productivity, reduction of lead time and quality through lean manufacturing system [26, 27]. One of the core subjects in lean management system is inventory management, which is the important part of the supply-chain that contributes to large amount of capital cost, especially for small-medium manufactures.

In inventory management, manufacturers always face the challenges such as availability of items, holding cost, ordering cost and other related elements. For example, a demand-pull replenishment method derived from lean principle called dynamic drum buffer-rope (DDBR) is implemented in the hospital inventory management, where it determines the appropriate buffer size, optimum replenishment quantities, accurate timing to maintain lowest inventory cost without late delivery [28] manufacturing industry, the word inventory is mentioned as the stocks of finished goods, work-in-process and raw materials [29]. The relationships between the different types of inventories are affecting each other. Inventory should never be too low that would affect the production line and delay any delivery. It also should not be very high that would incur too much capital cost. Hence, a proper control of inventory which includes planning, purchasing, handling and other business functions, will only bring to optimum and successful inventory management.

Apart from that, quality information in inventory management is always the key concern in the whole supply-chain process as any wrong information will lead to discrepancies of inventory errors such as shrinkage, misplacement and human error [30]. To reduce the errors, implement lean analytical model such as Kanban, levelling and Just in Time (JIT) with advanced technologies could improve the supply-chain performance and save large capital cost [31]. The integration of related information technologies in supply-chain management can improve management, customer satisfaction and overall functional efficiency [32]. The company always plans long term development of future and framework that can reach sustainable inventory management [33]. The elements of sustainability include product life cycle, supplier, capital flow and other long term factors in the company. These elements will help to satisfy the customer needs in manufacturing projects. The needs are the value of activities that were defined by customers. There are only two types of activities concerned by manufactures through Value Stream Mapping (VSM), namely, (a) value-added activities refer to the customer is willing to pay for and (b) non value-added activities refer to the customer is not satisfied to pay for [34]. It will promote and help for continuous eliminating of non-value-added activities and wastes.

For implementation of lean principles in waste reduction and inventory management, a computing foundation is important to maintain the stability and consistent of process flow so that meet the required delivery of products. The computing foundation should consider JIT, 5S (Sort, Simplify, Shine, Standardize, Sustain), Total Productive Maintenance (TPM), multi-skilled workers and etc. It will ensure the implementation of lean tools will not interrupt the stability of process flow [35]. Without a constant and smooth process flow, any application of lean tools is unsuccessful and wasting time [36]. With recent technologies, RFID serves as an important trend of lean application in terms of inventory waste reduction into the processes [14, 15]. The integration of RFID and lean tools can eliminate the barriers of lean principles such as insufficient of lean awareness, poor employee management, resource allocation, bad inventory monitor, extra lead time and other problems [37]. The affecting level also can reach supply chain management, logistic and inventory tracking by enhance the process visibility [38].

Next, transportation is important element in inventory control management due to its ability of controlling the flow of materials, affecting the logistic costs and determines operation performance of supply chain in a company. To a certain extent, transportation affects the desired value and variability of supply lead time, which means the elements such as optimum volume of order quantity, reorder point, safety stock, buffer stock and some inventory terms are involved. Therefore, fast and short transportation can logically reduce the lead time and relevant inventory costs [39].

Nowadays, technology allows process of manufacturing to become more complex and adjustable than it was in the old days. There is massive effort in improving wireless technologies (WTs) [40]. In addition, WTs also allow a broad variety of applications on factory and industrial level. Implementations of WTs can be easily found in case studies. Lean manufacturing is a well-developed philosophy of advancing project processes. Lean organization can use WTs to decrease waste. There is massive evidence that lean techniques and principles can fit rightly with WTs. For example, bar-coding, RFID, which is new technologies give a chance to aid in TPS which make the foundation for lean manufacturing. New technologies time to market is reducing sharply.

Kolberg shows a border framework and examples of Kanban, Andon, Heijunka and Bin to approach combination of Industry 4.0 concept and lean manufactured [41]. It is clear that RFID help to reduce seven wastes. Furthermore, Rafique et al. showed how RFID give positive impact to barriers which will affect lean manufacturing by managing an extensive literature review on lean's barriers and RFID-based lean manufacturing [37]. Simulated RFID scenarios are extremely effective in reducing wastes addressed in lean manufacturing.

Lean manufacturing involves the tools which can increase the profit and decrease waste in the process of manufacturing. In this situation, manufacturing companies need a real-time assessment tools to help them in measuring the monetary impact when lean improvements are implemented so that the gap between the operational and financial views can be narrowed down. However, as the traditional costing systems are not referring to lean principles, the lean manufacturing improvements on monetary systems are unclear. In this context, the VSM is used to track the costs of manufacturing [42].

To improve the effectiveness of VSM, a real-time system is needed. Hence, RFID technology can be used because RFID allows vital power for human to understand the world. RFID gives rapid data collection with accurate identification (i.e. IDs). In this context, RFID is very useful as it can be used for identifying, placement, tracking and managing physical objects. Past studies had revealed a fundamental real-time VSM integrating an "On-line RFID-based Facility Performance Monitoring" (ORFPM) system with RFID technology to trace the location of materials [43]. As a result, the system has successfully transferred data, expanded a database for transportation time and lead time and produced a real-time VSM.

RFID tags can reflect the identity of an object and transmit the information of the object wirelessly. By using this technology, the location, condition and history of the object can be known immediately. It can reduce human error during data management process.

In industrial circle, RFID technology is widely used especially in production automation and inventory management. When operators tracked operation, they will collect data and exercise barcode scanning operation. However, it can be completely carried out by using RFID technology.

There are two types of manufacturing systems that can use RFID in management which are conventional and distributed control. In conventional systems, it is quite common that RFID is used for data integration and production control systems. In this context, items in production can be automatically transferred to suitable locations. On the other hand, distributed manufacturing uses RFID in identified products so that the products can be triggered according to the command.

RFID is useful and it is used broadly in manufacturing applications. However, many managers were perplexed as they do not know how to look for opportunities even though RFID helps them to carry out a leaner manufacturing situation. It is because companies do not have sufficient knowledge in that area and lack of case studies which related to manufacturing. Hence, this research gap needs to be addressed to release the full potential of the integration of lean principles and RFID for manufacturing projects.

This case study attempts to investigate the process of plywood production. The aim of the study is to describe and figure out the possibilities of changes in the production process to enable the company to optimize the production flow and eliminate the wastes. One of the factors for the reduced cost is automated development system. In LWRIS, it can help the company to automatically manage the inventory system, monitor the production flow, increase the efficiency of resources and reduce the wastes. Many facts showed costs reduction in manufacturing company can be achieved by modern technology [40].

Another problem faced is having too many poor managers focusing only on setting goals and ordering the employees to achieve them [44]. Most of the time the employees have to find their own ways to achieve the targets and this makes the process inefficient. The key to success is to standardize and simplify the process. By implementing LWRIS, the employees always know their main tasks immediately without any delay. This can motivate the employees to achieve the goals and make the processes more efficient and effective.

Methodology

Deductive reasoning approach was adopted in this research. The design of the framework was modified from TPS in (a) designing the layout for the system in terms of lean manufacturing and elimination of wastes, and (b) investigating and incorporating the appropriate lean tools and advanced technologies. Subsequently, the required programming system to implement the framework for a real condition was developed.

Inventory wastes were selected as the target in the research, particularly for overproduction and waiting wastes. Reduction of inventory in the form of raw materials and WIP requires a comprehensive system that is able to eliminate the quantities of waiting items and overproduction items. Figure 1 illustrates their relationship should be considered important when they come into value stream mapping, which are non-value added activities.

Besides these wastes, transportation is also being considered as it affects the flow of supply chains and logistic costs. To identify and investigate the information of transportation in a company, the existing production layout and system are evaluated with the proposed framework by using software and formulas. The results including the optimum volume of order quantity, lead time, safety stock, buffer stock and some inventory terms can be measured in logical ways.

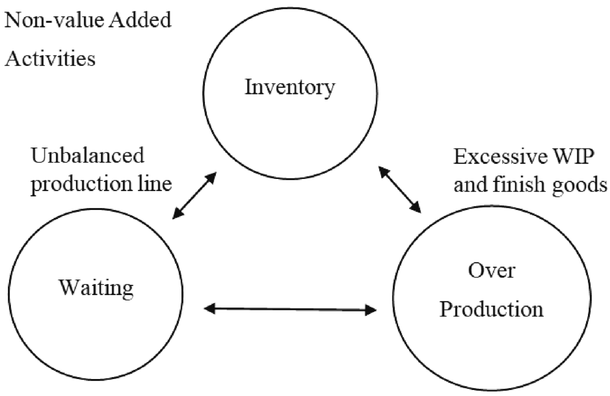

Fig. 1. The relationship of three wastes (Inventory, waiting and over-production).

Framework development

Conventionally, just in time (JIT) is the main concept to eliminate wastes of inventory, waiting and overproduction. However, JIT can be more reliable and effective in lean manufacturing when working with other suitable lean tools. Hence, some related lean tools were considered in the framework development as per their common uses in lean manufacturing, namely, production levelling, Kanban and VSM. Production levelling is to manufacture the product depends on the long-term average supply and demand. Product would be made at the same rate with the customer ordering and withdrawing. There should be no stack of inventory between lines to lines. This lean tool would reduce the WIP inventories and unnecessary costing of operations for the whole production process. Apart from that, Kanban was used to reduce inventor and limit the operation of every single production line to avoid overproduction. Basically, this lean tool is a type of communication among ordering, withdrawing and replenishing [45]. Every processing material would be attached with the information of Kanban. It would have the function of pulling. Besides, VSM is to analyse and investigate the value of the current and future state of the activities and events. It would evaluate and optimize the process lead time, cycle time and takt time. This could bring out continuous improvement in determining added and non-value activities.

Generally, a manufacturing company requires material requirements planning (MRP) to consistently maintain the supplies and orders. There are some contradictory aspects at different levels of management between lean principles and MRP, especially from the perspective of small-medium manufacturers [46]. One of the major reasons is JIT takes time for monitoring the data in response with lead time, cycle time and takt time. This is continuous improvement so that the production manager can determine the optimum inventory and lead time by modifying the production line after implemented the lean tools. In order to overcome these drawbacks, the lean principles need to integrate with appropriate advanced technologies to address the contradictions. Therefore, Automatic identification system (AIS) was considered in the framework to automatically identify each activities and objects, capture the data of activities and send information into a monitoring system. RFID was chosen to integrate and work with the lean tools to track the moving objects within an effective range through radio-wave which up to $3\sim5$ meters based on the tag properties. The detect range should able to cover the material flow or pallet without interrupt the production process. This could be served as a lean and RFID-based integrated system that would work as instant and accurate communication system among supplier, customer and production management. The design layout is based on lean principles and RFID. It shows the monitoring of information and material flows through the proposed inventory system. Any changes of inventory would be recorded and reflected to the functions in the program (see Fig. 2).

The performance of RFID would depend on the design of computerized programming, RFID infrastructure, production layout and algorithms implanted. It would monitor and interpret the information flow in a clear, accurate and swift manner. Figure 3 shows the monitoring process of the framework under an ideal situation. It would include inventory, production line, supply and distribution. Inventory refers to every item inside company and Kanban process reduces excessive inventory. Production line refers to the value of every production line is figured out by Value Stream Mapping and pull production maintains the least WIP to approach line balancing. Supply refers to the information of Material Requirement Planning (MRP) in supply-chain and obtain optimum replenishment inventory by lean-RFID process. Distribution refers to the information of Distribution Resource Planning (DRP) in business administration and obtains optimum planning order according to inventory, production line and supply.

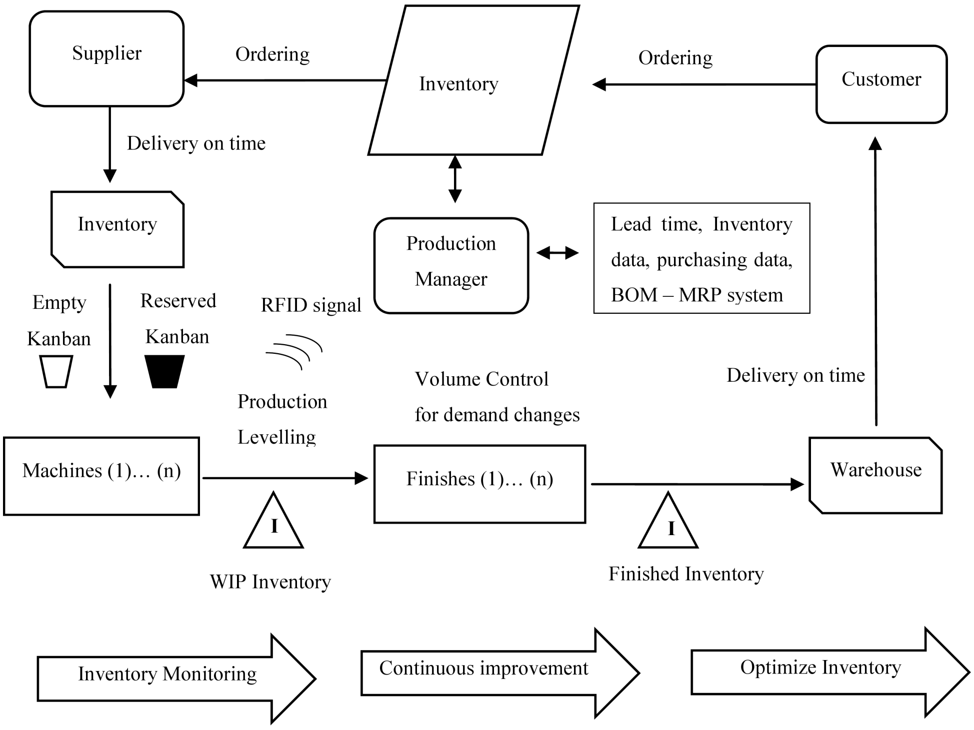

Fig. 2. Framework of LRWIS.

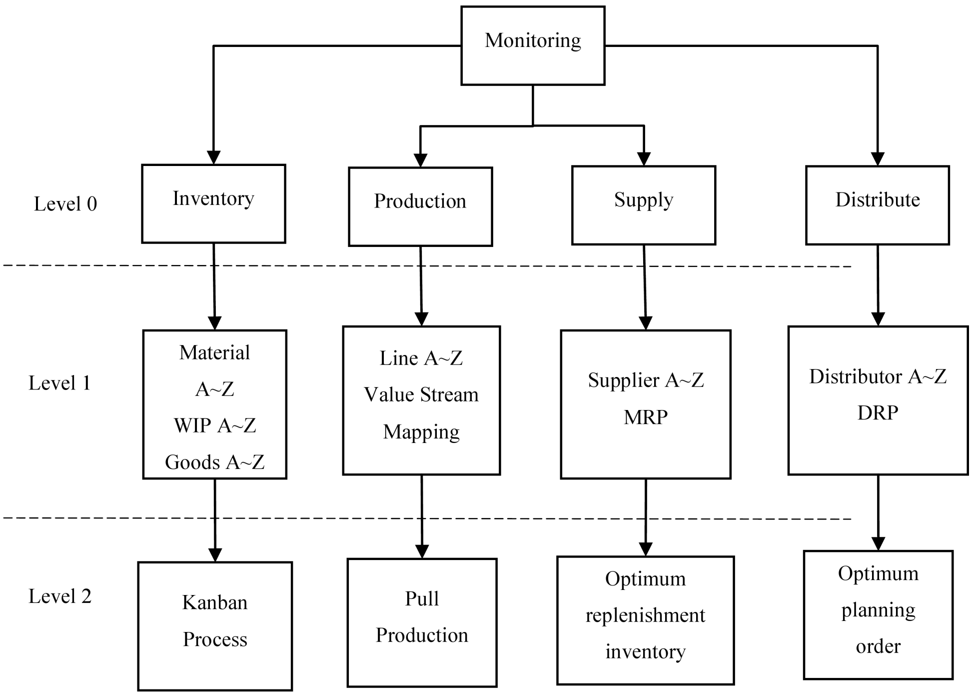

Fig. 3. The monitoring process of the framework.

The inventory section would assess the items including raw material, WIP and finish goods. The information involved daily average demand, production volume, safety stock, buffer stock and others. The data captured by RFID would be the current inventory volume and status of Kanban unit (maximum inventory for delivery without any lateness). Figure 4 shows the example of calculating the optimum inventory volume using the Kanban concept in the framework.

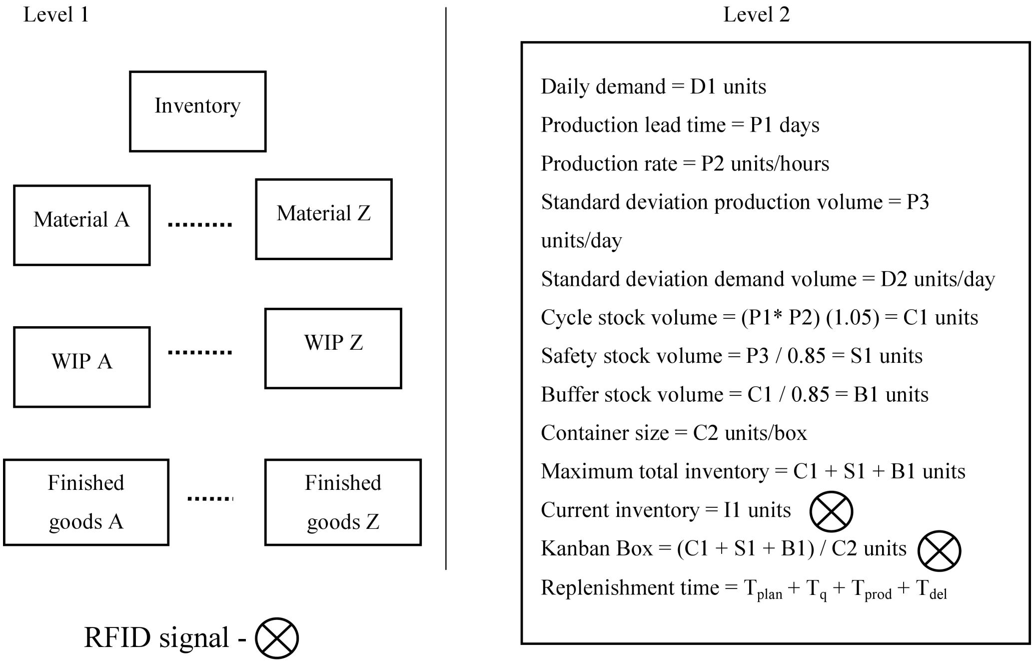

Fig. 4. Example of the inventory section in the framework.

The production line section would assess the workstations of production. The information shows the input/output of workstations, WIP inventory quantity, cycle time and waiting time. VSM concept could be adopted to identify value-added and non-value added activities. Figure 5 shows the simple construction of value stream mapping in the framework. The diagram and flow of mapping was constructed from beginning to end. RFID could capture the timely data of each workstation for real-time monitoring.

The supply section would monitor the status of supply at the beginning from raw material to WIP. This would show supply rate of the process, shipping time to station, delivery of each material and others. MRP could be integrated into the system and cooperated with the proposed LRWIS. RFID would sense the input and output of workstation so that the user could evaluate the required supply time to each station, forecast of replenishment inventory and procurement management. Figure 6 shows example of the materials supply rate in the framework. A fully integrated lean-RFID system and MRP could gain valuable feedbacks such as the performance of each supplier to control the quality of materials.

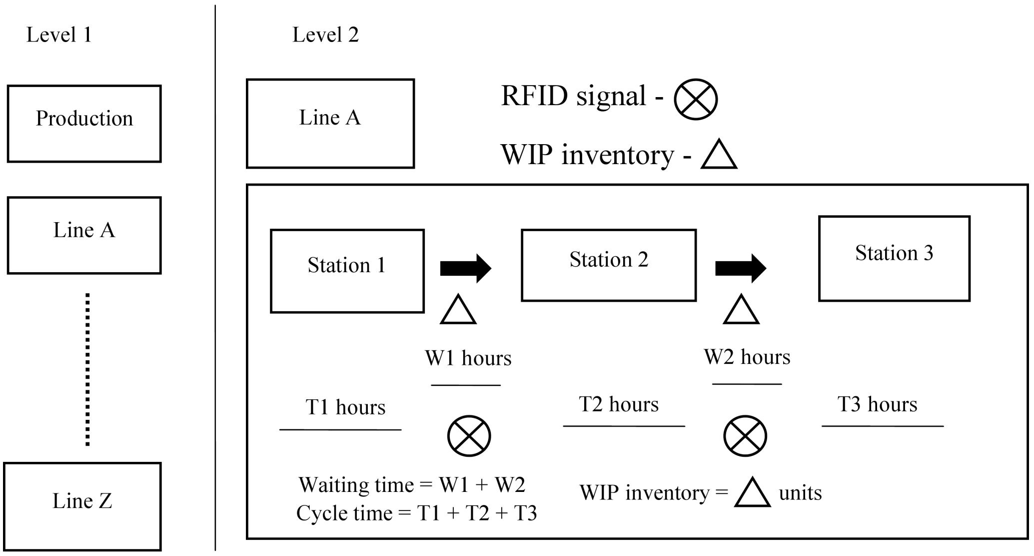

Fig. 5. Example of the production line section in the framework.

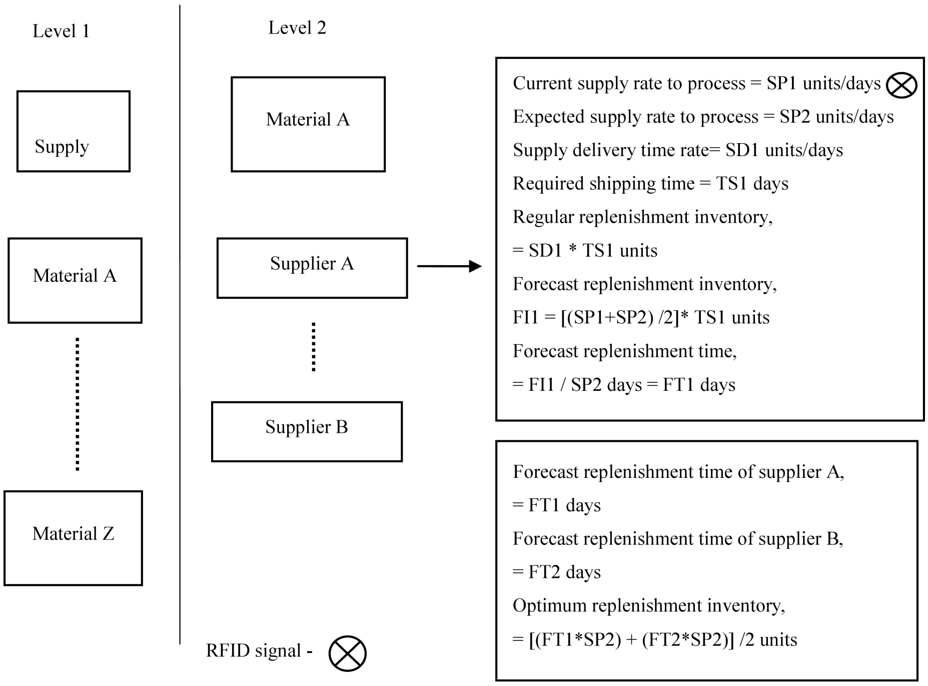

Fig. 6. Example of the supply section in the framework.

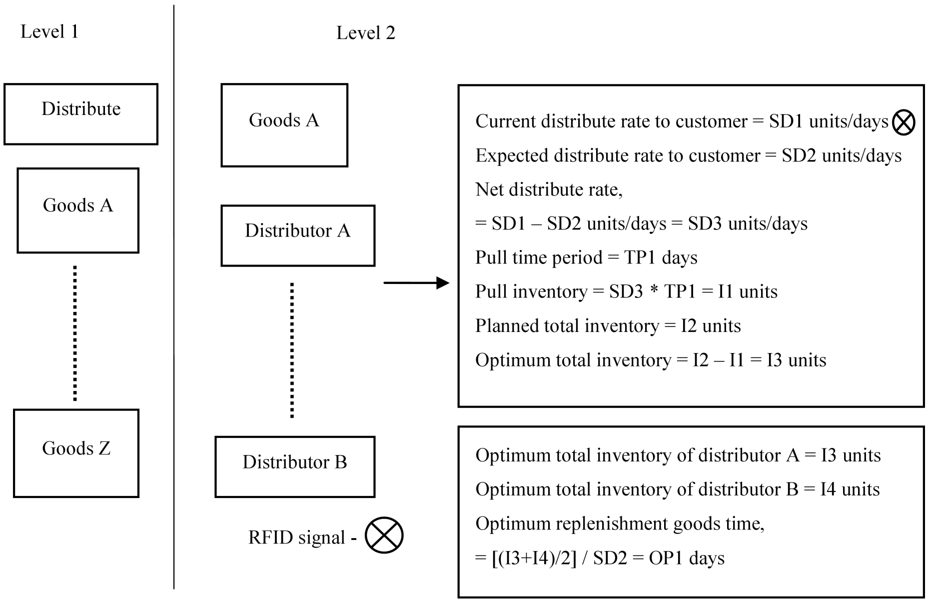

Fig. 7. Example of the distribution section in the framework.

The distribute section would monitor the flow of goods, distribution rate, planned/actual inventory and others information needed in Distribution Resource Planning (DRP). The performance of the distribute section would depend on the cooperation between business administration and production. Figure 7 shows the example of each good distribute rate in the framework. The formulas and concepts were derived from different references which are changeable for the company own sake.

Case study on a small-medium size manufacturer

Several preparatory steps were conducted to demonstrate the value of the LRWIS in the case study. First, a small-medium sized wood processing manufacturer was selected based on their acceptance of lean principles and willingness to participate in this research. Table 1 shows production details and background information of the manufacturer. In this discussion, the information is needed such as work stations, inventory status, storage system and others. Due to privacy issue, some commercial sensitive information would not be revealed and some calculations or amounts were estimated roughly. Figure 8 illustrates the production line of the company

Table 1
The production details and background information of the small-medium sized manufacturer.

Location	Sungai Buloh, Malaysia
Manufacturing area	Wood Processing
Product	**Primary:** • Single size bed board • Double size bed board **Secondary:** • Pallet • Finger-jointed bed board • Broomstick
Storage system (Inventory)	• Bulk Storage • No identification system • Manually checklist
Supplier	Weekly, 3 tons of raw woods (able to manufacture about 700 sets of single size bed board)
Client	Daily, average 150 order quantity.
Transport	• Forklift truck • Hand truck
Process	• Cutting • Moulding • Dovetail finger joint • Glue Binding • Pressing • Stapling
Average production output	**Primary:** • 150 sets average bed board and 50 sets average finger-jointed bed board daily **Secondary:** • Pallet (depends on the client) • Broomstick (depends on the client)
Some background questions for the person-in-charge	
Questions	**Answers**
Do you know about lean manufacturing?	No
Do you have applied any identification system for the production, inventory and transport system?	No. Manually control.
Do you have applied any computerized system and programming?	No. We are only using computer for daily paperwork such as Microsoft excel and Microsoft word.
Person in Charge comments	We do not have a clear inventory system. But, we are very interested if there is solution for the wastes and inventory problems.

Fig. 8. One of the workstations in the production line.

Second, the proposed framework of the LRWIS was used and modified according to the current status of company. Due to lack of information about supplier and client, the framework was focused on inventory and production. The computation of inventory for required RFID tags were designed based on the primary products. Third, the company's production layout was drawn by using Solidworks as illustrated in Fig. 9. This could help in visualising every work station, work-in-progress, and inventory.

Forth, the LRWIS was programmed by using Visual Basic and presented as Graphical User Interface (GUI). The selection of Visual Basic for riting the GUI program was due to its user-friendly platform and it can be imported into the database system such as Microsoft Access. The RFID module is chosen within ISO18000-6C (EPC Gen2) such as R2000 chip UHF RFID for implementation in manufacturing. This kind of module can be integrated into monitoring controller for automation purpose.

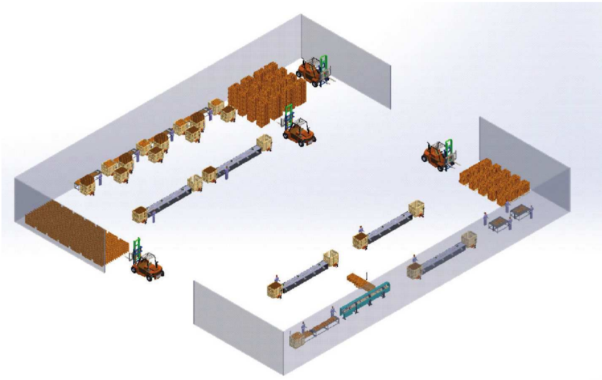

Fig. 9. The production layout of the manufacturer.

To evaluate the system, the production processes, storage system, replenishment time, production output and other related information were gathered. The outcomes could be organised into three categories, namely, inventory information, production layout and integrated system program and interface.

Inventory analysis

Two common finished products of inventory were targeted in the research, namely, single size bed board and double size bed board. For the inventory computation, daily shipment, takt time, production time, replenishment time, production rate and demand rate were calculated for the cycle stock, safety stock and buffer stock. To the cycle stock, all Kanban boxes were attached RFID tag and recorded into the computer system with 'Heijunka board' concept. For buffer and safety stocks, past records were used to measure them based on production rate (internal variation and demand rate (external variation) respectively. Table 2 shows one of the examples in summarizing the inventory computation for this system. With this Kanban concept, the company can maintain inventory level at optimum without excessive WIP and finished goods. The method of computation was derived from the implantation of lean manufacturing [23].

The safety factor and required replenishment time were critical to evaluate cycle stock volume depends on the production process. The required data to calculate the cycle stock, safety stock and buffer stock were as follows:

- Alpha to meet safety factor for replenishment time = 0.05.
- Daily Shipment = 75 sets/8 hours.
- Production time = 8 hours (one day working time).
- Takt Time = Production time/daily shipment = 0.1067 hour.
- Size for each Kanban container = 30 sets (container size depends on maximum volume of complete set of bed board that forklift can transport).
- Required replenishment time = Planning Time + Order Queue Time + Production Time + Delivery Time = 49 hours.
- Production rate = Daily shipment/production time = 9.375 sets.
- Cycle stock volume = replenishment time x production rate/(1 + safety factor) = 434 sets.
- Total cycle stock Kanban = cycle stock volume/container size = 15 containers.

Regarding safety and buffer stock, the acceptable level of delivery on time was set with 99% of confident. It would need Z score of 2.33 Sigma for one-tail test to meet required coverage. The required details were as follows:

- Standard deviation of production rate for a 30 days period = 7.06.
- Standard deviation of demand rate for a 30 days period = 5.62.
- Safety stock volume = sigma * standard deviation of production rate = 16.45 = 17 sets.
- Buffer stock volume = sigma * standard deviation of production rate = 13.09 = 14 sets.
- Total safety stock kanban = safety stock volume/container size = 17/30 = 0.56 (1 container).
- Total buffer stock kanban = buffer stock volume/container size = 14/30 = 0.46 (1 container).

Table 2
The computation results of the single size bed board inventory.

Stock Type	Theoretical Need (with 2.33 Sigma coverage)	Practical Volume	Kanban containers (with RFID tag)
Cycle	434	450	15
Safety	17	30	1
Buffer	14	30	1
Total	465	510	17

Production layout analysis

Basically, the production layout was to manufacture primary product (bed board). The process started with cutting, then followed by moulding, grinding and binding. Finger joint process is only triggered when there are excessive woods cut from the raw material. Figure 10 illustrates the original layout of the company (Solidworks – Top view). With this layout, the material handling distance and time, production layout efficiency and flow of materials were evaluated and estimated.

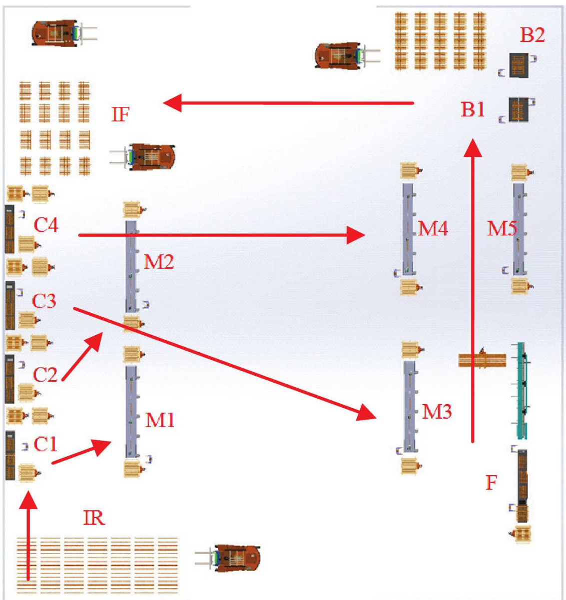

Fig. 10. The original production layout of the production line (legends: C – Cutting process; M – Moulding process; B – Binding and Stapling process; F – Finger joint process; IR – Raw Inventory; IF – Finished product Inventory).

Besides, some conditions and assumptions were set and confirmed with the manufacturer to evaluate each work station to make clear their overall production process, such as:

- All processes were at equal priority.
- Cutting Process (C) per set was completed with one set of bed board. (2 seconds * 6 pieces * 2).
- Moulding Process (M) per set was completed with one set of bed board. (7 seconds * 6 pieces * 2).
- Finger Joint Process (F) per set was completed with one piece of 12ft wood length.
- Binding Process (B) per set was completed with one set of bed board.
- All workers had same walking pace.
- 1.2 second was needed to travel 1 meter.

From the production layout, the transportation time of material handling from beginning to end of the production line was calculated. Table 3 shows the required transportation time of the company based on the original production layout. Some transportation distances were considered as wastes and should be eliminated.

Table 3
Summary for transportation time of material handling.

Material transport	Transport distance (meters)	Time consumed (seconds)
Raw inventory to Cutting station	10	12
Cutting station to Moulding station	17.3	20.72
Cutting station to Finger joint station	44.6	53.52
Finger joint station to Moulding station	1.4	1.68
Moulding station to Raw inventory	6.8	8.16
Moulding station to Binding station	24.2	29.04
Total	104.3	125.16

To have a better implementation of the lean and RFID-based inventory system, the production layout was restructured after consulting with the person-in-charge of the company to ensure its logicality and practicality. Hence, some relocations were conducted for the workstations, work-in-progress, RFID reader station and inventory. Figure 11 illustrates the restructured layout for each work station.

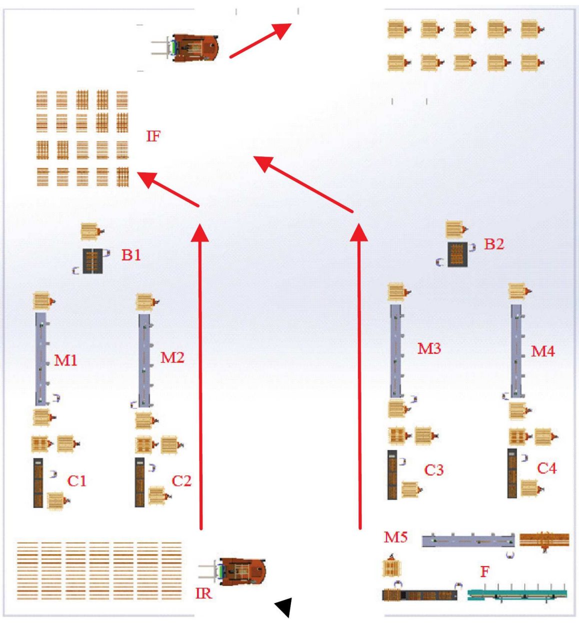

Fig. 11. The restructured production layout of the production line.

There are some reasons for the need of layout reconfiguration. Firstly, the major advantage of product layout was to achieve a balance for each workstation in reducing the waiting time. For example, WIP volume of each work station was maintained at the maximum output as 75 sets for single size bed board and 50 sets for double size bed under a single line of production. The workers then would start their tasks immediately without waiting. RFID system can clearly identify the purpose of each process and provide feedbacks of their performance to reduce the waiting time.

Secondly, the cost of RFID tools could be reduced. If implement RFID in the original structure, it will be more costly and ineffective due to lack of orderliness.

The new production layout had become more standardised, simple and clean as per the criteria of lean 5S. RFID infrastructure can be planned in a convenient, lean and simple way.

Besides, the unnecessary transportation of material handling was removed. The required distances for each material handling were shortened significantly. For example, previously the line C1-M1-B1 was 13.32 seconds for material handling. After modification of layout, it had shortened the required distance of material handling to approximate 5 seconds. Subsequently, the cost of material handling had been reduced significantly without disrupting the production process.

Integrated program analysis

To construct LRWIS into feasible solution for lean purposes in manufacturing company, the program should be fulfilled some criteria.

Firstly, it can automatically identify the wastes remaining in the company including supply chain, inventory, transportation and distribution. Since small-medium companies are lack of lean awareness, to make the managements easier for understanding lean and LRWIS, the program has adopted basic lean theories for enhancing implementation.

The program can detect and evaluate whether the operations and processes performing 5S. Table 4 shows the tracking properties of RFID helps the company indicating and monitoring the status of 5S on daily basis. Some sensors will be utilized for signal feedback and transportation purposes. Table 4 shows LWRIS performing 5S for remedy the lack of awareness from the users.

Next, the program can provide VSM according the Fig. 11 which is the layout after reconfigured. Product layout is suitable for implementing RFID-based VSM due to every single process can be monitored through RFID feedback. They can know whether the production line maintaining the desired performance by checking their waiting time, cycle time and input/output rate. If there are any unusual indications from the program, the user knows which section is occurring unexpected situation that may lead to wastes such as waiting, overproduction or inappropriate processing. The program is able to perform VSM to analyse the current state and provides the data to the user who can eventually improve the processes in the future state. Figure 12 shows RFID are utilized according to the idea constructions of Figs. 4, 5, 6 and 7 for recording the required data. These data are important for the user to determine the value and non-value processes or steps. Furthermore, this can extend to continuous improvement due to consistently monitoring the data captured from RFID.

Table 4
LWRIS providing 5S framework.

Categories	Target	Status
Sorting	Unknown items or wastes are transported to specific location.	RFID will be triggered and report to the worker if the wastes pallet is moved to the specific location. Alarm signal will off after the sector is clear and empty pallet go back to original place.
Set in order	Each item is being arranged according to RFID defined locations including raw materials, finished products and remaining wastes.	Each item that recorded up to present must being sorted according their own allocated places and volumes. For example.
Shine	Every work piece attached with RFID tag in the process will be clear after the day.	RFID provides tracking signal to make sure no work piece in the line and process.
Standardize	Establish each process by attaching RFID tags and define them according to the work pieces properties. The things will be monitored for their exact locations.	Every items or work piece that attached RFID tags will be monitored and always located at the right place. If the thing is not located at the right place, alarm signal will be triggered.
Sustain	RFID system is programmed to make every feedback are maintained and ensure defined items are in their arranged processes.	Any unusual happens or not in arrangement within the program, the alarm signal will be triggered.

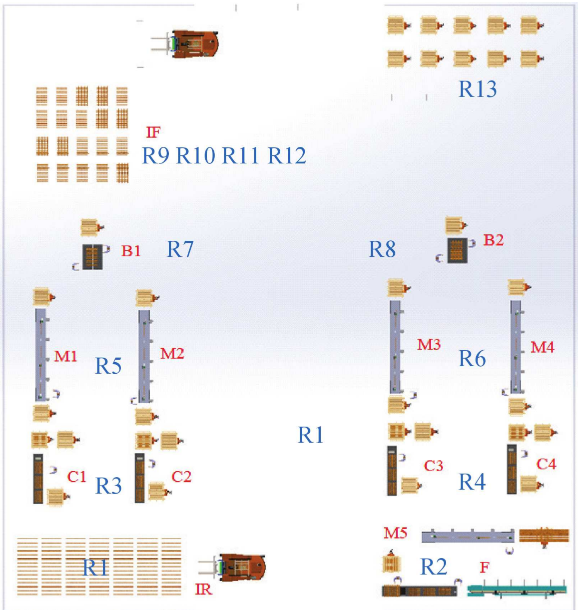

Fig. 12. RFID implementation in reconfigured layout (R labels means RFID field signals; R1 – raw material inventory, R2 to R8 – machine station, R9 to R12 – different finished products, R13 waiting replenishing items).

Due to every station and item are being tracked, the production can always immediately receive unusual happenings and provide relative responses. For example, if output rate of production line C1-M1-B1 is not in expectation, there might be due to some reasons such as workers skill, machine maintenance or material supply. The person in charge can quickly observe the situation in order to settle the problems such as machine repair, urging supplement or provide relevant training. The real time response of RFID can help the production continues the tasks and avoid delay in production or delivery by producing immediate feedbacks and relative solutions.

Pull production analysis

With this GUI, the user could monitor inventory status of each item anytime by using RFID identification system. Figure 13 illustrates the location of RFID reader station. All RFID signals were received by microcontroller and monitored in Visual Basic GUI. The black arrows show the direction flow from production to deliver, which was to ensure a smooth delivery circle. In which, every item would be replenished and every production would only be triggered according to RFID signals.

Figure 14 shows the actual status of each RFID-attached inventory. Single size bed board refers to numbers 1–17; meanwhile double size bed board refers to numbers 18–31. For example, there were three ‘empty’ containers for single size bed board, which they were empty stock waiting for replenishment. Three ‘in the progress’ containers were still being replenished. Eleven ‘complete’ containers had been completed with thirty-three sets of single size bed board. As a result, the user could immediately know the current stock available of single size bed board.

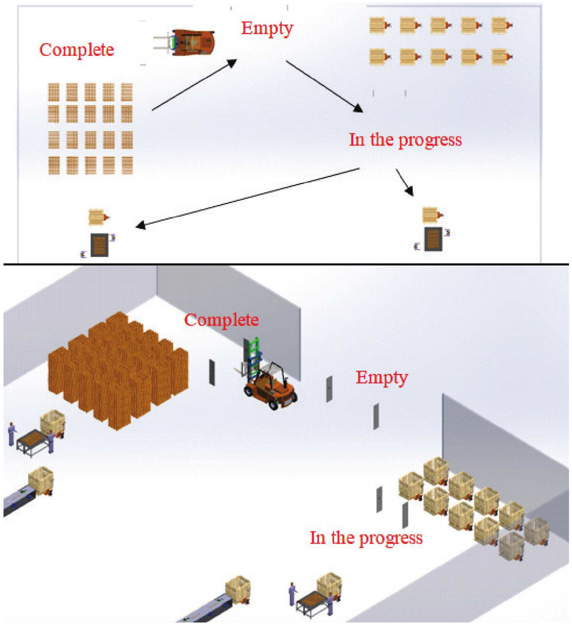

Fig. 13. The location of RFID scanner.

Besides, the LRWIS can monitor real-time inventory and production status. The manufacturer can allocate the right workers and optimise the production as shown in Fig. 15. For example, when the containers 1–3 were ‘empty’, the Worker A needed to replenish the items immediately as they were under the priority tasks. After complete replenishment, the Worker A could continue the secondary tasks, which was to manufacture finger-joint bed board. Consequently, the workers could perform their tasks without waiting time and improve worker efficiency and productivity.

After implementing this system, the manufacturer can optimise the quantity of the primary products and deliver them on time because the workers can replenish the necessary items according to the real-time RFID information of each container. Next, the manufacturer can also make decision immediately for manufacture different products in the production progress. For example, if there is complete replenishment of primary items, the user can immediately order the workers for manufacturing secondary products such as pallet or broomstick depends on the needs of clients. No time was wasted for waiting orders. In short, this can maximum the output of each work station and improve worker productivity.

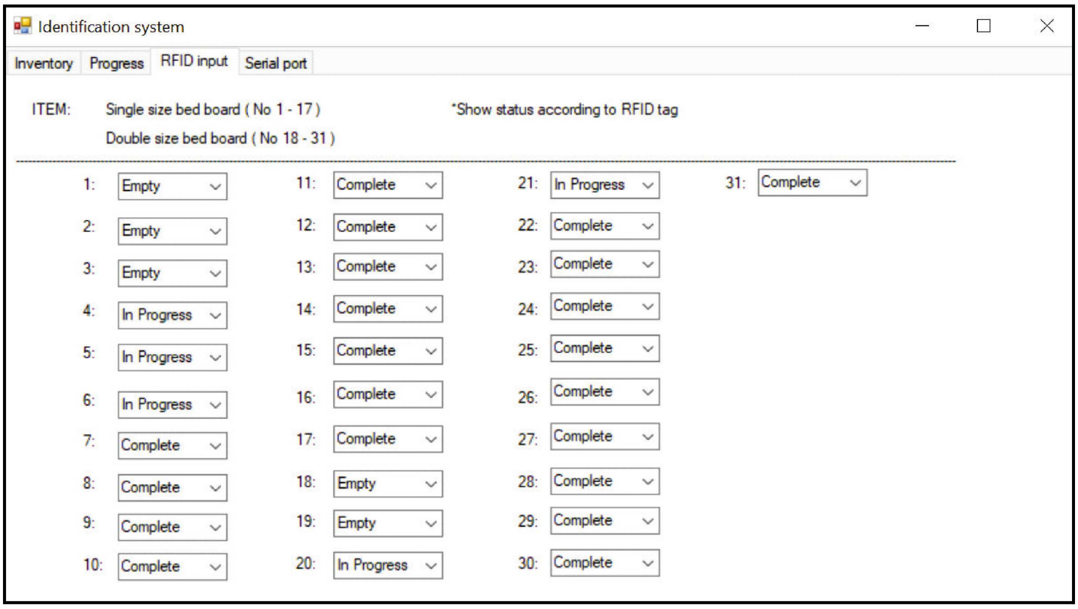

Fig. 14. The current status of inventory.

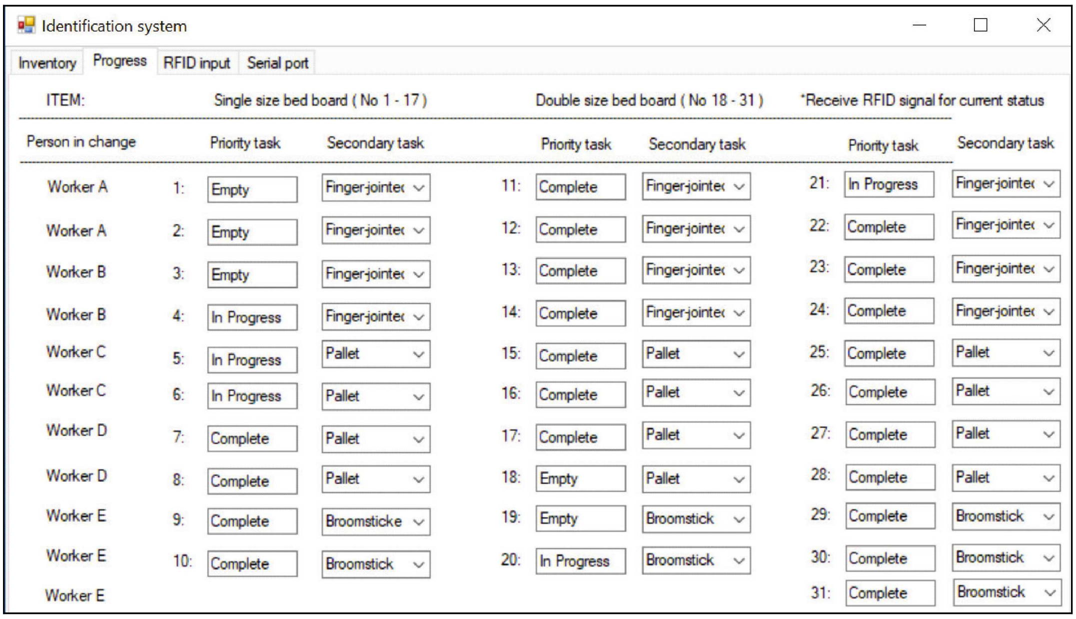

Fig. 15. Monitoring of workers' progress.

Discussion and conclusion

The research has used related lean concepts such as JIT, production levelling, Kanban and Value Stream Mapping, and integrated with the appropriate advanced technologies such as RFID and its designed software in developing and implementing the LRWIS. The system has been tested in a small-medium sized wood processing manufacturer. It has yielded a very positive result in terms of wastes reduction for inventory, over production and waiting time. It has been proven as a practical system to reduce the wastes and maintain the production process at the optimum level.

Generally, small and medium sized manufacturers have limited capital and financial capabilities, which they would have different operating systems, management commitment, privacy and cultures. As a result, the LRWIS is designed with simple constructed framework that is with simple RFID configurations and a low cost infrastructure. The manufacturers can still benefit from real-time RFID information from the production process and control of system easily, without having a complicated and expensive infrastructure for Internet of Things [13, 15], cloud computing system [47] and the like. The LRWIS is proven as a workable and practical system that is able to eliminate wastes and focus on performing value-added activities. From the results, some non-added activities have been detected and eliminated such as excessive transportation distances and waiting time. The LRWIS has significantly reduced the unnecessary wastes such inventory, waiting time, overproduction and including transportation. These wastes reduction is critical for small and medium sized manufacturers for their improved quality, cost and delivery of their production.

In addition to that, a study based on lean production in small and medium size companies requires an enterprise resource planning (ERP) system and uses capability maturity model (CMM) as a path for pull production [48]. In order to reach the highest target of pull production in CMM, the ERP system is utilized to support continuous improvement and its real-time performance measurement is adopted to optimise the pull production system. However, as per the research findings, LRWIS is one of the capable models to support E-Kanban, E-Heijunka, optimum resources allocation and other lean objectives. RFID can track the processing time of each activity, optimise greatest performance of inventory levels and balancing production scheduling. In short, LRWIS can help small and medium size companies to accomplish lean purposes without a complete ERP system.

Besides, MRP is a common system for the manufacturing company to schedule the supplying of material depends on the forecast ordering. However, pull system make MRP difficult to determine the volume of inventory because pull system is needed to focus on immediate system status that confusing the direction of MRP. Hence, the lean principles need to integrate with RFID to accommodate the functions of MRP for improving the scheduling of production process and material supply. The sensors of RFID would provide instant information into the LRWIS and help the manufacturer in decision-making and responding to different production situations. The pull production then only triggers the required functions of workstations according to the production needs. This requires the cooperation and commitment between the management of business administration, procurement and production.

Certain limitations need to be considered in this research. The LRWIS is one kind of small scale of lean manufacturing system. It can be further developed for strategic planning and management in the company. For instance, some regulations and safety requirements may affect the production needs and layout of the manufacturer. The complete system in the future should consider other organizational activities and availability of resources within the company. To the technical enhancement of the system, the company can consider a larger scale of implementation such as automated storage and retrieval system (ASRS). The flow of materials and operations can be more efficient for complicated tasks. Besides, inappropriate implementation of lean concepts or tools will cause unstable production flow. For other manufacturers without lean awareness or with complicated production process, the proposed LRWIS can be redesigned or modified accordingly before implementing it into the production. This is due to LRWIS is implanted with basic concepts of lean manufacturing such as 5S, VSM, pull production and automatically monitoring the processes by RFID system regardless the company is executing the correct lean process.

Last but not least, LRWIS is practical and beneficial to small and medium sized manufacturers as the development process and cost of the system are rather simple and economic, whereby the research approaches can be generalised and referred by other types of production. The RFID system records the historical data and big data analysis is conducted to enhance improvement. Hence, if LRWIS is applied in a company, the management should always monitor the collected data, analyse and investigate the meaning of the data. LRWIS is sustainable as ongoing improvement can be done continuously based on the analysed big data. Continuous improvement will eventually deliver the ideal expectation of JIT and lean manufacturing.

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