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Lean manufacturing analysis of a Heater industry based on value stream mapping and computer simulation

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Abstract

Manufacturing companies implement lean manufacturing (LM) tools to keep their competitiveness over their competitors by improving the manufacturing system's productivity. Value Stream Mapping (VSM) is a critical tool for implementing the lean approach, and it can be used to many sectors in industry. The paper aims to implement the VSM approach along with computer simulation for identification and elimination of wastes in a small-scale Heater industry by using lean principles and time-frame formulation through takt time calculation. Based on the future VSM improvements, results showed that production lead time (PLT) reduced from 17.5 days to 11 days, and the value-added time decreased from 3412 seconds to 2415 seconds. Takt time also was decreased from 250 seconds to 192 seconds. Our results are a valuable resource for managers and industrial engineers to improve the productivity of manufacturing in a cost-effective and timely manner.

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Keywords: Lean manufacturing; value stream mapping; computer simulation; Heater industry; Arena

1. Introduction

Due to the high competitiveness of the manufacturing market in today's world, firms have to make their utmost efforts to enhance their efficiency. Competitiveness and efficiency are key challenges motivating manufacturing companies to adopt and continuously update their management strategies [1]. In such a context, manufacturers need to constantly think about the most effective ways for delivering their products or services in the shortest time, lowest cost, and most acceptable (or best) quality [2]. To achieve these objectives, various methods are adopted by firms aiming to remain competitive with other manufacturers in or out of the country. Among all methods proposed in this sense, 'lean manufacturing (LM)' is one of the most popular ones.

Lean production or lean thinking is based on the concept of achieving improvements in most economical ways with an emphasis on "Muda" (waste) elimination and is in line with Ohno's Toyota Production System [3]. Lean employs minimum resources for maximum output, and it is based on five principles [3]:

- specify the value by specific product,
- identify the value stream for each product,
- make the value flow without interruptions,
- let the customer pull value from the producer, and
- pursue perfection.

Top management should create a polyvalent company by fostering teamwork and focus on lean tools and techniques that help to find problems and their causes, instead of searching and punishing the responsible [3].

Lean manufacturing plays a vital role for elimination of waste, optimization, monitoring of processes, and

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involvement of people [4]. There are several tools and approaches have been developed to facilitate lean implementation, such as the value stream mapping to design the flow of value of a product [5].

Value stream refers to all activities (value-added activities and non-value-added ones) that are essential to produce a certain product through the implementation of three critical management skills, i.e., information management, problem-solving, and physical transformation [6]. In LM, some tools and approaches are used, including Just-In-Time (JIT), 5S, Cellular Manufacturing, and Total Productive Maintenance (TPM) [7]. In addition, LM is a corresponding approach accompanying with lean thinking that would help production and industrial engineers to achieve precise, reliable, and timely information when making decisions. As a result, implementing and controlling the lean system is indeed an innovative approach to having successful strategic management [6].

For providing a visual demonstration of the exact place waste that is created through a given process, there is a need to build a VSM. With the use of this map, current manufacturing processes can be easily evaluated, and ideal future state processes can be created. With such a tremendous spread of the manufacturing field across the world, firms need to be well adapted to business strategies that are continually evolving in such a thrilling context [8].

Another effective method used widely in this field is simulation modeling. The popularity of this method is because that it is highly flexible and has a high capacity for simulation and evaluation of both static and dynamic systems regarding variability and uncertainty between systems like those of manufacturing lines [9], ports and maritime industry [10], supply chain [11], and building sectors [12]. In the computer simulation combined VSM approach, both managerial and operational aspects of manufacturing processes are considered. This way, managers will be able to do something more than conventional static performance analyses. VSM helps the managers in differentiating value-added from non-value-added activities; also, it can be applied as a strategic tool for decision making applicable to redesigning of processes and improving them continuously. If the comprehensive information attained from this VSM is well considered, we can check whether the increased revenues or overall cost savings can be achieved through adding to capital investment.

The implementation of the simulation-guided VSM is done more straightforwardly, conveniently, interactively, and spontaneously in comparison with the conventional VSM that was based on paper-and-pencil use. Simulations provided in this system offer an adequate level of flexibility needed for VSM to effectively handle the changes in permutations and combinations that often take place in this manufacturing process.

Accordingly, the present paper mainly aims to enhance, as a case study, the productivity of the welding section of a heater manufacturing industry with the use of VSM and computer simulations. To date, this firm has not implemented the value stream mapping as an instrument to enhance the quality of its operations. The key objective of the present study is to achieve a 30% reduction (at least) in the current lead time. To this end, first, the team needed to document the current state of the production process thoroughly. The formation of an initial and final state of VSM enabled the team to draw conclusion based on the data they had collected. They succeeded in accomplishing the project's primary objective. The second objective of the project is operational enhancements in facilities provided for production processes.

2. Literature review

There are some studies that have applied VSM in different manufacturing industries to deal with different waste reduction-related problems [6]. Hines and Rich [13] applied VSM using seven tools and concluded that this approach was not only limited to automobile industry but can also be applied for different industries as well. Rother and Shook [5] used the VSM and developed current and future state maps for a stamping factory. Seth and Gupta [14] developed VSM to decrease cycle time and enhance productivity in an Indian industry. The production output per person worker was enhanced to 17.54 frames from 13.95 frames. Lead time decreased significantly from 3.215 days to 0.54 days. Lasa et al. [15] highlighted the practical application of VSM by implementing it in a real manufacturing company. They decreased the lead time to 4 days using VSM process. Grewal [16] used the VSM in Indian camshaft manufacturing industry. They highlighted that lead time decreased from 19,660 to 19,449 minutes by adding two workers at final inspection section. They also applied the lean tool 5S in every section of work-in-progress (WIP).

In another study, VSM along with computer simulation was used to decrease shortcomings of mapping process. They applied QUEST software to simulate the current and future state models of a door and pipe production line for a period of 30 days. Total lead time was decreased from 37.87 days to 12.68 days [17]. Suciu et al. [18] implemented the VSM tool along with the help of single minute exchange of dies (SMED) in a cycle manufacturing company. Change over time was improved from 60 to 9 minutes in threading operation. Singh and Singh [19] implemented the VSM in an auto parts manufacturing company and decreasing its cycle time by almost 70%. In another paper, the pump industry made an action plan to reduce the wastes and minimize the root cause related to product inventories. They used the VSM and lean approaches such as pull system to decrease the lead time from 54 days to 36 days. They improved the inventory reduction from 33 days to 22 days with proper communication flow of the system [20].

Zahraee et al. [21] used the Taguchi method along with computer simulation for finding an optimum factor setting for three controllable factors, which are the number of welding machines, hydraulic machines, and cutting machines by analyzing the effect of noise factors in a heater manufacturing industry. Maximum productive desirability was achieved when the number of welding machines, hydraulic machines, and cutting machines was equal to 17, 2, and 1, respectively. Abrishami et al. [22] simulated a heater manufacturing industry using the Arena simulation software. They evaluated three different scenarios to find a better design of production line. They suggested to add two welding machines and two welding operators which led to a considerable reduction of the line at welding station. Moreover, it was suggested for adding one compressor machine and one testing operator that led to increase the production. Also, it was proposed to reduce existed idle times by reduce the number of coal grinding operators (specific operators in each station) from 4 to 3 people who help each other, and subsequently increase the rate of output product. In another recent study, VSM along with computer simulation was implemented for a plastic bag manufacturing unit to identify the waste and bottleneck processes. Simulation results showed that takt time reduced from 46 minutes to 26.6 minutes. Value added time increased by 74.5% [23].

Table 1 presents more typical sample with real research and application of VSM in contexts that differ from the manufacture of parts. Many researchers have confirmed the effectiveness of applying VSM to different industries through the identification of its high applicability by conducting comprehensive literature reviews. Most of the case studies in the literature are implemented on large-scale industries. Requirement of a generalized framework which can be applied primarily to a small-scale industry is a research gap. So, this paper aims at combining the VSM lean tool and computer simulation to find the waste root and increase production rate to satisfy the customer demand in a small-scale heater industry.

Table 1. VSM application in different sectors

Industry	source
Construction	[24]
Mining	[25]
Industrial product system	[26]
Color	[27]
Information stream in production	[28]

3. Methodology

3.1. Case Study

As the case study for the present research, a heater factory was chosen. The factory includes four sections, namely, welding, framing, painting, and assembly. According to some interviews held with management and engineers, it was decided to consider the welding unit for simulation and evaluation of production processes. This unit is mainly responsible for producing the main heater fount frames and transporting them to the assembly unit. The number of operators and equipment applied in the welding unit is presented in Table 2. A total of 22 operators are working throughout the group.

Table 2. Details of equipment and operators

Row	Machine Type	Number of Machine	Number of Operator
1	Impact Press Machine	1	1
2	Rolling Machine	1	1
3	Welding Machine	15	15
4	Hydraulic Machine	2	2
5	Test Compressor	2	2
6	Cutting Machine	1	1

3.2. Value stream Mapping

Value stream mapping (VSM) refers to a lean tool that is implemented to explore the firm's current scenario and the information flow, helping in the solution of the problems that appear in the current state, which can be a big help in the future states [29]. This mapping tool encompasses the whole process starting from customer order and manufacturing of product to delivering it to the consumer.

One of the benefits of VSM is that everyone is capable of observing the production and information flow of the manufacturing line, hence simply determining and removing the system's bottlenecks [29]. The most beneficial point regarding the use of VSM is that it determines the prospects for future improvements. It can be plotted using the following set of rules. The VSM needs to involve all value-added and non-value activities of a product being produced. Typically, for drawing a current state map, pencil and paper are utilized. In the following step, the map is analyzed through the exploration of the problems and provision of relevant solutions as well as the preparation of an effective action plan to implement the solutions concerning defined deadlines, targets, and responsibilities. VSMs are indeed pictures of the production activities and applied to the documentation of both the current VSM (reality) and the future VSM (the goal). The former refers to the firm's current situation based on which all improvements are measured, while the latter refers to the project team vision depicting how the value stream is seen in the future after applying the improvements [29].

3.3. Computer simulation

In this study, Arena simulation software was used. Arena application focus addresses the needs of manufacturing [30], as well as decision support for many other areas including supply chain management [31], construction sector [32], and transportation [33]. In this study, Arena was employed for modelling and recreating some specific parts of the manufacturing procedure [34]. For each operation, certain data like the machine parameters and cycle time need to be entered. Arena-made models typically work based on modules.

To develop an Arena simulation model, a key step is the collection of required data [34]. In the present study, the data required were collected from the factory environment when the manufacturing processes were being executed. In gathering some data, the researchers made use of the "stop-watch" method. When the collection of data corresponding to duration of all processes is completed, a probability distribution function is needed then to be fitted to every activity, which is due to the variability of the activities. Following that, various resources that are involved in manufacturing procedures together with their relationships, tasks, and the fitted probability distribution of each data sample of process duration are determined. Then, this is the turn for the simulation model of the investigated manufacturing system to be developed. As mentioned earlier, to construct the simulation model, the authors made use of Arena Version 13.9. The logic view of the simulation model is summarized in Figure 1.

4. Results and discussion

4.1. Current VSM

In this paper, the Rother and Shook's [5] proposed method was used to collect the complete information regarding the current-state map of VSM. The current VSM designed and displayed in Figure 2, where small boxes show the manufacturing processes, and the number of the boxes signifies the number of operators working for every machine. It is noted that 15 welding machines and 2 test compressors are considered in one small box separately. Moreover, a data box was assigned to every process, which included the:

cycle time (CT): is the time it takes to complete the production of one unit from start to finish, changeover time (CO): is the time it takes to set a process up for the next product type, machine reliability (MR): measures the failure rate of a machine to perform its intended task.

All processing and set up times were based on the average of collected data in the factory. In the case of each process, CT indicates the average CT indeed determined with the help of real data in the company. Figure 2 depicts the timeline, which includes two parameters. The first one shows the production lead time (in days) that defines as the period of time between a customer order being placed and an order being fulfilled and completed. It is calculated by summing the number of lead-time from every process. The total lead time was recorded as nearly 17.5 days. Value-added or processing time is equal to 3412 seconds. It is the time spent that improves the outcome of a process. It was calculated by adding the processing time for every process in the production line.

4.2. VSM: Takt Time

The Takt time is the time between completions of each product of the manufacturing system. The formula presented below (Equation1) is generally used to compute the Takt time [1]:

Takt time has significant effects in the production line. With the use of Takt time, users can effectively estimate the minimum batch sizes in situations where changeovers are involved [11].

$$\text{Takt time} = \frac{\text{Available minutes for production}}{\text{Required unites of production}}, \quad (1)$$

$$\text{Takt time} = \frac{8*3600}{115 \text{ per day}} = 250 \text{ seconds}$$

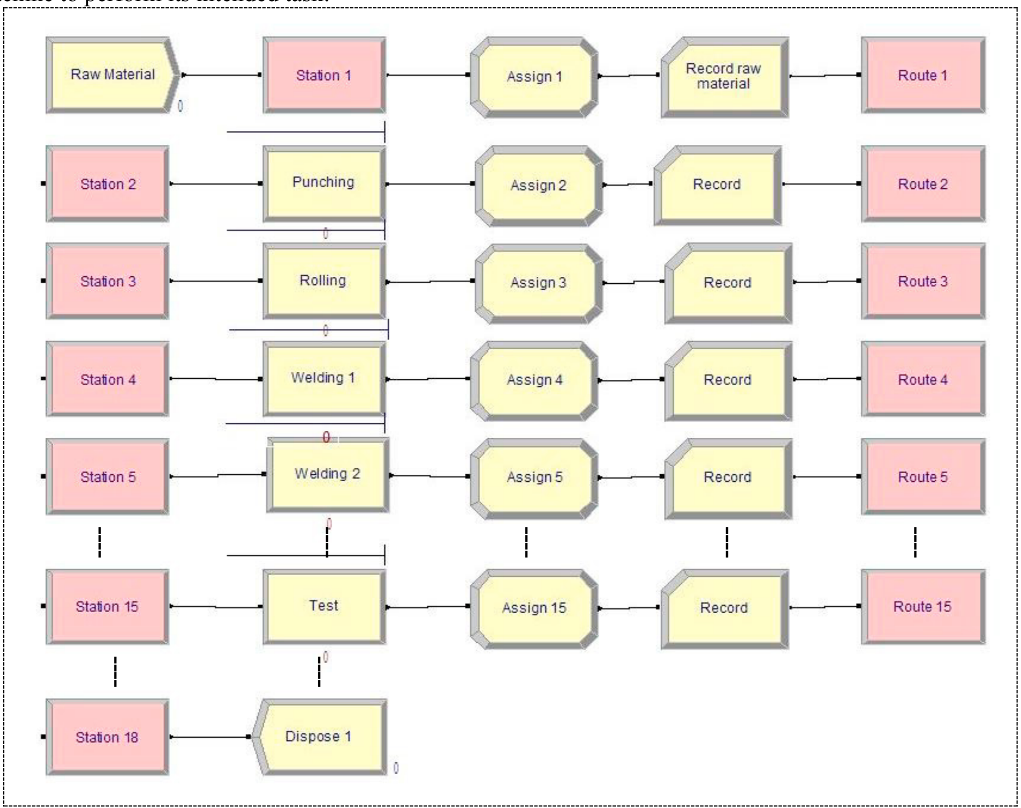

Fig. 1. Logic view of simulation model

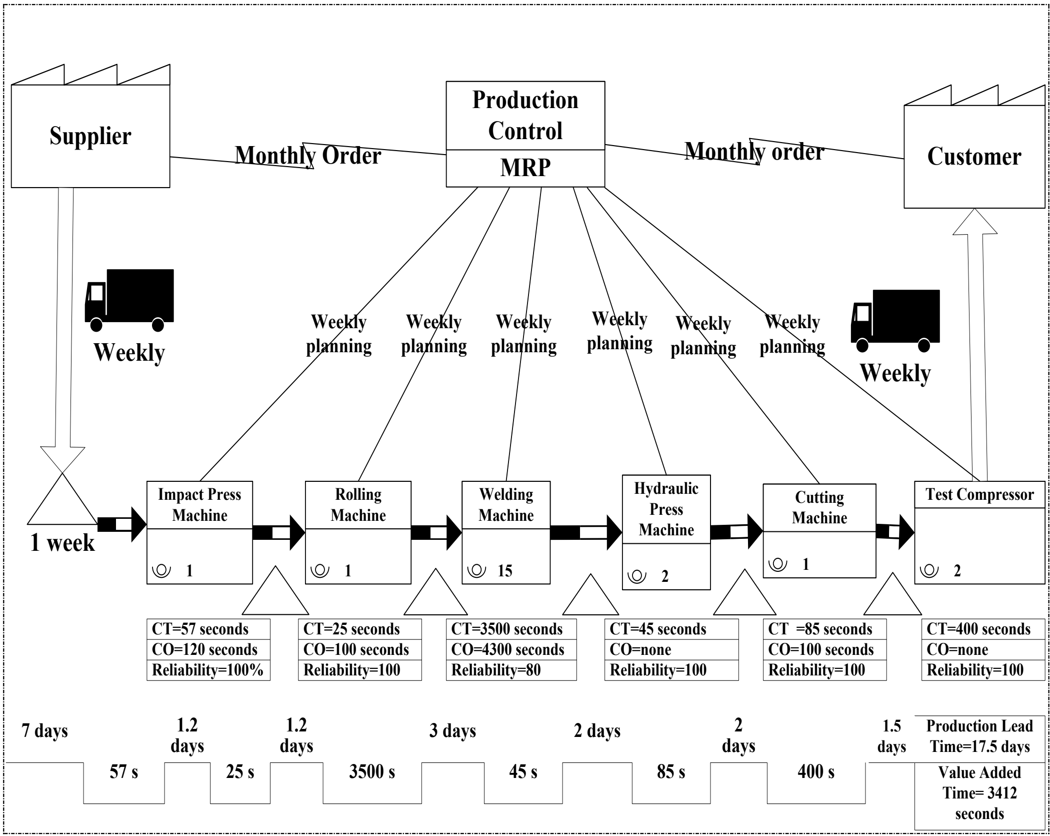

Fig. 2. Current VSM

4.3. Future VSM

The future-state map is used to demonstrate the company's future after the lean tools are well implemented. This map provides tools that are essential for continuously improving the company's performance. Some required in-depth operational analyses were done; then, some recommendations were given for balancing the production lines and optimizing the delivery times. In addition, several recommendations regarding the 5S concepts were provided for the factory, applicable to the standardization of the work and material flow. Operational improvements were accomplished by optimizing the delivery times and inventory levels and by decreasing the total cycle time.

Simulation results pointed out the high idle times for welding machines and test compressor. The simulation outcomes and the lean techniques were employed to create a future map as follows:

Making the line balanced: First, there is a need for value stream in order to realize the existence of a line. An important actor that causes a delay between the production activities is queuing. It accumulates the work, and this way, causes uncontrollable bottlenecks to be created. To minimize the occurrence of this problematic situation, the following techniques are recommended to be adopted:

Removing bottlenecks: Based on the current VSM, the welding machines have the highest cycle time with 3500 seconds, which makes WIP before the station. For this reason, two more operators and two welding machines were added to the production line. It causes to decrease the cycle time from 3500 seconds to 2000 seconds. Moreover, two more labors are also added to hydraulic and press machine to decrease the cycle time near 35%. Finally, one more test compressor with one labor cause to decrease the cycle time from 400 seconds to 280 seconds. The team also suggested the factory management to add one operator to the cutting machine and one to the hydraulic press machine, who can give help to each other, thereby increasing the output product rate.

Another important problem is discontinuous flow due to the high differences in cycle times. Continuous flow is used to produce required products with the use of a batch of the size of one. This can be recognized as a highly efficient means of production because between the process steps, no inventory is formed, and it can remove numerous types of waste. Accordingly, the Kanban method was adopted to eliminate the waste generated from overproduction and inventory procedures. It completely removes the physical inventories; instead, it relies on signal cards to show in cases more products are required to be ordered.

Note that the safety stock inventory must be computed precisely in order to keep a high level of customer services. Numerous firms consider their demand fluctuations, then assume that enough consistency does not exist for the prediction of future variabilities. Subsequently, these firms fall back on trial-and-error or rule-based methods to hold both cycle stock and safety stock inventory; for instance, by holding a certain number of weeks of historical average demand. As a result, the safety stock inventory was performed before the test process, which helps to:

- ✓ Provide an effective protection against unpredicted variations in supply
- ✓ Compensate for the imprecision of predictions (only in cases where demand exceeds the prediction)
- ✓ Avoid disruptions that may take place in manufacturing or product deliveries
- ✓ Avoid stock out to keep high levels of customer service and customer satisfaction.

Equation 2 calculated the Takt time for the Future VSM as follow:

$$\text{Takt time} = \frac{\textit{Available minutes for production}}{\textit{Required unites of production}}, \quad (2)$$

$$\text{Takt time} = \frac{8*3600}{150\ \text{per day}} = 192\ \text{seconds}$$

Figure 3 shows the future state of value stream map based on the improvements.

4.4. Discussion

It is confirmed that computer simulation could be performed as an important part of VSM. Simulation of current state map provided insights into root causes of the wastes. VSM tools were utilized to eliminate non-value adding activities and create future state map. Simulation can provide significant information completing what attained from future-state mapping. Besides, simulation make the process visualization easier through forming a shared consensus about the process and where improvement solutions can be accomplished.

Within the future-state map, two welding machines, one test compressor, and five operators were added to decrease the non-value-added time during processes. The use of stock inventory technique, the Kanban method, and continuous flow led to an efficient organization of the workplace, shrinkage of work location, minimization of losses related to failures and breaks, and a significant enhancement in both work safety and quality. Supermarkets are placed between processes for the purpose of decreasing the inventory wastages of each activity and for converting the process from a build-to-stock process to a make-to-order process. The flow of communication and information between production lines was improved through using pacemakers in the production line that changed from push to pull using the Kanban method.

By implementing these techniques, some significant improvements were done. The PLT decreased from 17.5 days to 11 days, the value-added time reduced from 3412 seconds to 2415 seconds, and the Takt time was decreased from 250 seconds to 192 seconds (Figure 4).

Note that VSM and its related lean approaches need to be considered with a focus at a factory level. Computer simulation needs to be taken into consideration as a guided approach that only improves but not replaces VSM. It can be achieved through observation and quantification of long-term impacts that cannot be simply observed on the factory floor. Impacts that are accessible from conventional production information systems, or those that are very time consuming or costly to be experimented on the factory floor. Essential elements of a lean system include the instillation of appropriate organizational values, holding continuous programs to improve the company’s performance, provision of effective policies for organizational learning and empowerment of employees, the establishment of reliable organization structures, and effective systems for information management. To achieve all benefits of VSM, these measures mentioned above must be completely executed; otherwise, its performance might be even poorer than the system it replaced.

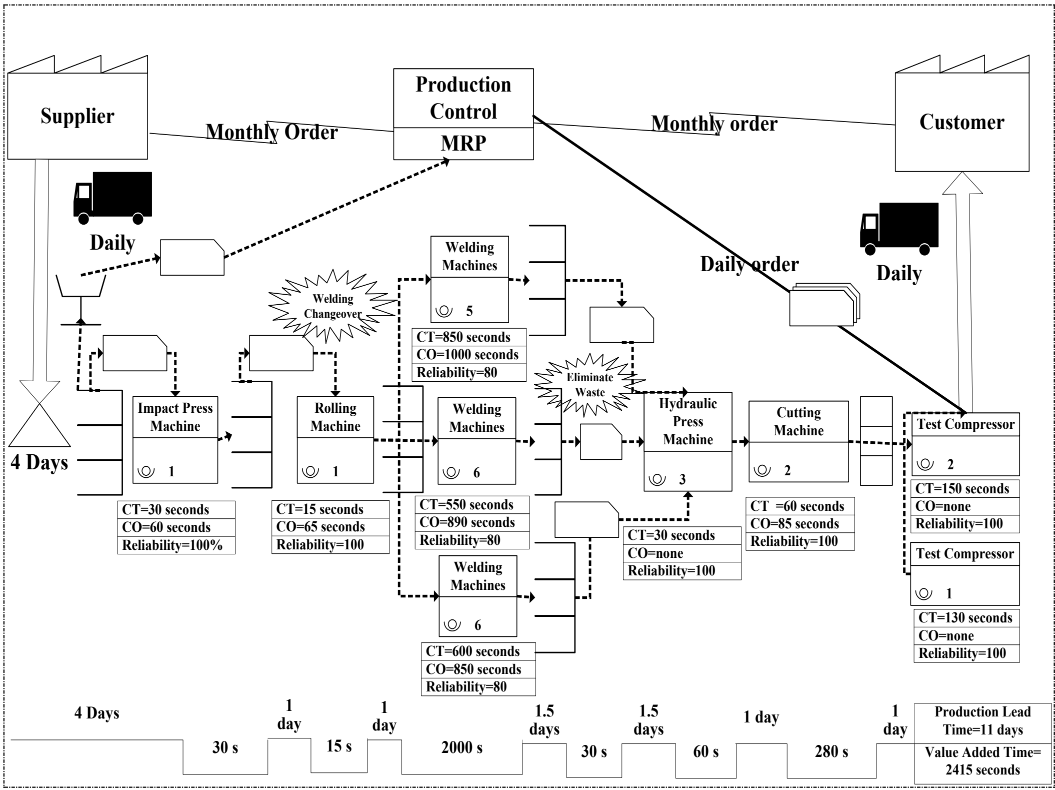

Fig. 3. Future VSM

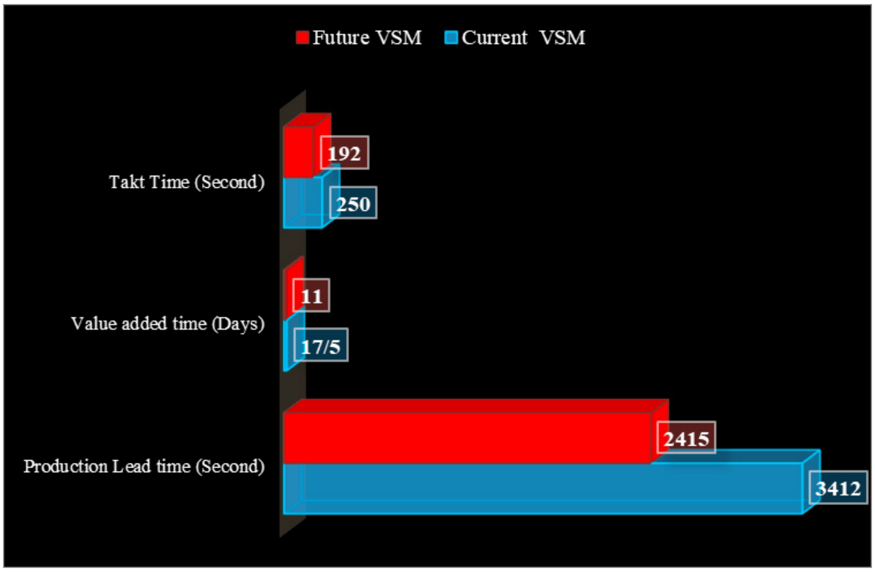

Fig. 4. Current state vs. future state

5. Conclusion

In this paper, a LM framework is developed for a small-scale heater industry unit by applying VSM combined with computer simulation. Computer simulation model was developed for the aim of improving VSM (not replacing VSM) through visualization of the better dynamic status of the future state before implementation. Various simulation scenarios have been analyzed by calculating the actual production times of each unit in the manufacturing line, and then describing their variation in terms of distribution functions. The results show that our approach can make substantial improvements in production lead time, value-added time and Takt time. The results obtained from this study have been presented to the management of heater industry for further consideration and implementation.

The result of this study can help the managers and industrial engineers to update the knowledge about the application of VSM and computer simulation to improve the productivity of manufacturing in a cost-effective and timely manner. These improvements can be achieved through the implementation of the lean tools, especially in specific units of the firms where problems exist on the lead time, cycle time, and excess rework that often occurs due to more inventories.

Future studies can focus on the implementation of green manufacturing factors for minimizing waste and pollution, enabling economic development, and recycling waste produced during industrial activities.

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