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DETERMINATION OF PROCESS VARIABILITY BY USING TRIANGULAR FUZZY NUMBER TO MINIMIZE PRODUCTION LEAD TIME IN A DYNAMIC VALUE STREAM MAPPING

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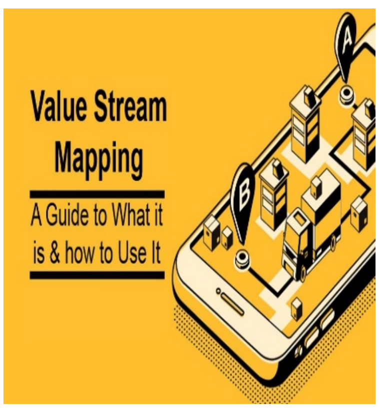
Graphical abstract



Abstract

This paper shows the incorporation of Value Stream Mapping (VSM) with triangular fuzzy numbers to determine variability and uncertainty in a conveyor manufacturing company. VSM is a pen and paper tool which is used to indicate wastes and bottleneck processes graphically and develop an action plan to enhance the production line. However, some weaknesses are identified in the conventional VSM where it fails to consider variability in a dynamic manufacturing environment. As such, this paper fills up the research gap by using Triangular Fuzzy Number (TFN) to illustrate time intervals, inventories and other variables of VSM operation. The purpose of this paper is to minimize total production lead time (TPLT) and total value-added time (TVAT) in the current value stream of the conveyor chain. More accurate details of variability in the dynamic manufacturing environment can be illustrated by a Triangular Fuzzy Number (TFN) of VSM. As a result, the future value stream map shows 50% and 22% reduction in TPLT and TVAT respectively compared to the current value stream. In conclusion, this paper also recommends that in order to optimize the accuracy of VSM analysis further, a discrete event simulation can be used to examine the fuzzy VSM.

Keywords: Value Stream Mapping, Triangular Fuzzy Number, Variability, Dynamic Production, Production Lead Time

1.0 INTRODUCTION

Lean manufacturing is a complex set of tools, practices and techniques that hold the purpose of minimizing wastes and uplifting the performance and effectiveness of a production system [1][2]. This 'lean' terminology, used to illustrate a system that consumes a minimal number of resources during production that includes space, labor, inventory equipment and less engineering inputs during the manufacturing process for fabricating an equally quality product of those produced by conventional mass production system.

The application of lean practices and tools in manufacturing sectors have been investigated by many researchers in past years. However, due to frequent alterations in technologies and products advancement, the initiatives of lean gradually become less overtime [3,4]. According to the value stream point of view, an effective application of a lean system can be obstructed by either internal or external challenges [5]. Although the application of VSM has aided to visualize the benefits of lean practice in the manufacturing sector, several drawbacks prevented VSM from being applied in a broader approach [6]. The main existing limitation of VSM is related to its static nature which makes it unable to take into consideration process variability that most commonly occurs in Make-To-Order manufacturing companies [7,8].

In high-variety and low-volume factories, the conventional VSM method becomes complicated and inefficient [9,10]. As such an investigation was conducted on a SME in Malaysia which is a high-variety and low-volume conveyor chain producing factory located in Balakong. Due to high product variety and high process variability, it causes high inaccuracy of inventory level, causes high Work In Progress (WIP) due to longer waiting time and overall, it leads to higher production lead time which is up to 8 weeks compared to standard lead time which is 2-3 weeks.

The purpose of this research was conducted to pursue an enhanced procedure model to optimize value streams which are more dynamic in nature by integrating VSM with a fuzzy algorithm to determine process variability and achieve reduction in total production lead time and value-added time [11,12].

1.1 Related Work

Value Stream Mapping has several definite features that makes it special and important for lean manufacturing compared to other mapping techniques. As an example, apart from managing the manufacturing process, VSM also enhances the whole manufacturing system by creating a holistic view of it [13,14].

VSM is also known as a door-to-door demonstrating tool for envisioning a production process not only at the single process level but also for the whole plant level. It also demonstrates the flow of materials and information not only for distinctive manufacturing plants but also for the entire supply chain [15][16]. Furthermore, the value stream map portrays information concerning the production times, as well as inventory levels, and also presents a reflection of systemic vision maintaining local details of process by graphically joining material flow, information flow and timeline [17].

In addition, by accessing operating parameters such as takt time, which determines the production rate at which each processing stage in the manufacturing system should operate, VSM links product planning and demand forecasts to production scheduling and flow-shop control.

The variabilities that are identified in the value stream parameters can be handled by fuzzy set theory by transforming the uncertainties into fuzzy numbers in order to handle the variability in a computational way [10]. A fuzzy set can be viewed as a subset from the real number set that constitutes uncertain values [18].

2.0 METHODOLOGY

The present study aims to determine the most suitable future state value stream by applying fuzzy numbers in order to map the value stream. A conveyor manufacturing company was selected as a case study due to the high variety and low volume process [19]. The manufacturing system is make-to-order type and has a high variety of products with varying process parameters [20,21]. Due to the high customized order from the customer a product family was selected based on their weight, component type, changeover time, shape and size. Prior to the development of a current state map, the relevant process data such as cycle time (CT), changeover time (CO) and setup time (ST) are collected.

The varying process parameters, CT, CO and ST were controlled by a fuzzy algorithm such as Triangular Fuzzy Number (TFN). This paper adapts triangular fuzzy numbers to denote inventories, time intervals and related variables of VSM operation. TFN calculates highest, lowest and mean data sets of these parameters as inputs for current value stream map (CVSM) [13,22]. A general TFN Ã is described as equivalent to (a,b,c). In equation (1), a represents lower bound whereas c represents upper bound. As such the fuzzy level of Ã is represented by the c-a values, where high values of c-a define a larger level of fuzziness and vice versa. The membership function μÃ(x) is demonstrated in the following equation from (1) until (4) which adapted from [21, 22]. The application of TFNs are seem to be suitable with the objective of VSM, as they provide a good adjustment between the accuracy in the final ranking and computational costs.

$$\mu\tilde{A}(x) = \begin{cases} 0, & x \leq a, \\ \dfrac{x-a}{b-a}, & a < x \leq b, \\ \dfrac{c-x}{c-b}, & b < x \leq c, \\ 0, & x > c \end{cases} \quad (1)$$

$$a = \frac{(\min(\text{sample}) - 0.1b)}{0.9}, \quad (2)$$

$$b = \mu(\text{sample}), \quad (3)$$

$$c = \frac{(\max(\text{sample}) - 0.1b)}{0.9} \quad (4)$$

2.1 Collection Of Data

The manufacturing processes of the chain are divided into five main sections such as Coining (Coin), Drilling (Drill), Chamfering (Chamfer), Welding (Wel) and Assembly (Asy). Information concerning manufacturing processes data such as cycle times (CTs), changeover times (COs), number of operators, materials deliveries' frequency and quantity, inventories' quantity and places, working time and other variables were collected by walking through the production floor, in Japanese term called 'Gemba' and together performing a time study. This time study was performed with at least 60 measurements in order to collect the data that is closer to accuracy. Then, based on the measurement results, the parameters such as: minimal CT

(CTmin), average CT (CTave), maximal CT (CTmax), minimal CO (COmin), average CO (COave) and maximal CO (COmax) should be determined.

The collected data were carefully planned to take into consideration various criteria that affect variability. Especially, in the collection of cycle time, the recorded data for each manufacturing process is influenced by various factors such as different product groups, machines, operators and times of day (morning or night shift). About 60 groups of data were gathered and examined in detail in order to generate a sufficient sample to conduct analysis that follows. Based on the equation as stated from (2) to (4), the time intervals can be portrayed in the form of TFNs as shown in Table 1 and Table 2. The CVSM of the company was established using Microsoft Visio software to reveal where the bottleneck process and non-value-added activities occur that increase total production lead time. By analyzing the CVSM, the identified bottleneck processes and non-value-added activities are reduced using lean tools and techniques.

2.2 Industrial Application

The conveyor chain producing company`s production was managed by Enterprise Resource Planning (ERP) systems that coordinate different departments such as marketing, Production Planning and Control (PPC), purchasing, production and logistics in one platform. Job sheet sends to production leaders to run and control production orders. Finished goods will be reported in the ERP system and prepared for shipping by logistic departments. The standard cycle time for coining, drilling, chamfering, welding and assembly is 77s, 164s, 187s, 432s and 1600s respectively.

A descriptive statistic of the sample containing 100 groups of observation data, were described as shown in Table 2. The current state map of the company starts from receiving goods until shipping will be demonstrated in Figure 1 of the next section 3.1. The standard and triangular fuzzy timeline approaches were demonstrated at the bottom of the map.

3.0 RESULTS

Table 1 shows the standard variable and Table 2 shows triangular fuzzy number (TFN) of cycle time and WIP for six workstations.

Table 1: Standard variables of cycle time and WIP for six workstations

	Standard Variable	
	Mean	Std. Dev
Raw material inventory (days)	5.78	2.37
Coining (s)	74.77	6.74
Buffer 1 (days)	3.99	1.72
Drilling (s)	161.4	7.66
Buffer 2 (days)	5.78	2.09
Chamfering (s)	199.1	7.06
Buffer 3 (days)	4.02	1.85
Welding (s)	435.36	8.67
Buffer 4 (days)	3.98	1.72
Assembly (s)	1541.2	7.96
Buffer 5 (days)	3.45	1.68

Table 2: TFN for calculated cycle time and WIP for six workstations

	Observed Value			
	Min	Mean	Max	TFN
Raw material inventory (days)	1.1	5.78	12.0	(1.1, 5.78, 12.0)
Coining (s)	58.32	74.77	98.12	(58.32, 74.77, 98.12)
Buffer 1 (days)	1.2	3.99	10	(1.2, 3.99, 10)
Drilling (s)	120.23	161.4	198.32	(120.23, 161.4, 198.32)
Buffer 2 (days)	1.2	5.78	9.1	(1.2, 5.78, 9.10)
Chamfering (s)	152.40	199.12	298.52	(152.40, 199.12, 298.52)
Buffer 3 (days)	1.11	4.02	8.2	(1.11, 4.02, 8.2)
Welding (s)	298.32	435.36	658.7	(298.32, 435.3, 658.7)
Buffer 4 (days)	1	3.98	8.12	(1.0, 3.98, 8.12)
Assembly (s)	900.12	1541.2	2000	(900.12, 1541.2, 2000)
Buffer 5 (days)	1.0	3.45	8.0	(1.0, 3.45, 8.0)

3.1 Current Value Stream Map

Figure 1 shows the current value stream map of the company.

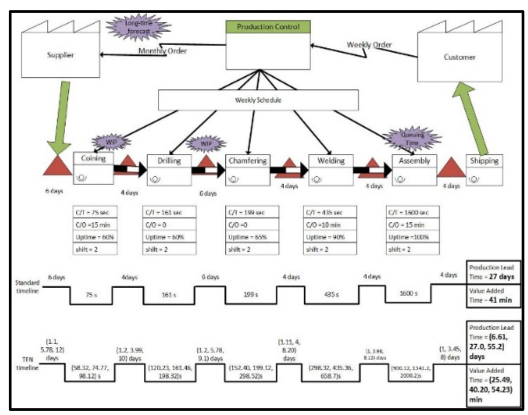


Figure 1: Current Value Stream Map

3.2 Triangular Fuzzy Number

In order to handle the variability of value stream parameters in a computational way, fuzzy set theory is applied to transform the uncertainties into fuzzy numbers.

From the CVSM, it can be observed that the total production lead time is 27 days (TPLT) whereby the total value-added time (TVAT) is 41 minutes, indicating a need for development. Using a triangular fuzzy timeline, TPLT (days) can be described as TFN A = (6.61, 27.0, 55.2) with the membership function as follows:

$$\mu\tilde{A}(x)=\begin{cases} 0, & x \leq 6.61, \\ \frac{x-6.61}{20.39}, & 6.61 < x \leq 27.0, \\ \frac{55.2-x}{28.20}, & 27.0 < x \leq 55.2, \\ 0, & x > 55.2 \end{cases} \quad (5)$$

TVAT (min) can be denoted as TFN B= (25.49, 40.20, 54.23) with the membership function as follows:

$$\mu\tilde{B}(x)=\begin{cases} 0, & x \leq 25.49, \\ \frac{x-25.49}{15.42}, & 25.49 < x \leq 40.20, \\ \frac{54.23-x}{14.03}, & 40.20 < x \leq 54.23, \\ 0, & x > 54.23 \end{cases} \quad (6)$$

4.0 DISCUSSION

Based on the observation of the current value stream of the production process, some modification can be applied in the production line in order to minimize waste and upgrade overall performance. A future value stream was created in accordance with the modification carried on the production process.

i. Follows a daily Heijunka schedule in order to obtain a fast response to the customer order by pulling from downstream with low changeover times.
ii. Kanban systems and Supermarket applied in the production line instead of WIP and prevent overproduction. At the beginning of the internal value stream, a supermarket was set together with a Kanban withdrawal system for informing line leaders to receive and transfer items to the coining stage from the supermarket. Materials are delivered to the production line on a regular basis. Hence, 8 hours was fixed as the maximum capacity of this supermarket. In order to manage the final assembly to cater the shipping schedule, another Kanban system and supermarket are to be planned at the end of the internal value stream prior to shipment of finished goods. Shipping is scheduled daily as such the maximum capacity of this supermarket will equal to 8 hours.
iii. Process improvements and actions must take place to implement the future state map by accomplishing the material and information as listed below:

   a) The production manager should accept the continued demand orders.
   b) The dedicated time to period programming
   c) Capability of changing the CNC machine programming by operator
   d) Going and check the production pace follows production planning

4.1 Future Value Stream Map

Table 3 shows the cycle time and WIP for future VSM and Figure 2 represents the future VSM. The production lead time (TPLT) TPLT in future VSM is (3.31, 14.78, 26.7) in days whereby the value-added time (TVAT) in future stream is (15.40, 30.09, 44.45) in minutes. The result of the future value stream leads to significant improvements in TPLT and TVAT that are 14 days and 32 min respectively compared to 27 days of TPLT and 41 min of TVAT as in the current stream.

Table 3 Cycle time and WIP for future-state value stream map

Items	Estimated Value a	b	c	TFN
Raw Material inventory (days)	0.26	4.2	5	(0.26, 4.2, 5)
Coining (s)	40.1	75.2	75	(40.1, 75.2. 75)
Buffer 1 (days)	0.61	1.53	5.1	(0.61, 1.53, 5.10)
Drilling (s)	60.41	81.21	197.2	(60.41, 81.21, 197.2)
Buffer 2 (days)	0.52	3.25	4.31	(0.52, 3.25, 4.31)
Chamfering (s)	78.23	83.6	280.2	(78.23,83.6, 280.2)
Buffer 3 (days)	0.71	1.73	4.16	(0.71, 1.73, 4.16)
Welding (s)	200.1	401.32	618.35	(200.1, 401.32, 618.35)
Buffer 4 (days)	0.31	2.6	3.31	(0.31, 2.6, 3.31)
Assembly (s)	545.3	1164.1	1496.17	(545.3, 1164.1, 1496.17)
Buffer 5 (days)	0.91	1.53	5	(0.91, 1.53, 5.0)

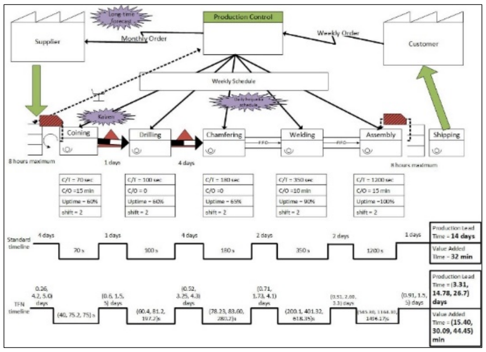


Figure 2 Future Value Stream Map

5.0 CONCLUSION

In conclusion, according to the case study depiction, the integration of fuzzy logic to the conventional value stream analysis makes it capable of covering the unpredictability and varieties of each step of the process and develops to the whole value stream. The purpose of using fuzzy logic in this VSM is to express values using fuzzy numbers instead of deterministic values. Triangular fuzzy membership functions include factors of variability in optimization and analysis. TFN is used to analyze inventories, time intervals and other operating values in a value stream. An industrial application shows the functionality and the usefulness of the proposed fuzzy VSM using TFN to integrate variability in VSM analysis.

As such, for the future research, fuzzy VSM can be developed to reduce the drawbacks and optimize its benefits. The optimization of the proposed fuzzy VSM depends greatly on the manual analysis. As such transforming manual analysis to simulation to calculate fuzzy VSM can be a significant development in upgrading the accuracy of VSM analysis.

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