Process improvement using value stream mapping and lean methodology: a case study application in batch chemical process industry

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Abstract. Intensifying competition in the global chemicals market is increasing the pressure on companies to adopt lean manufacturing and improve their operational efficiency to remain competitive. Companies operating in emerging economies are no exception. This study looks at the application of value stream mapping (VSM) in the production process of a batch chemical manufacturing company based in Indonesia. The application of value stream method is a multistep approach. A value stream scope is determined in the beginning, followed by a data collection step to construct a current state map. The current state is analysed to gain a deep understanding of how things currently operate and provides the foundation for the ideal future state of the production process. The production process is then redesigned following lean manufacturing principles, and the future state map is drawn. Analysis is then conducted to estimate the potential cost reduction from implementing the proposed future state. The results indicate a more efficient production system as shown by decreased production lead time and reduced production costs.

1. Introduction

The challenge to feed the world is an increasingly difficult task as the world population continues to grow, especially in Africa and Asia. In 2050, it is estimated that the world population will have grown by roughly 30%. This means from now to then, nearly 83 million people will be added every year [1]. On the other hand, it is estimated that 12 million hectares of agricultural land are lost annually due to urbanization among other causes, and by 2050, there would remain only 0.16 hectares of farmland per capita compared to 0.52 hectares per capita in the 1950s.

This situation highlights the need for a more productive farming technique that utilizes technology to increase yield per hectare of available farmland. One of the many tools available to farmers is the use of herbicide to combat the growth of nutrient sapping weeds. In Indonesia, the agricultural sector is an important source of employment as it represents approximately 7.78% of the gross domestic product in 2019. An efficient and reliable herbicide product supply is therefore impactful towards the nation’s economic stability and vital in ensuring food security in the country.

Increasing globalization has led to intensifying price competition in the herbicide industry. This situation necessitates industry players to increase their operational efficiency and push towards the productivity frontier in order to thrive in the industry. This case study looks at an herbicide manufacturing company that is facing challenges from fluctuating sales volume. It sees demand surges at certain times of the year, overwhelming production lines and leading to overtime costs increase.

Ace Chemicals (the real name of the company is not disclosed for confidentiality reasons) is a wholly-owned subsidiary of a global chemical conglomerate that is amongst the world’s largest agrochemical producers. Ace Chemicals produces herbicide products for both local and export markets. The company has a large footprint in Indonesia with a significant market share in both local and export markets. Local market sales account for roughly 75% of the company’s total sales, and sales to various overseas markets including Australia, New Zealand, Korea, and Japan make up the remaining sales.
volume. Among the global chemical organization’s core strengths are customer centricity and process excellence, and one of its most far-reaching initiatives to reflect those core strengths is the launch of a production system with the aim of standardizing its supply chain operations worldwide and increasing its operational efficiency. The initiative was launched in mid-2019, and Ace Chemicals became the organization’s first site in Asia to implement the new production system. The organization’s production system follows the pattern set by other manufacturing companies and can be traced back to the Toyota Production System (TPS) [2].

Due to intensifying competition in the industry, and in order to align with the parent organization’s long-term business sustainability goals, the company needed to improve its production process and reduce its production costs. The research question in this study is on how to utilize the value stream mapping (VSM) and lean principles to analyze and improve the production process of a batch chemical plant producing an herbicide product family for the local Indonesian market. VSM is used as it allows the identification of wastes’ sources and offers a systematic approach to realize improvements that takes into consideration the constraints and opportunities from the perspective of the whole process [3]. VSM applied in the context of lean manufacturing has been successfully deployed in many different manufacturing settings from its original application in discrete manufacturing to continuous process manufacturing [3][4]. More recently there have been cases of researchers applying VSM in software development labs to the hospital environment [5][6], demonstrating the versatility of this approach. Additionally, the discussion on VSM and lean in a complex manufacturing environment such as batch chemical manufacturing is still limited [7][8], and this paper aims to explore this topic further to test the applicability of VSM and lean production in the context of batch chemical manufacturing.

2. Literature Review

Lean manufacturing methodology has its origin in the Toyota Production System (TPS) developed by the Toyota Motor Corporation starting in the 1940’s in post-World War II Japan. The person largely credited with the invention of TPS is an industrial engineer working for Toyota named Taiichi Ohno [4][9][10]. TPS has two guiding principles. The first is the principle of Just-in-Time production (JIT) that mandates the production of only what was needed, and only when it was needed. Any divergence from the true needs of manufacturing a product is condemned as waste or muda in Japanese. The second principle is that of jidoka where any production problems are instantly self-evident, and when problems are detected, production is immediately stopped to allow the issue to be resolved. In other words, jidoka insisted on built-in quality in the production process and condemned any deviation from value-addition as waste. In the Toyota Production System book, Taiichi Ohno classified waste into seven categories, which are briefly described below [11]:

- Transportation: unnecessary movement of materials or people within a process causing additional needs for maintenance, increasing lead time and introducing risk of damaged product
- Inventory: including raw material, work-in-progress (WIP), and finished goods. Inventory increases operational costs (including conveyance costs, storage costs, and risk of obsolescence)
- Motion: unnecessary movement or motion of people or machine that does not add value to the product
- Waiting: time wasted by people or machines waiting for the completion of a work cycle, which includes waiting for other people, machines or material
- Over processing: this includes all activities or operations that are not required to meet customer demand and does not add value for the customer
- Overproduction: Producing sooner, faster, or in greater quantities than is required by the customer. Overproduced items end up as excess inventory or may even be scrapped
- Defects: Producing parts or products that do not meet customer specification

There are various tools that are commonly deployed during implementation of lean including kanban, visual control, poka yoke, 5S (i.e. a systematic and sustainable method to organize the workplace), TPM (i.e. Total Productive Maintenance), DDS (i.e. Daily Direction Setting), and value stream mapping [7]. VSM is used for detailed analysis of the production process to identify waste and allows for process
improvements to lower production costs, improve response time to satisfy customer demand and produce higher quality products [5][7]. VSM is indispensable for an organization seeking to implement lean. It forms an essential part of lean manufacturing implementation. Mapping the organization’s value stream is one of the five principles of lean [12]:

- **Define value**: understand what value is by discovering what customers find valuable, in other words, value is what the customer is willing to pay for in a product
- **Map the value stream**: value stream consists of all actions required to develop and manufacture a product or deliver a service
- **Create flow**: once the value stream has been mapped, each step in the process is then analyzed to maximize its efficiency, reduce, and ideally, eliminate waste to create a state where products flow between production steps
- **Establish pull**: this means letting customers pull (i.e. order) the product according to their needs instead of constantly producing and pushing unwanted products regardless of customer’s demand
- **Pursue perfection**: this part emphasizes that lean is a cyclical approach to the process of waste reduction to bring the greatest value for the customer

Implementation of company specific production systems built on lean principles has been found to provide competitive parity in the manufacturing industry using the resource-based VRIO (Valuable, Rare, Inimitable, and Organized) business analysis framework [2]. Lean manufacturing has been demonstrated to produce higher levels of quality and productivity and better customer responsiveness. Lacerda, Xambre, and Alvelos [4] demonstrated that they were able to identify lean wastes in an automobile component manufacturing plant using VSM methodology and proposed fourteen solutions to eliminate those wastes, of which eleven were implemented. As a result, the authors were able to reduce the cycle time and improve the efficiency and productivity of the plant [4]. Abdulmalek and Rajgopal [3] presented the application of VSM in process industry by combining VSM with simulation of lean tools at a steel mill and found that VSM is universally applicable in the process industry [3]. Schmidtke, Heiser, and Hinrichsen [7] applied VSM to batch chemical process manufacturing. In their study, the authors observed that there were some challenges related to the application of VSM in batch chemical processes due to its origins in the automotive industry and mechanical production processes requiring some adaptation for use in chemical manufacturing environment. The authors found several limitations in VSM methodology due to process variability, complex process flow, and conflicting cost factors often found in the chemical industry. Nevertheless, the authors were able to apply VSM methodology coupled with Discrete Event Simulation (DES) tool to gain satisfactory cost reduction in their case study application in the production process of exhaust gas purification catalysts [7].

### 3. Methodology

The objective of this research was to study the application of value stream mapping in a batch chemical production process that include analysing the current state of the company’s main production process to identify wastes, designing an improved process following lean manufacturing principles to achieve a more efficient production system shown by decreased production cycle time and reduced production costs. The study began by clarifying the research question. Here the main problem to be addressed was the need by an herbicide manufacturer for an improved production process of its main product to remain competitive in the market through the application of value stream mapping (VSM) methodology complemented by lean manufacturing approach. Next, a literature review focusing on the application of VSM and lean manufacturing methodology was conducted to gain a thorough understanding of the topic.

Data were collected through observations and time study of related processes to gain a true picture of how things are in the current state. Field observations were conducted directly at the company’s manufacturing facility during real production activities whenever possible. Next, VSM of the current production process was drawn based on collected data, followed by the creation of a future state map with improved manufacturing process. Then, analysis was carried out to quantify the potential savings from implementing the future state map in the manufacturing process. In the final stage of this study,
conclusions were drawn from the results of the analysis made in the previous stages to highlight the implications of this study. Research flowchart in this study is shown in Figure 1.

Value stream maps were developed for the current and targeted future states. The identification of the dominant “product family” in a production process served as the starting point for the creation of a value stream map. A product family is defined by Rother and Shook as a group of products that pass through similar processing steps and over common equipment in the downstream processes. Next, customer requirements were determined including required product quality, quantity, and tact time. The value stream maps were drawn using paper and pencil on an A3 sized paper to record information and material flows in Ace Chemicals. For each process step, the Process Time (P/T), Delay Time (D/T), and Percent Complete and Accurate (CA%) data were collected and shown on each data box. Inventory and Work-in-Progress (WIP) were counted and recorded on the current state map. Variables used in value stream mapping in this study are shown in Table 1.

Data collection in this study began with an initial sampling of 15 observations [4] for each process step to calculate their mean and standard deviation. The number of required sample size was calculated based on accuracy level of 5% and confidence level of 95% using the following formula:

\[
\text{Required Sample Size (n)} = \left( \frac{zs}{h\bar{x}} \right)^2
\]

Where \( z \) is the standard deviation from the desired confidence level, \( s \) is standard deviation from initial sample, \( h \) is desired accuracy level, and \( \bar{x} \) is the mean from initial sample. Additional observations were then gathered to reach the required number of samples, and standard time for each process step was then calculated. Performance rating factor was set at 100% since production was running at normal load and all observed operators were trained to do the work and have more than one year of working experience at the plant. An allowance factor of 10% was used in calculating the normal time to consider worker fatigue, bathroom breaks, and delays. The future state map was drawn according lean principles to implement pull and reduce inventory level to achieve lower lead time and production costs [4, 7]. In addition, the future state map aimed to achieve increased production capacity to meet seasonal demand for the product. Finally, financial analysis of the proposed future state was carried out to estimate the expected costs savings.
Table 1. VSM variables used in capturing process data.

| Term                          | Unit | Description                                                                 | Formula                                      | Data collection method |
|-------------------------------|------|----------------------------------------------------------------------------|----------------------------------------------|------------------------|
| Processing Time (P/T)         | s    | The time spent actually performing work and does not include delay time within a process. It can be further broken down into Value Added, incidental and Non-Value-Added time | N/A                                          | Site observation       |
| Delay Time (D/T)              | s    | The time waiting within a process step. There is no value is being added in delay time | N/A                                          | Site observation       |
| Cycle Time (C/T)              | h    | The time span between repetitions of the same task. Thus, it is the time taken by all the slowest station or operator in the process | $Cycle\ Time\ (C/T) = \frac{Processing\ Time\ (P/T)}{\ +\ Delay\ Time\ (D/T)}$ | Calculation            |
| Percent Complete and Accurate (CA%) | %    | The percentage of time customer (internal or external) requirements are fully met first time in a process step | N/A                                          | Site observation       |
| Takt Time (T/T)               | s    | The pace at which the manufacturer has to produce its products to meet the demand of the client. This metric synchronizes the rate of production to the rhythm of sales | $Takt\ Time\ (T/T) = \frac{Available\ work\ time\ per\ shift}{Customer\ demand\ rate\ per\ shift}$ | Calculation            |
| Wait Time (W/T)              | h    | The time when no work is being done as a result of the delay between process steps (i.e. sitting in the inventory) | $Wait\ Time\ (W/T) = Cycle\ Time\ (C/T) \times Inventory$ | Calculation            |
| Lead Time (L/T)              | h    | The time it takes for a product to pass through the value stream or the process from the very beginning to the end | $Lead\ Time\ (L/T) = \sum_{i=1}^{n} C/T_i + W/T_i$ | Calculation            |
| Rolled Throughput Yield (RTY) | %    | Rolled Throughput Yield (RTY) is the % of time that the process delivers a product or service completely and accurately from intake to the delivery to the end customer | $Rolled Throughput Yield\ (RTY) = \prod_{i=1}^{n} CA\%_{i}$ | Calculation            |

4. Results and Analysis
This paper focused on the main product family that makes up around 75% of Ace Chemical’s annual production volume. The main difference within this product family is the pack sizes of the final product. The product is delivered in three pack sizes: 1-liter bottles, 4-liter jugs, and 20-liter jars. The normal average demand per week is calculated to be 270,000 litters with 173,000 litters in 1L bottles, and 97,000 litters in 4L pack size. However, during peak production months, demand reaches an average of 472,500 litters per week.
litters comprised of 202,500 litters of 20L jars, 173,000 litters of 1L bottles, and 97,000 litters of 4L pack size. The production process is shown in Figure 2.

![Block flow diagram of case study process.](image)

**Figure 2.** Block flow diagram of case study process.

The production process begins with the neutralization step where acid active ingredient in the form of wet cake in FC bags (i.e., 1-ton bags) are transported from the raw material storage area by forklift and hoisted to the neutralization reactor where it is reacted with base solution in water. The product from this neutralization process is called the active ingredient salt and is stored in surge tanks while waiting for further processing. Next, the active ingredient salt is transformed to finished bulk product in the formulation tank by mixing the salt with surfactant and other materials. The finished bulk product is stored in storage tanks before being transferred to the packaging lines. The packaging machines are run continuously during normal work shift (i.e., 8-hour shift in a 5-day workweek). A process pump transfers the finished bulk to the packaging lines consisting of Line 1 (1L) with 80 L/min capacity, Line 2 (4L) with 48 L/min capacity, and Line 3 (20L) with 94 L/min capacity. Line 1 (1L) and Line 2 (4L) each requires five operators to run, while Line 3 (20L) is run by four operators. Finished goods are pelleted and transported by two forklift operators to the finished goods warehouse for storage before shipping to the customer.

Data gathered from each process step is shown in Table 2. Forklift 1 showed the largest variability compared to other processes due to raw material storage areas that were situated at varying distances from the next process (i.e., neutralization). The decentralized nature of the plant’s raw material storage locations was partly due to the high raw material inventory requiring storage space that was more than the capacity of any one storage location. The neutralization step required a sample size of 22 due to variation introduced by rework causing longer batch time. High sample variability was also observed in the shipping process step. This variability was the result of varying truck sizes observed during the sampling process (i.e., large delivery trucks require longer load time per pallet, and vice versa).

**Table 2.** Current state map process data.

| Process step   | Mean (s) | Std Dev (s) | Required sample size | Actual sample size | Normal time (s) | Standard time (s) |
|----------------|----------|-------------|----------------------|--------------------|-----------------|-------------------|
| Forklift 1     | 1.311    | 157         | 30                   | 31                 | 1.311           | 1.442             |
| Neutralization | 4.425    | 522         | 22                   | 23                 | 4.425           | 4.868             |
| Formulation    | 17.126   | 1.963       | 18                   | 18                 | 17.126          | 18.839            |
| Line 1 (1L)    | 705      | 66          | 13                   | 15                 | 705             | 775               |
| Line 2 (4L)    | 1.301    | 125         | 14                   | 15                 | 1.301           | 1.431             |
| Forklift 2     | 113      | 9           | 9                    | 15                 | 113             | 124               |
| Shipping       | 299      | 30          | 28                   | 28                 | 299             | 329               |
The factory operates on an 8-hour shift schedule for 5 days a week, and customer demand is 270,000 liters per week; therefore, the tact time is 533 seconds per kL product. The current state map is shown in Figure 3. The map shows high raw material inventory, push production arrangement, and process bottleneck at the neutralization step as indicated by the lowest P/T to D/T ratio of 0.12. Current lead time was calculated to be 754.5 hours or roughly 31 days with only 0.93% value added time in the whole process.

An opportunity assessment analysis that included several rounds of interviews and workshops with each area personnel was conducted to gain insights on possible improvements to the current state with the aim of eliminating waste and applying lean principles to the herbicide production process. The list of potential improvements was narrowed down by considering potential benefits and ease of implementation to the following items:

- Implement pull and inventory supermarket
- Debottleneck neutralization reactor by reactivating an idle reactor with existing neutralization personnel sharing the manning responsibility (i.e. no additional headcount requirement)
- Reduce acid active ingredient inventory to 75D supply
- Reduce finished bulk inventory by one-third
- Reduce finish goods inventory to a week’s worth of stock
- Increase formulation capacity to balance with new neutralization capacity
- Bring Line 3 (20L) machine online
- Continuous improvement/ operational excellence initiatives: 5S, TPM, DDS

During peak season, demand reaches 472,500 liters per week, and tact time becomes 305 seconds per kL product. The future state map was drawn up to reflect the proposed changes and shown in Figure 4.
The main features of the future state are the establishment of supermarkets to enable the downstream “pull” of materials at their desired rate to prevent inventory build-up, issuance of weekly production schedule to a single point at the packaging line, and increased production capacity to enable the plant to change output rate to match demand.

**Figure 4.** Future state map.

Table 3 shows a comparison between the present state and future state. The analysis shows that production lead time could potentially reduce by 30% and value-added time percentage could increase from 0.93% to 1.31% by applying the future state map to current production process.

**Table 3.** Current state and future state lean metrics comparison.

|                | Current state | Future state |
|----------------|---------------|--------------|
| Lead time      | 754.5 h       | 525.0 h      |
| Value added time| 0.93%        | 1.31%        |
| Inventory      | RM 575 batches| 434 batches  |
| WIP            | 150 kL        | 100 kL       |
| FG             | 900 kL        | 472 kL       |
| Capacity       | 54 kL/shift   | 94.5 kL/shift|

The potential savings from implementing the proposed changes are shown in Table 4. The savings are achieved from reduction of inventory costs and overtime costs during peak demand season. Due to confidentiality issues, the numbers shown have been masked, but still nevertheless indicate the potential cost impact from the improvement initiatives.
5. Conclusions
The objective of this research was to study the applicability of VSM in a batch chemical production process of an herbicide manufacturing company in Indonesia. In this paper, the production process of an herbicide product family was studied by gathering the information regarding current production process. Process improvements were identified following lean principles and a new redesigned process was presented with a reduction of 30% in manufacturing lead time. An analysis of potential savings from implementing the changes was also presented showing a positive return on investment. To implement the proposed changes, Ace Chemicals will have to renegotiate its raw material purchase agreement with its suppliers to synchronize the raw material shipment to customer tact time, engage with engineering contractors to execute its reactor turnaround plan, and formalize its lean manufacturing initiatives to sustain employee participation in the new production system.

This study demonstrated the ability of VSM as a tool to show and analyse the end-to-end view of a manufacturing process in a batch chemical plant. The method was shown to be effective for achieving balanced production rate and meeting customer demand. Managerial implications of this study include highlighting the value of continuous improvement using lean methodology even in a mature plant that has been in operation for years and the applicability of VSM outside of its discrete manufacturing sweet spot (i.e. in batch chemical process industry). Limitation of this research is the single case study at a single production site in Indonesia that makes up part of the parent organization’s global presence, which may limit some generalizations to other companies with different levels of resources, process complexity, and readiness for change. Future research may address this limitation by conducting larger study involving more companies in the process industry. Other opportunities that may be explored further include studying the impact of changeover to productivity and lead time and studying the application of simulation to model customer demand variability to further reduce production costs and lead time by optimizing inventory level and formulation batch size.

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