Methodology for preparing a Cost-Value Stream Map

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Abstract. This paper proposes the methodology for preparing the Cost Value Stream Map (CVSM) which possesses the advantage of measuring the cost involved and time consumed in the production process stream. A value stream map addresses the value addition process in terms of time domain in a production process. CVSM addresses both the time and cost information simultaneously in a production process. This CVSM method equips the study of the production process in detail and helps to figure out the wastages in the process directly in terms of the cost involved in the production. The cost line added alongside the time line in the modified VSM is a simple tool which can be utilised by lean experts in identifying the wastage in terms of the cost involved. CVSM is prepared by collecting data from company in the prescribed format. All this data thus collected can be consolidated to prepare CVSM. A case study is conducted and a CVSM is prepared in a scaffolding pipe manufacturing unit in Kerala.

1. Introduction
Lean was first introduced by Taichii Ohno and Shigeo Shingo into a concept called Toyota Production System (TPS)[1]. Lean manufacturing is a concept used to reduce cost and hence enhancing the firm’s productivity by eliminating non-value added items or wastes in the production line. ‘The machine that changed the world’ is the book which describes the entire lean concept. Lean tools include 5S, just-in-time (JIT), cellular manufacturing and total productive maintenance (TPM)[2].

One of the major lean tools developed for reducing waste is value stream mapping (VSM) and it is developed by Rother and Shook in 1998[3]. Value stream mapping is a systematic approach of visual mapping and communication technique to eliminate the wastes in a company. Hence the competitiveness of the company will get improved because of enhanced productivity. Environmental value stream mapping (E-VSM) is the extended technique of conventional VSM and in this case, environmental factors are also taken into consideration[4]. The two major phases involved in value stream mapping are mentioned below [5].

- Value stream analysis: - Present value stream is plotted and studied.
- Design of value stream: - Non-value added wastes are minimized by implementing lean tools.
Value stream mapping is a paper pencil tool to identify non-value-added activities in the production process. It gives a visual representation of the material and information flow associated with the production stream. Value stream mapping technique utilizes current state map to assess the present condition of the manufacturing system and future state map for proposing the changes that are to be incorporated for addressing the issues found with the help of the first current state map.

The application of value stream mapping is widely spread into variety of areas, like paint[6], steel[7,8], aircraft maintenance industries[9]. Figure 1 show the procedural steps for implementing VSM in an industry.

Studies were also carried out on the field of value stream mapping in small and medium enterprise which are manufacture-to-order[10]. A new product is planned, designed, created and marketed in the field of product development (PD). Value stream mapping is implemented in the product development field also to minimize the lead-time[10]. Single Minute Exchange of Die (SMED) can be used as a Kaizen tool to implement future VSM to reduce lead-time in small-medium enterprise[11,12]. Also, simulation models can be used to identify the bottlenecks in the production line and modified algorithms were used to reduce the lead time in a midsize glass fabrication company[13]. Value stream
mapping can be combined with the decision-making tools like discrete event simulation to improve the productive performance[14]. One of the major drawbacks of VSM is the iteration process to implement future state. To overcome this difficulty, an immersive virtual reality approach is presented to visualize the image of real models[15]. Other major problems related to VSM is mentioned below[16].

i. Incomprehensibility of procedures.
ii. Collection of data in processes is difficult.
iii. Current state map becomes obsolete.
iv. VSM is compromised in the case of flexible production line.
v. It is difficult to implement when standardisation and stability of the process is poor.

In this paper, a new tool is developed which combines both value stream mapping and Cost Time Profile (CTP)[17]. Value stream mapping gives the information of the processes in units of time and with the help of this we can reduce or eliminate the mistakes and hence reduces lead time and value added time. In this paper, value stream mapping combines with activity-based costing to develop a new tool to estimate the process costs. By using this technique, it will be easy to identify the processes which possess highest cost and greater lead time and these processes can be called as critical processes. Hence, both cost and time can be visualised in a single figure and improvements can be done to reduce both cost and time of the critical process.

2. Development of CVSM

A case study has been conducted in a company which manufactures scaffolding pipe assembly in an MSME unit in Palakkad, Kerala, in one shift per day. The product consists of the production of two major parts namely the Exterior and Interior pipes assembled together using a nut-bolt and locking lever mechanism. Exterior pipe and interior pipe used for the construction of scaffolding pipe assembly is made through two parallel processes as shown in figure 2. Time is recorded on a normal working day with all breaks and all operators present for duty. Cost of operators, Resources required at each process, Machine Cost, Maintenance cost, Tooling Cost etc. are accounted annually and arrived at the cost rate of each of the above mentioned parameters per hour. Along with the standard value stream map which shows traditionally the time line is modified by showing the cost line which gives a direct measure of non-value-added cost associated with all processes.
After creating the process layout, next step is to collect data for the above mentioned processes. From the historical data of shipments available in the company, the daily demand of the selected product was identified. After that, the net available time was calculated and finally with the help of above collected data, takt time was calculated and it is mentioned in the equation (1).

### 2.1 Primary data to be collected from the company

- Daily average demand
- Working hours per shift
- Break time
- Net available time = (Working hours – break time) minutes.

After collecting the primary data about the product demand, product volume per day and the net available time per day we measure each process by its cycle time. From each activity of the manufacturing process the time data such as Loading time / Changeover time, Cycle time and Waiting time is to be recorded. Number of semi-finished goods in between each work station is to be accounted for further analysis. Material flow and information flow is to be recorded in each machining centre. The time recorded as per the above list is refined by applying the weighted averaging procedure for more accuracy. Here the time taken for each event is recorded three times at random (most likely) and then it is approximated for more realistic measure by considering the most pessimistic and most optimistic time as reported by the operator of each machine as shown in table 1.

### Table 1. Template for measuring time

| Activity Duration (Seconds) |
|----------------------------|
| Most likely (Average of three random values) | Most Optimistic | Most Pessimistic |

Next step to draw current VSM is the collection of data of each processes like cycle time, change over time, number of operators. Work in process (WIP) inventory data collection is the next critical step in
the VSM. All the necessary data were collected from the company when there is a continuous flow of production. Also, the mode of transaction within and across the company was obtained from the top management level. Table 2 shows the collected information for VSM from the company.

Table 2: Collected data for current state VSM.

| Activity          | Process Description | Cycle time (mins) | Change over time (mins) | Waiting time (mins) | Number of Operators | Work In Process Inventory |
|-------------------|---------------------|-------------------|-------------------------|---------------------|---------------------|--------------------------|

In this work, a new term called ‘cost investment’ is added and this gives the waiting cost for the work in process (WIP) inventory which is a major non-value added cost. For the calculation of overall cost, both total cost and cost-investment is calculated. The summation of both above mentioned costs gives the overall manufacturing cost of the product. Again, the total cost is divided into material cost and activity cost. The summation of both operator-cost and resource cost implies the activity cost. More precisely, the resource cost is again divided into machine depreciation cost and machine maintenance cost. Hence, almost all value added and non-value added costs are taken care of by this cost analysis method. Both machine depreciation cost and machine maintenance costs are calculated using equations (2) & (3) respectively.

\[
\text{Takt time} = \frac{\text{Net available time/ daily average demand}}{\text{minutes/unit}}. \tag{1}
\]

\[
\text{Machine depreciation cost} = \frac{\text{Price of the equipment}}{(\text{Years of life} \times \text{Time units it is used in a year})}. \tag{2}
\]

\[
\text{Machine maintenance cost} = \frac{\text{Maintanence cost per year}}{(\text{Time units it is used in a year})}. \tag{3}
\]

\[
\text{Resource cost} = \text{Machine depreciation cost} + \text{Machine maintenance cost}. \tag{4}
\]

Equation (5) gives the activity cost calculation and the total cost was calculated using equation (6).

\[
\text{Activity cost} = \text{Operator cost} + \text{Resource cost}. \tag{5}
\]

\[
\text{Total cost} = \text{Activity cost} + \text{Material cost}. \tag{6}
\]

Waiting cost is termed as cost investment in this research work and finally the direct cost calculation is shown in equation (7).

\[
\text{Direct cost} = \text{Total cost} + \text{Cost investment}. \tag{7}
\]

For the calculation of cost investment, the rate of return for the company was assumed as 15%. Table 3 shows the resource cost calculation.

Table 3. Resource cost calculation

| Activity         | Machine cost (Rs) | Machine depreciation cost (Rs/min) | Machine maintenance cost (Rs/min) | Resource cost rate |
|------------------|-------------------|-----------------------------------|-----------------------------------|--------------------|

Table 4 depicts the whole cost calculated for the scaffolding pipe assembly. Here the cost rates are calculated by considering the total emoluments for each operator annually and then converting this data to calculate the cost rate per hour for maintaining such an operator. Then the cost rate of each
operator depending upon his position and experience in that company is found out. Activity cost rate is calculated by combining the operator cost rate and resource cost rate.

**Table 4.** Value and non-value added costs.

| Activity | Operators | Operator cost rate (Rs/min) | Resource cost rate(Rs/Min) | Activity cost rate(Rs/Min) | Activity cost(Rs) | Material cost(Rs) | Total cost(Rs) | IRR (Internal Rate of Return)(%) | Cost investment(Rs) | Direct cost(Rs) |
|----------|-----------|-----------------------------|-----------------------------|-----------------------------|-------------------|------------------|----------------|--------------------------------|------------------|-----------------|

From the above mentioned table, it is easy to understand and differentiate all the value added and non-value added costs. After the identification of critical process which has greater non-value added costs, control measures can be applied to reduce these costs. The figures 3 and 4 show typical CVSM for Exterior and Interior pipes. From this map the non-value-added processes can easily be identified directly because of its cost-domain representation.
**Figure 3.** CVSM of exterior pipe.
3. Conclusions

This work proposes a methodology which combines both value stream mapping and costing. The general tools required to collect the data from a production firm is designed and explained for the preparation of the conventional VSM and modifying it further to finally arrive at the CVSM. These general procedures can be conveniently employed by anyone who is familiar with lean manufacturing tools. A scaffolding pipe company was selected for the implementation of this new tool. The result obtained from the case study is shown in Fig 3 and Fig 4 which clearly depicts the cost-line along with the conventional time-line of VSM. The results in cost-line combines the material cost, activity cost and the waiting cost of production for the in process inventory as well as all other inventories waiting to get processed. The waiting cost account for the cost investment of all resources which are involved

Figure 4. CVSM of interior pipe.
in the production process. Therefore the CVSM can be utilized as a very simple and effective assessment tool for identifying the non-value-added (NVA) cost involved in the process of production. From the cost-line it is easy to identify the most NVA process in the order of their financial liability and then to recommend a suitable lean tool as a remedial measure.

References

[1] Ohno T 1988 The Bible of Toyota Production system
[2] Abdulmalek F A and Rajgopal J 2007 Int. J. Prod. Econ. 107 223.
[3] Rother M and Shook J 1998 Learning to See : Value stream mapping to create value and eliminate muda Brookline,MA: Lean enterprise institute
[4] Huang Y and Tomizuka M 2007 Procedia CIRP 61 446.
[5] Anon The Bible of Toyota Production - Ohno’s Manuscript.pdf
[6] Rohani J M and Zahraee S M 2015 Procedia Manuf 2 6.
[7] F. Adullah, "Lean Manufacturing tools and techniques in the process industry with a focus on steel", 2003.
[8] Mishra K C and Khokhar E V 2017 Int. J. Mech. Eng. Inf. Technol 05 616.
[9] Luciana L and Lestari Y D 2015 J. Bus. Manag 4 1119.
[10] Tyagi S, Choudhary A, Cai X and Yang K 2015 Int. J. Prod. Econ 160 202.
[11] Azizi A and Thulasi M 2015 Procedia Manuf 2 153.
[12] Das B, Venkatadri U and Pandey P 2014 Int. J. Adv. Manuf. Technol 71 307.
[13] Helleno A L, Pimentel C A, Ferro R, Santos P F, Oliveira M C and Simon A T 2015 Int. J. Adv. Manuf. Technol 80 1059.
[14] A L Helleno, Pimentel C A, T S, R F, M C O and A T S 2015 Integrating value stream mapping and discrete events simulation as decision making tools in operation management
[15] Tyagi S and Vadrevu S 2015 Int. J. Adv. Manuf. Technol 81 1259.
[16] Forno A J D, Pereira F A, Forcellini F A and Kipper L M 2014 Int. J. Adv. Manuf. Technol 72, pp.779.
[17] Rivera L and Chen F F 2007 Robot. Comput. Integr. Manuf 23 684.