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Lean Six Sigma for Process Efficiency Improvement: Case Study at Roof-Tile Manufacturing Company

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ABSTRACT

Lean Six Sigma is regarded as a strategic business change to improve the efficiency of the processes. A combination of Lean Manufacturing and Six Sigma's theory is a powerful practice by companies looking for ways to improve their productivity. The roof-tile company under study faced issues with high inventory and high lead time affecting the manufacturing efficiency. The team from UTeM was consulted with the objective to investigate the issues and propose improvement plans. Lean Six Sigma DMAIC-VSM methodology was used to systematically guide the project implementation. The Define-Measure-Analyse-Improve-Control process was explained in detail including the use of the current state value-stream map (CVSM) to identify the bottleneck and the fish-bone diagrams to evaluate the key issues. The three main problems uncovered were the high cycle-time at the hand spray coating process, the hydraulic press, the high waiting time for the clay bat process. Why-why analysis was used to define the countermeasures. The implemented improvements will enable the company to improve the bottleneck capacity and production efficiency by 42% without incurring additional costs. The company has benefitted from this study by having the right focus on the improvement plans to achieve a leaner production for the manufacturing line.

Keywords: Lean manufacturing, six sigma, lean six sigma, DMAIC-VSM

1. INTRODUCTION

The rise in the economic challenges and customer expectations prompt companies to be more competitive. Thus, organizations are constantly looking for better ways to optimize their product or service characteristics, enhance their processes, decrease costs, increase resource efficiency and improve customers satisfaction. Company with happy clients is more likely to develop and a successful business which eventually contributes to higher revenue.

Nowadays, combination of Lean Management and Six Sigma's theory, namely Lean Six Sigma (LSS) became the consequence of the introduction of new technology and standards, a the quick shift in consumer needs, and the evolving supplier networks. Lean manufacturing is based on waste elimination while traditional Six Sigma concentrates on defects reduction. Both Lean and Six Sigma focuses on improving productivity and manufacturing performance. LSS has become one of the world's most common ways of making company and corporate processes more productive and cost efficient. Further, LSS has been used in the manufacturing sctor to adapt to the challenging market competition and seen as a holistic business improvement to enhance business processes in the organization to get better production efficiency. However, to ensure a successful implementation, it is also necessary to promote monitoring, frequent communication, and correct use of information technology. Among the benefits reaped by the various manufacturing industry implementing LSS include enhanced delivery efficiency, reduced inventories, waste removal and continual process efficiency which results in the manufacturing performance especially the productivity and profitability [1].

Due to the Covid-19 pandemic, various businesses face challenges with the sluggish market impacting the global economy. The manufacturing company under study was no exception. The 25-year old roof-tile manufacturing facility lacks modern technology, knowledgable workers and is facing revenue loss do to Covid-19 pandemic. The company faced high inventory and high lead time issues. The newly hired regional director for the company seeked help from the Universiti Teknikal Malaysia Melaka’s team to work with the company’s manufacturing team with the aim to identify areas to focus on waste elimination and devise a plan to improve the manufacturing performance.

The following sections describe the concepts of Lean, Six Sigma and LSS being used in this study. Specifically, the LSS’s framework employing the Define, Measure, Analyse, Improve and Control (DMAIC) project management approach to systematically conduct the study will be detailed using the manufacturing case study data. Lean Current Value Stream Mapping (CVSM) will be used as a visual tool for the team to deeply examine each process and identify the various wastes occurring in the manufacturing line. In addition, fish-bone-diagram and Why-why analysis tool will be used as a brainstorming tool to concentrate efforts on the vital few issues that were affecting the manufacturing performance.

2. LEAN SIX SIGMA

Lean Six Sigma (LSS) is a powerful tool which is widely used to increase performance [2]. Recently, LSS have gained recognition among the industries to dramatically decrease waste and increase the efficiency of the industrial sector [3]. Snee [4] defines LSS as a well-structured technique that enhances results, encourages management and customer satisfaction. LSS is gaining popularity because it combines two powerful tools; the Lean technique of waste management and the Six Sigma, the process improvement methodology to reduce the process variations. Among the objectives of LSS are to reduce cycle time, non-value added work, eliminate waste and improve production system’s instability [5].

The first component of LSS is Lean. Lean tends to concentrate on waste control and increased flow. Lean manufacturing emerged from the Toyota Production System fundamental objective to improve the efficiency in the automotive industry [6]. Samarrokhi et al. [7] stated Lean is designed to remove uncertainty, waste and constraints, bringing greater value to customers. In addition, Oliver et al. [8] explained that Lean also minimizes the overall cycle time and lead time. However, lean requires fundamental change in an organization's culture. Albliwi et al. [9] argued that creating a culture is a major challenge in the adoption of Lean which requires a change in the stakeholder's mindset and the drive to minimize costs and waste.

One way to describe Lean waste is "something that does not add value." To be successful, any any businesses must focus on waste disposal. Taiichi Ohno, Toyota's chief engineer, as part of Toyota's Production System (TPS), developed the original seven waste (*Muda*) which include transport, inventory, motion, waiting, overproduction, over processing and defects and the acronymed as ‘TIMWOOD' [10a]. Later in the 1990s, the eighth waste of the unused talent or "skills" was introduced [11]. El-Namrouty [12] further established three major obstacles that could have a negative effect on the work of the company: *Muda* (wasteful activities), *Muri* (overburden) and *Mura* (unevenness).

To achieve Lean, lean approaches may be used depending on the manufacturing issues to be addressed. Among the common lean tools are the value stream mapping (VSM), 5S system, Kanban, Kaizen, Total Quality Management (TQM), Just in Time (JIT), Gemba, poka-yoke, pull system, and visual management [10b]. Vinodh et al. [13] stated that VSM is an effective method to study a production system. In addition, Singh and Singh [14] reported using VSM in an auto industry to increase productivity. VSM can be termed as a waste-defining tool and can be categorized into three different types which are current, ideal and future VSM. The current VSM shows the various information flow across all the supply chain from the supplier, manufacturing until the customer delivery. Next, the ideal VSM visualizes the supply chain with minimum or no wastes occurence. Eventually, the future VSM allows for the creation of highly efficient production of goods and services if the ideal state is fully implemented.

Figure 1 shows the general template of the VSM which consists of three major parts:

i. Information Flow - This segment illustrates how information about processes are shared and transmitted.
ii. Product Flow – This segment include a variety of data points for practical purposes, highlighting specific information such as changeover and set-up time queueing time, workers, etc.
iii. Time Ladder – Include information regarding the value added time, non-value-added time, production lead time and total processing time.

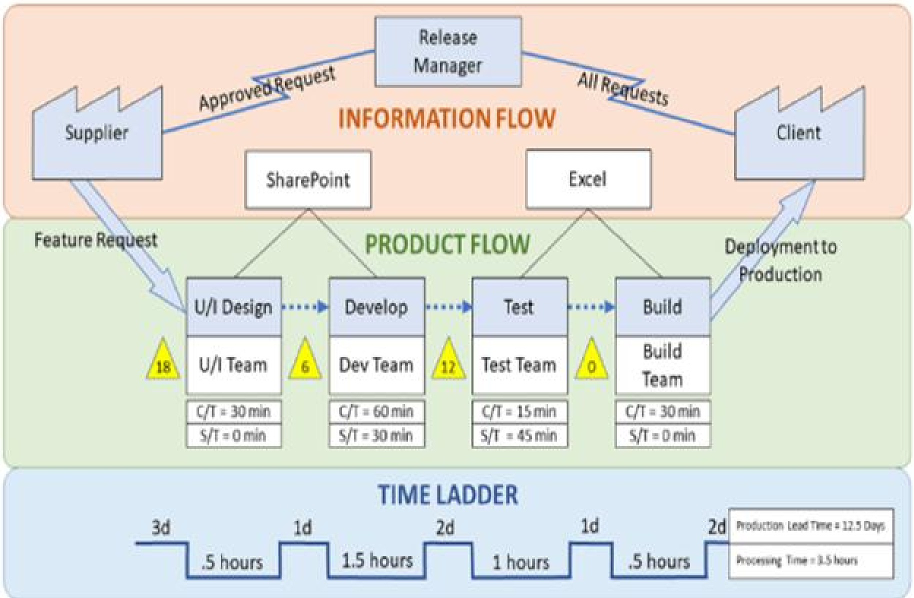

Figure 1. Value stream mapping template.

Apart from Lean, another key component of LSS is Six Sigma. Six Sigma is an advance process efficiency and process output methodology [15]. The Six Sigma strategy was introduced by the Motorola Corporation in the mid-1980s with the goals to minimize costs by reducing process variability which causes product failures. Motorola defined Six Sigma as the 3.4 defects per million based on statistical process concepts. In the 1990s, Six Sigma was made popular by General Electric.

Six Sigma is often used to minimized defect waste and inefficiencies in a process. Any organization should focus on eliminating processes that does not meet customers' needs. Thus, Shaw [16] emphasized that listening to customers' needs is the most critical task in Six Sigma in deciding what matters for the customers and the relevance to the quality of the product and the process according to the customers' perspectives. However, over the years, Six Sigma has progressed from the fundamental framework to a broader applications such as in the project management, transitional management, and as problem solving tool [17]. The Define, Measure, Analyse, Improve, Control (DMAIC) sequential-ordering strategy is becoming a powerful methodology employed to promote business improvement change in an organization. Figure 2 provides the details of the Six Sigma DMAIC methodology.

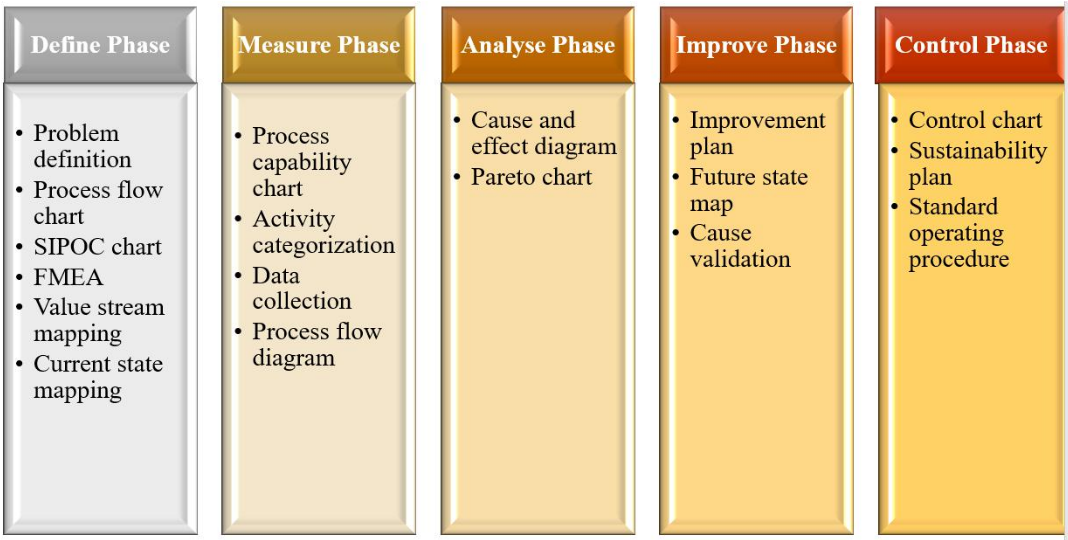

Figure 2. The six sigma DMAIC methodology [17].

3. METHODOLOGY

This study employed the LSS framework as shown in Figure 3. In the Define stage, the problem statement was defined in order to establish the project charter which was also the objectives of the study. A flowchart is a good method to use where it introduces the production process system, which enables the team to better understand the processes involved in the roof-tile production. The flow chart also translates the voice of the customer (VOC) and the expectations of value to meet the cost to quality (CTQs).

Next, the Measure stage involved activities such as the gathering of the product, process, equipment, manpower and other vital information to develop the Lean Current Value Stream Map (CVSM). This included the throughput produced by the manufacturing line, the amount of raw materials used, the type of equipment, the cycle time, changeover and set-up, operator quantity, working and break time and quality inspection. Work study using stop-watch and historical data gathering were used to gather the necessary data for the development of the CVSM. The brainstorming sessions with the company's team were also critical at this stage to verify and validate the CVSM.

In the analyse phase, detail evaluation of the CVSM was done to identify the various types of wastes occurring in the system prior to proposing the Future State Map (FVSM). The top three major processes with the highest cycle time were selected to be studied. Six Sigma quality tools such as cause-effect diagram, was used to identify the root causes of these top three major issues of the manufacturing system. A Failure-Mode-Effect-Analysis (FMEA) was also developed to evaluate the processes failure risks based on the Risk Priority Number (RPN), Severity (SEV) and occurrences (OCC). The Why-why analysis was used to further probe the causes and formulate the countermeasures to overcome the issues.

To create a leaner manufacturing system, suitable Lean tools such as the Kanban system, Pull System and 5S were proposed to be implemented aimed at reducing or eliminating inventory and motion wastes in the manufacturing. Finally, an improvement plan with assigned company's resources and specific timeline with quarterly review session was developed to ensure the successful implementation of this project.

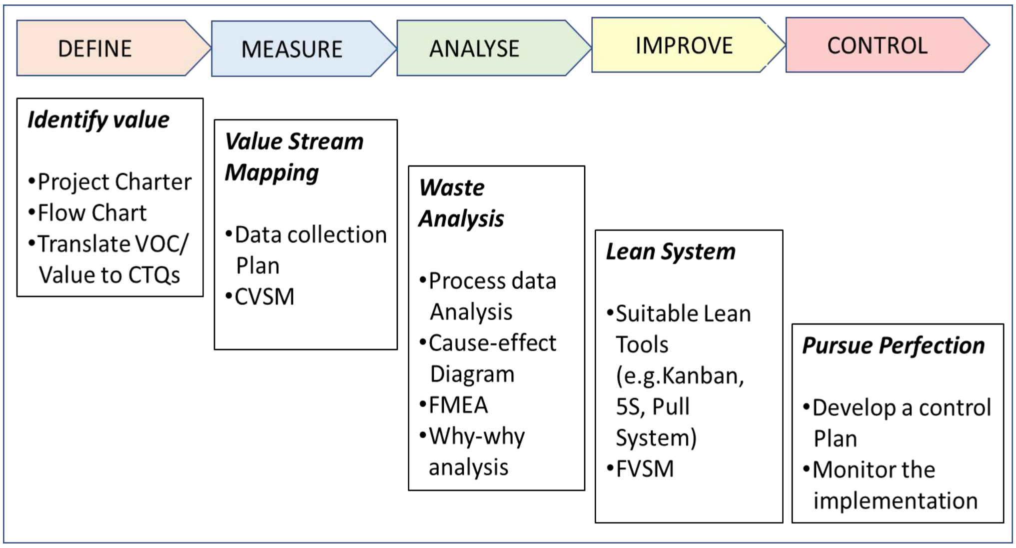

Figure 3. Lean six sigma framework used in case study.

4. CASE STUDY RESULTS

The Lean Six Sigma framework employing the DMAIC systematic methodology in this case study is detailed in the following sub-sections.

4.1 Define

A project charter is a useful tool to translate the voice of customers into project goals and to ensure commitment and ownership of responsibility not only from the project team but also from the management. Thus, a Lean Six Sigma team was set up comprising of a cross-functional team with members from the consultants, material planning and scheduling, manufacturing process, engineering, maintenance and quality assurance led by the new regional director. The goal of the project was set to study the issues along the manufacturing process flow and identify the areas to focus on improvement activities.

The next step was to identify the product to be studied. The company offers the customer a very good range of high-quality clay roof tiles and its accessories made from high-quality raw materials. One of the accessory products, the ventilation pipe or known as the V-pipe under the fitting product family was selected to be studied since it constituted of 40% monthly demand, the highest in the product profile. Figure 4 illustrates the V-pipe product.

Figure 4. The V-pipe.

The Figure 5 shows the process flow of the V-pipe manufacturing. The process starts with the raw materials, which is the clay being dug up from the quarry and brought to the factory. A certain combination ratio of chemical, water and clay are mixed and flows in the vacuum extruder creating the clay bat, which is then arranged by the operator on a trolley that can hold 60 pieces of clay bat. The trolley is then pushed by an operator called a runner to the fitting press or also known as the hydraulic press for the clay bat to be shaped into the V-pipe. The V-pipe trolley will next be sent by runner to the chamber dryer to dry up. A forklift will pick up the V-pipe to be hand-sprayed using a special coating chemical. Next, a batch of 1600 pieces of V-pipe are burned in the kiln. After the burning process, the QA will check the products for any irregularities such as crack, warp or bump before product is ready to be packaged.

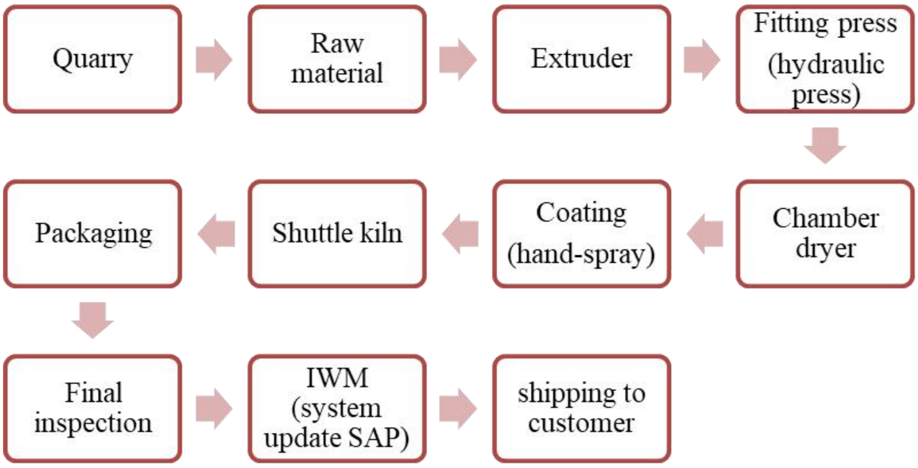

Figure 5. The V-pipe manufacturing process.

4.2 Measure

Antony et. al. [18] explained that once the problem has been defined, the measure phase requires more data collection and systematic evaluations. First, data gathering was conducted at the key processes to gain information regarding the cycle time, changeover time, working shift and operator allocation. The manufacturing operates in one 9-hours shift a day, 20 days in a month. The operators is given a 60-minutes lunch break, a 15-minutes morning break and a 15-minutes afternoon break for the shift. There is also a mold changeover every 150 minutes and housekeeping for another 15 minutes. Therefore, the available time for this manufacturing process is calculated as:

Available Time = Working Time – Break Time – maintenance time
= (9 x 60) – (60+15+15) – (150+15)
= 285 minutes or 17100 seconds

The Takt Time or the manufacturing pace is then determined based on the available time and also the customer demand which is 120 pieces / day.

Takt Time = Available Time / Demand
= 17100 / 120
= 142.5 seconds / piece

This means the manufacturing line must produce a piece of V-pipe every 142.5 seconds.

All the gathered data is visually represented in the Current Value Stream Mapping as shown in Figure 6. CVSM is a useful visual tool to represent the current condition of the manufacturing process. From the CVSM, the Process Lead Time (PLT) is 3.8 days, the value-added-time is 129696 seconds (1.5 days or 39.5%) and the non-value-added-time is 199224 seconds (2.3 days or 60.5%). Among the issues identified which are represented using the Kaizen bursts are waiting time at pick up claybat, waiting time due to limited tray and frames, limited transportation tray called H-cassettes, inefficient manual spraying method and improper handling methods to loading and unloading.

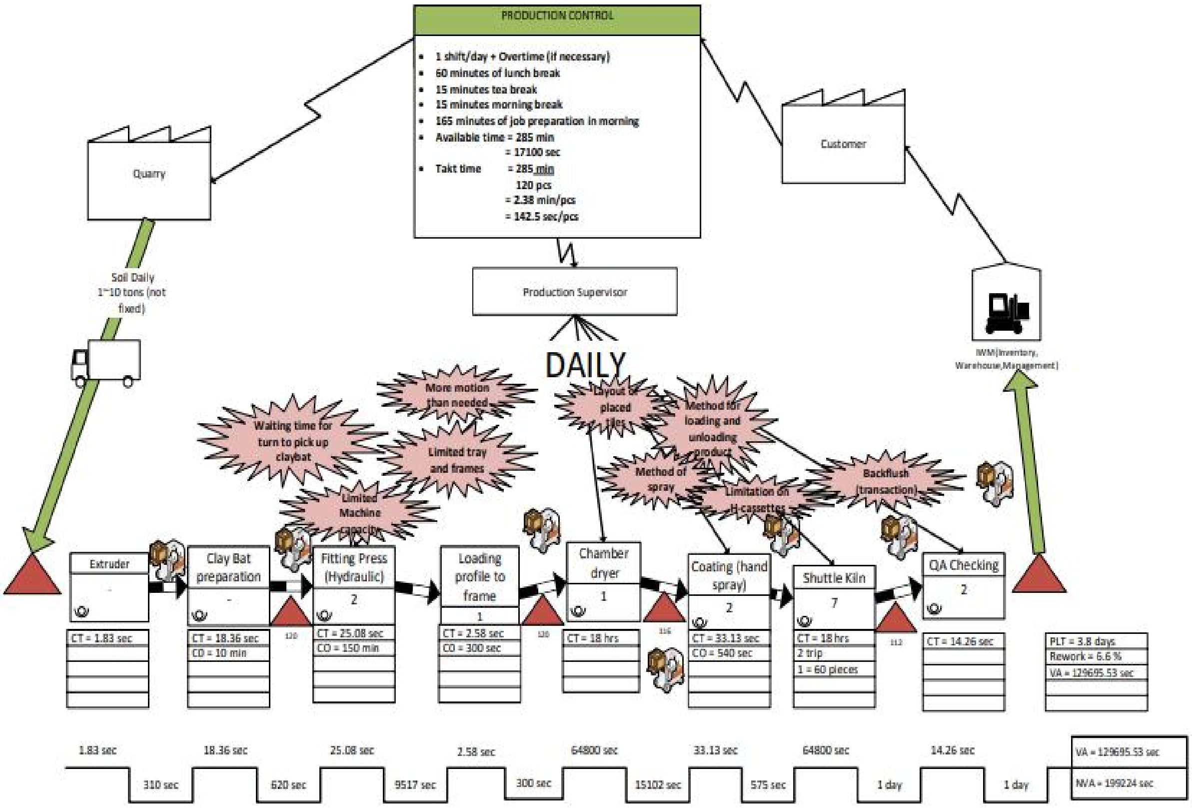

Figure 6. Current value stream map (CVSM) of the V-pipe manufacturing.

In addition to the CVSM, a capacity graph is drawn to further appreciate the actual capability of each process and expose the real bottleneck in the manufacturing system. Figure 7 presents the capacity graph drawn from the cycle time data and using the equipment quantity and the working time values of 4.5 hours (from the available time). From the graph, the hand-spray coating, the hydraulic press and the clay bat preparation are the top 3 problematic processes that require further detail attention.

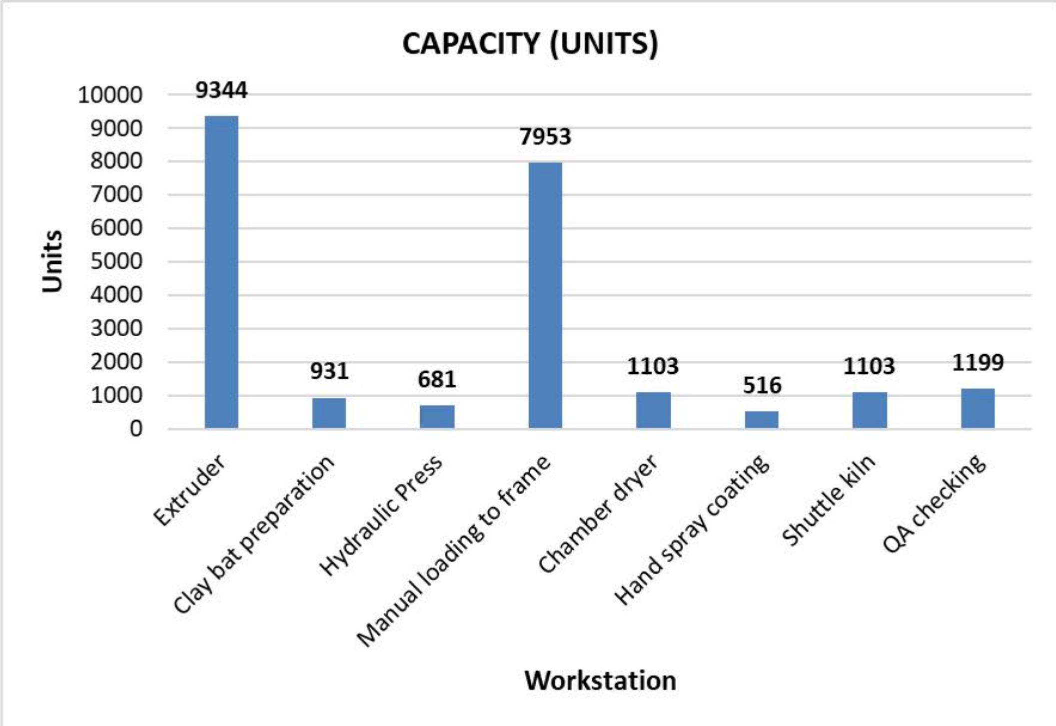

Figure 7. The process capacity graph.

4.3 The Critical Analyse

Among the top three areas to focus identified from previous figure (Figure 7) are detailed in Figure 8. The manual hand spraying of the product although only took about 33.13 seconds per unit, involves many steps on non-value-added activities such as arranging the tiles in a row, vacuuming the product surface and waiting for the forklift to pick up the finished product (530 secs).

For the second area; the hydraulic press, the majority of time wasted at the machine was due to cleaning the mould cover (7410 secs), testing the mould (720 secs) and waiting for the forklift to pick up and load the tray onto the machine (420 secs). The third area; the clay bat preparation process involves high motion wastes during this process due to activities especially waiting for transportation (300 secs) and set up (300 secs).

Figure 9 shows the fish-bone-diagram for the manual hand spray operation. Analysis on the man, machine, method and material indicated that the company clearly needs to consider to convert the manual process into at least a semi-automated process which also include a conveyor system to reduce the non-value-added time for this process. This will also solve the high absenteeism issue due to the workers having back-pain problem.

Next, attention is focused on the second bottleneck; the 25-year-old hydraulic press. Figure 10 shows the fish-bone-diagram developed by the project team members to further identify issues at the hydraulic fitting press machine including taking about 3 hours to perform the maintenance, mold damage and mold membrane not sealing well. Further, the work-in-progress material has issues with being rejected due to crack and also high waiting time. The process also has high absenteeism issue due to the workers experiencing physical discomfort and back pain problems. This has to do with the method of setting up the mould and also the loading of the clay bat into the mold press.

For the clay bat process, the 620 seconds wastes occurring at this process include high motion during the set-up process and also waiting for the forklift to pick up the clay bat to the next process, the hydraulic press which is one of the critical process for the manufacturing system. Thus, the company need to improve the scheduling of the forklift to transport the product and to avoid material downtime for the hydraulic press to start the process. This is also highlighted in the fish-bone-diagram in Figure 10 on the material cause.

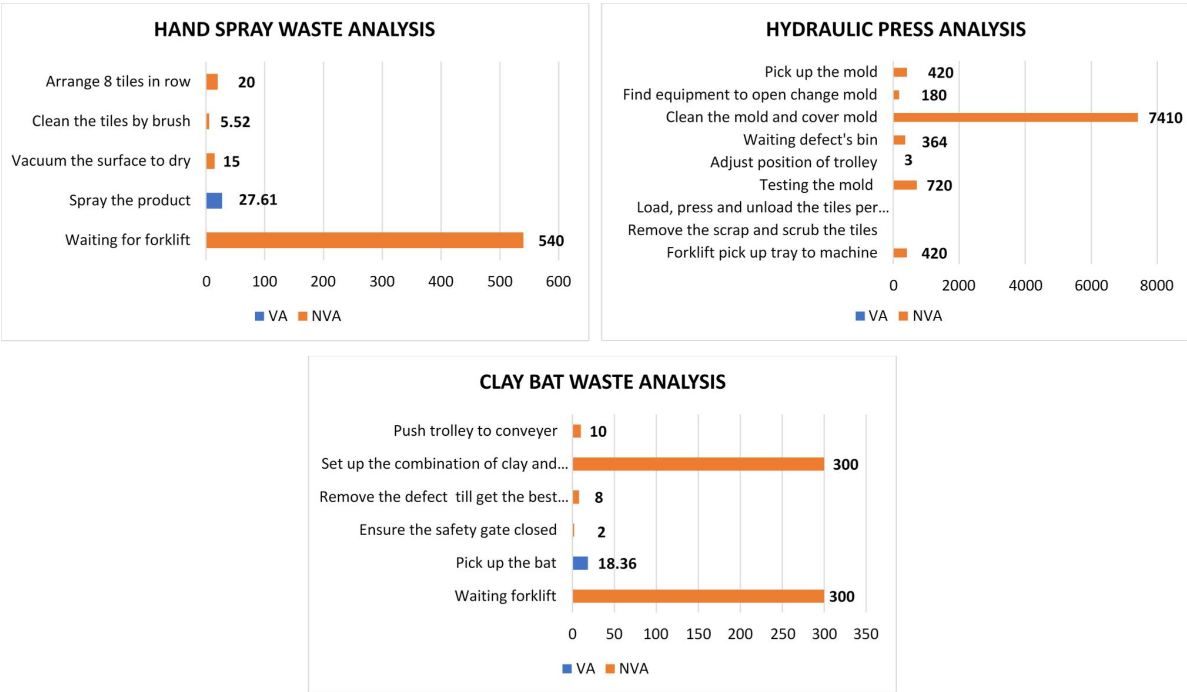

Figure 8. The top three bottleneck lean waste analysis.

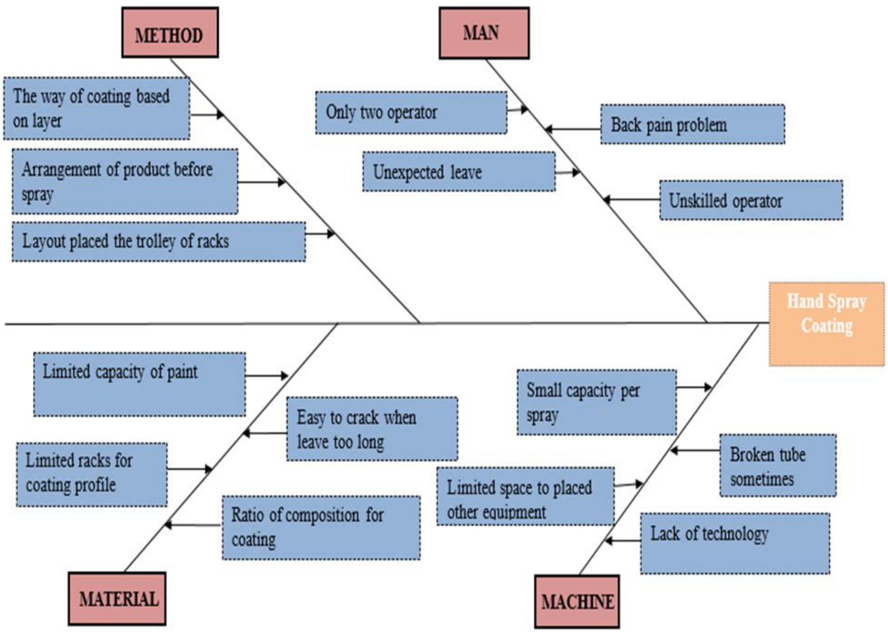

Figure 9. Fish-bone-diagram of the hand spray coating.

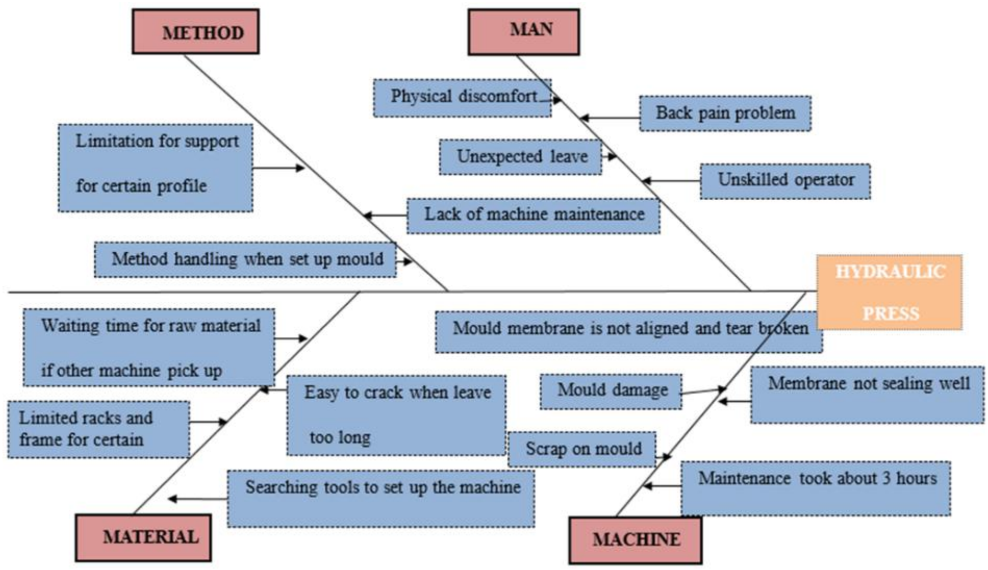

Figure 10. The fish-bone-diagram of the hydraulic fitting press.

4.4 Improve and Control

In the improve stage, suggestions were made after a brainstorming sessions using the Why-why analysis method to focus on the following areas:

i. For the clay bat operation, the main issue is the availability of the forklift to transport the material to the hydraulic press. A forklift is capable of holding 60 pieces of units. The process time for the clay bat is 18.36 seconds per piece or 1101.6 seconds (18.36 minutes) for every 60 pieces. Therefore, the forklift should pick up the finished product approximately every 20 minutes.

ii. At the hydraulic press, a more detail study on the Overall Equipment Efficiency (OEE) should be done to solve the 3 hours maintenance issue and also a detail Sig Sigma study to solve the issue on the mold damage and mold membrane not sealing well causing defect waste. For the time being, the company has agreed to perform 5S at the process to resolve the improper cleaning issue.

iii. To mitigate the back pain issue at the hand spray process, suggestion is made to cross-train the operators and provide a rotational schedule to perform the task. A more frequent rest allowance should also be provided to the workers. Improvement should also be focused on the method of spraying which is only currently at two-pieces per spray with limited spray paint capacity.

iv. The current available time is 17100 seconds or 4.75 hours per shift from the 9 hours working time of a shift or only at 52.7% efficiency. To improve the efficiency, hence increasing the capacity of the manufacturing system, the company management should consider reducing the 165 minutes of the time to perform work preparation during the beginning of the shift. The work preparation includes the taking of worker's attendance and production planning. If this work preparation is reduced to only 45 minutes, the available time can be improved to 6.75 hours resulting in the production efficiency of 75% and manual hand spray bottleneck process capacity from currently 516 pieces to 733 pieces (42% productivity improvement) without any additional cost incurred.

In the control phase, each improvement activities identified were assigned a team leader to lead the improvement projects for the hand spray process, hydraulic press and the clay-bat process. The director will follow-up on the progress during their monthly review meeting.

5. CONCLUSION

The study has achieved the objective of investigating the current production process to identify the top three major problematic areas for the roof-tile manufacturing company to focus on their improvement projects. Lean Six Sigma DMAIC-VSM approach was applied with successful results to visually show the company management the manual process of hand spray coating as the key bottleneck of this operation. In addition, major issues with the hydraulic press and clay bat process were also uncovered with various different types of wastes identified. The fish-bone-diagrams were developed to further analyse the pertaining issues before Why-why analysis was done to plan for the countermeasures. The company will reap the benefits of the study especially achieving 42% improvements on the efficiency improvement if the action plans were diligently implemented.

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