LEAN CONSTRUCTION: VALUE STREAM MAPPING FOR RESIDENTIALS CONSTRUCTION

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ABSTRACT

Lean construction is an applied form of a concept practiced in production and operations management in the manufacturing sector. It mainly focuses on continuous improvements in the production processes by eliminating redundancies from the value chain, resulting in improved delivery of the finished goods offering more value to the end customer. Value Stream Mapping (VSM) is a lean tool which enables the user to map a process with respect to the value addition activities for the customer. It gives a visual representation of the flow of information, processes and their durations involved in the production process. A non-value added activity is identified as waste on a value stream map. Using VSM, a current state map of the production process is prepared and analyzed. On identification of the potential wastes, an improved process map called ’Future State Map’ is prepared. In this research work, the authors have focused on the construction process of a residential construction project and attempted to implement VSM to gain an enhanced lean construction system. The authors have planned to prepare the current state for the floor-floor production process of a residential project. After performing a systematic analysis, a future state map shall be prepared to state the benefits of minimizing the waste activities in the process. The following work is an attempt to build up the application of VSM for lean construction practices

Key words: Value Stream Mapping, Lean construction, Residential, Wastes, Continuous improvement.
1. INTRODUCTION

Lean is a way by which value is created to the customer in a value creation process by eliminating waste. This is achieved by adopting lean thinking and implementing those concepts in the production process by optimizing the flow of products and services through entire value stream that flows horizontally to deliver the end product to the customer.

The term being coined in the late 1980’s by the Toyota’s Production Company, which focused on waste elimination expanded to include improved workflows, and came to be known as “Lean Manufacturing”. At present, this is being practiced worldwide by all the manufacturing industries. The principles of lean manufacturing eventually made its roots into the construction.

Lean Construction emerged as a modern aspect in construction planning by the application of lean concepts that approach value rather than cost. It served as a predictable and robust management system that benefits the all the project participants by making every individual voice out better opinions, commit to those opinions and perform to those commitments. This helps in continuous improvement of the processes which will provide a high quality and low cost project to the end customer.

Lean Construction is defined as the process of generating the maximum amount of value by designing the production system in such a way that waste is minimized. The waste can be in terms of materials, time and effort (Raghavan, Kalidindi, Mahalingam, Varghese, & Ayesha). Construction industry in India has been suffering huge loss due to late delivery of projects in within the stipulated budget and the quality as demanded by the customer (Desai & Shelat, 2014). Prolonged delivery time and substantial amount of waste generation in the construction process has resulted in increased efforts from the project management to look for effective ways in which the lead times can be reduced and process reliability can be improved along with quality to the customers (Resident VSM). Value as perceived by the customer should be used as a driving factor by the project managers and approached accordingly. The construction project is always viewed as a network of interlinked activities that can be managed and controlled by all its participants (Sawhney, 2011). But it can often be difficult to broadly define the steps that generate value as the projects are mostly unique in nature which is apparent that value is viewed differently by each participant (Rother & Shook, 1999). There are several indicative studies on the construction productivity which reveals that enormous waste is generated in the production process (Desai & Shelat, 2014) that can originate at any stage of the project. Waste generation can be prevented by effectively managing the flow of information, materials and resources. This can be achieved by training the site management to cleverly distinguish value adding activities and non-value adding activities which are generally termed as waste and eliminate them. These improvements can be made possible only with the help of certain aids or tools that will help in implementation of the lean concepts and theories for the elimination of the identified wastes. Among the various tools for implementation that are available, Value Stream Mapping permits a systematic view of the process, identify the process flow and pull the waste according to lean principles. It is also defined as a pen and pencil tool that uses special flowcharts and symbols to represent the production process. It can be effectively used in the analysis of repetitive processes. Residential sector of the construction industry is claimed to be unique because the production volume is high and the flow is controllable with large amount of inventory.
involved within processes (Yu, Tweed, Al-Hussein, & Nasseri, 2009). VSM is a static tool and doesn’t capture the variation in processes in different scenarios. Further it helps in the identification of wastes and bottlenecks and suggest for improvements (Sawhney, 2011). Wastes that are generated out of various processes can be categorized into any of the following: Overproduction, waiting, over processing, inventory, motion, defects and transportation (Ohno, 1988). A value stream map has two elements namely the Current and Future State Maps. The current state map depicts the current scenario of the process whereas a future state map is prepared by analyzing and identifying wastes from the current state map and eliminating them using lean principles. The accuracy of the future state map with improvements depends on how precisely the current state map is developed and analyzed (Rother & Shook, 1999). Thus, it is taken as a challenging task by the researchers to judiciously gather information and interlink the problems with the existing practices. The future state map must aim in providing a continuous workflow where the movement of processes, information and resources are undisturbed and controlled along the end-end production process (Thomas, Horman, Minchin, & D, 2003).

2. OBJECTIVES & METHODOLOGY

Value Stream Mapping focusses on continuous improvement of the production process by eliminating redundancies along the value chain, resulting in improved delivery of finished goods offering more value to the end customer. To elaborate this advantage of VSM, a construction process of a residential construction project is selected for case study and current state map is prepared and analyzed for potential wastes. By eliminating them, an improved process map called the Future state map is prepared which aims in achieving an activity based improvement from the existing process. These improvements are made iterative to generate a value creation process benefitting the end customer. The lean improvements and suggestions that are suggested for enhancements of the current state are developed based on the discussions with the project management and a hypothesis of solutions are generated.

2.1. Value Stream Mapping

Value in construction is an attribute provided to the customer along with his product in terms of quality, time and cost. It should be the main perspective through which all the construction projects should be viewed. Adding value to the construction process is considered as a main objective in order to provide customer satisfaction. It is to be incorporated right from the beginning of the project.

Value stream is the set of actions that are required to bring a specific product or service through the processes from to raw product to end customer. The value in the processes should flow smoothly like a straight river without any sharp bends. Thus, the product will reach downstream from upstream without any disturbances. In reality, flowing without any disturbances is an ideal condition. This condition can be made effective to a certain extent with the help of lean tools.

Value Stream Mapping is a lean tool introduced by the Toyota Motor Company in the 20th century for easy implementation of lean principles to the processes. Lean strategy implies to think and see the flow process in way of transforming it for continuous improvements. Value Stream Mapping tool helps to systematically view the entire production process and identify the problems and wastes that flows along. It is a pen and pencil tool that helps to see and understand the flow of material and information as the product moves through the value stream. Value Stream mapping divides the process activities into Value Adding (VA) and non-value adding (NVA) activities. By mapping a holistic view of the entire stream, it can be
comprehended to eliminate the accumulated wastes between processes and provide opportunities for improvement.

2.2. Mapping Methodology

Value Stream Mapping (VSM) is a lean tool which aids the user to map a process with respect to the value addition activities for the customer. A visual representation of the flow of information, processes and their durations involved in the entire production process is achieved with the use of different symbols and flow charts which helps to develop a structured map. Seeing through the entire process, the wastes that emerges off can be identified easily and can be planned on eliminating. This process of eliminating waste is carried out in two steps. Firstly, a ‘current state map’ is prepared by walking through the entire process and capturing all the elements that make up the system. It helps to understand the entire process and determine the complexities with much ease. The current state map should be able to depict the current scenario at the site as it is. All the information that is pertinent to the selected process should be included in the map. A thorough understanding of the system is arrived by having interviews regarding the carried-out activities with the site personnel and workers involved. The time taken for each activity is noted down. Time plays an important role in delivering the customer’s requirement. That is one way in which customer value is enhanced. The current state map after plotting is analyzed for its difficulties for not meeting customer demands. On identifying the waste, various solutions are developed to eliminate them. This development is depicted in improved process map called the ‘future state map’. This is used as medium to propose process improvements for the current scenario which can be achieved to satisfy the customers in the near future.

3. DATA COLLECTION & CASE STUDY DISCUSSION

Being a quantitative tool, VSM requires a real-time data of a production process to carry out the mapping. The thumb rule of mapping is to walk through the whole process to identify the current state practice and provide logical information on the material and information flow. But this is merely impossible as there is a huge gap that exists between the planned and actual on-site executions in construction industry. The durations are often variable and lengthy to be monitored. Therefore, a Primavera tracked progress of the residential tower is used as a data analysis tool. Further practices pertaining to the construction activities are collected by visiting the site and keenly observing the processes.

3.1. Case study Details

The case study analyzed here is a high-rise residential project consisting of 5 towers with 31 floors and 2 basement levels each. The project has faced many ups and downs right from its inception stage. There are major bottlenecks that prevent the timely completion of the project and invariable incur of losses.

There are various approaches for carrying out a production process. VSM aims to identify a unique value stream through which maximum value is generated to the customer. It is found to be effective for implementation in repetitive processes only. To supplement this the floor-floor construction process for the residential project was taken to consideration. The details of different activities and data pertaining to their quantities and resources were gathered. The current scenario of on-site practice was monitored. Interactions were made with the site engineer and contractor. Based on the details collected, the current state map is drawn.
Figure 1 shows the activities that make up the floor-floor production process. Since it is a fast track project, the pour cycle (Reinforcement of verticals \(\rightarrow\) RCC) of each floor was planned to achieve in 15 days. In order to meet this target a monolithic type of construction methodology was adopted where the entire floor is casted in a single pour. Owing to the large floor area, the pouring was executed in 2 cycles (Pour cycle 1 & Pour Cycle 2). Another special type of construction that was adopted for the longer spans is Post Tensioning of Slab which also contributed to one among the major hardships in execution.

3.2. Preparing Data for Mapping

The schedule was analyzed for the first 8 floors with the PT slab. The schedule was a Primavera tracked progress which specified only the actual start and completion dates. For detailed understanding, a Gantt chart was prepared to find the flow of activities throughout the stream. It helped to interpret the overlapping of activities and the handoffs in between them, lengthier activities and cycle times. It is found from the schedule that each floor had different pour cycles that showed huge variations in every floor. The production process has a disturbed workflow. This workflow variability was to be analyzed in order to smoothen the flow.

<table>
<thead>
<tr>
<th>Material</th>
<th>Per floor</th>
<th>Column</th>
<th>Slab</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Per floor</td>
<td>Per pour</td>
</tr>
<tr>
<td>Steel</td>
<td>46MT</td>
<td>28MT</td>
<td>14MT</td>
</tr>
<tr>
<td>Shuttering</td>
<td>1800m²</td>
<td>1085m²</td>
<td>542m²</td>
</tr>
<tr>
<td>Concrete</td>
<td>270m³</td>
<td>134m³</td>
<td>67m³</td>
</tr>
<tr>
<td>PT Tendons</td>
<td>1.720MT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 1 shows the quantity of materials that are required in the production process of each floor. The details were collected from the site engineers. Steel was procured in such a way that it is made available for the production of the consecutive 2 floors at least. It was stocked at the steel yard which is located quite away from the built-up area. The site had 2 concrete batching plants of capacity 30m$^3$/hr. 4 transit mixers of 6m$^3$ capacity were used for the transport of concrete along with a concrete pump and air compressor. The contractors had their own shuttering materials of required quantity. The staging materials were rented from a sub-contractor. The formwork systems used for the columns and slab were Mivan shutters of aluminum material with which the entire floor can be casted monolithically. Once the floor decks are laid, the slab reinforcement commences. The Post Tension contractors are called for after the first layer of reinforcement. On their arrival, the PT ducts and tendons are laid in the Post Tensioning portion of the slab. Concreting is done at once after the checking is done. Once the concrete attains a 3000psi strength after its pour which generally takes 4-7 days, the tendons are stressed with pneumatic hydraulics and then grouting is done.

In order to build a timeline for VSM, the process should have standard cycle times in execution. But in this case, the production process and pour cycles had varying time in each floor as shown in Table 2. Therefore, to streamline the cycle times, the floors with the least, intermediate and longest durations of pour cycle were analyzed. The current state map for these pour cycles were prepared.

<table>
<thead>
<tr>
<th>CYCLE / FLOOR</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
<th>F7</th>
<th>F8</th>
<th>F9</th>
<th>F10</th>
</tr>
</thead>
<tbody>
<tr>
<td>POUR CYCLE 1</td>
<td>47</td>
<td>19</td>
<td>16</td>
<td>22</td>
<td>31</td>
<td>47</td>
<td>44</td>
<td>63</td>
<td>76</td>
</tr>
<tr>
<td>(days)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POUR CYCLE 2</td>
<td>65</td>
<td>26</td>
<td>15</td>
<td>21</td>
<td>30</td>
<td>42</td>
<td>25</td>
<td>79</td>
<td>67</td>
</tr>
<tr>
<td>(days)</td>
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</tbody>
</table>

### 3.3. Analysing CSM

The planned pour cycle of 15 days was achieved in the 4th floor alone (Table 2). Apparently, this 15 day pour cycle was not sustained in all the floors due to various bottlenecks that were faced since inception of the project. The current state map after plotting was analyzed for the various constrictions that hindered the continuous workflow process.

The current state map 1 & 2 depicts the pour cycle with the least durations. This map can be considered to be ideal as the cycle was completed in 16 days and 15 days respectively. When holistically viewed, the production process seems to be refined, but internally the flow is not even. Although the pour cycle has been achieved in the stipulated time, both the cycles did not follow a standard procedure of execution. Each activity time seems to be individually varying in both the cycles.

The current state map 3 & 4 depicts the pour cycle with the intermediate durations with a pour cycle of 31 & 30 days respectively. Pour cycle here seems to be extended because of lengthier activity durations than actually planned. Most of the time was consumed by reinforcement of slab activity in both the cycles and RCC took consumed too many days in
the pour cycle 2. Pour cycle 1 has a handoff delay between reinforcement of verticals and their shuttering.

The current state map 5 & 6 depicts the pour cycle with the longest durations of 76 & 79 days respectively. The cycle time of each activity seemed to be unpredictably longer due to various reasons. Apart from the handoff delay from decking and reinforcement, the reinforcement has consumed a lot of time to complete.

In all the pour cycles, the handoff from laying of PT ducts and checking done by the client was delayed due to the untimely completion of the slab reinforcement. Apart from that there was no standardized way in the post tensioning process.

These wastes were initially identified from the available data and then the on-site practice was studied to determine the root cause of the emerging wastes. This will bring a detailed discussion on all the difficulties and technicalities that were faced and the major bottlenecks that hindered the production process.

4. RESULTS & DISCUSSION

These wastes were initially identified from the available data and then the on-site practice was studied to determine the root cause of the emerging wastes. This will bring a detailed discussion on all the difficulties and technicalities that were faced and the major bottlenecks that hindered the production process.

4.1. Identification of Wastes in the Current Process

- The foremost difficulty faced was building up the timeline for the VSM. The activity times were varying with each floor. There was a variable workflow process which needs to be standardized. Workflow variability is common in most of the construction projects but this has to be in accepted levels. Reliable workflow has to be established for a smooth and continuous value stream.

- The factors that were affecting the workflow variability and reliability were longer activity durations and the waste generated from handoffs. Activities took longer time than actually planned due to shortage of labour (mostly skilled) and timely unavailability of materials in major parts of the project.

- There was unwanted movement done by the workers and vehicles in moving the materials. One major contribution to this is the poor logistic plan of the site. The logistic plan of the entire site done during the initial phase of the project was very poor. It was too late when this was realized. The steel yard was located far away from the built-up area which made the workers wear off soon and hence decrease in their productivity. The canteen was located at a shorter distance which caused most of the workers to take rest often. This was a simple psychological problem faced with the workers.

- Labour shortage was a major issue faced throughout the project. The planned vs actual labour was never achieved which delayed the deployment of work in most of the cases. The amount of skilled labour available was very less which reduced the productivity of most of the activities.

- Labour attrition was another problem that added on to existing shortage of labour. Most of the labour left the site without any notice. Besides leaving, the carry the safety equipment provided to them which is another loss that adds up to the situation.

- The labour shortage and attrition problems were out of reach from the managements hands.

- A part of the staging materials that were procured deprived quality. Most of them had to be replaced.
Another experimentation that resulted in generating waste was the usage of different type of formworks. Most of the formworks used did not meet their advantages. The formwork used for the floor production was Maivan formwork which is used in monolithic casting. This formwork was of aluminium material and can be used for a number of repetitions. But the workers lacked ownership and underutilized the materials. There was no proper supervision of the shuttering materials. Most of the shutters and ply’s used were subjected to vandalism.

Another major bottleneck that was faced with shuttering materials was its shortage for the consecutive cycles. The shuttering and staging done in the cantilever portions of the slab where post tensioning is done, cannot be removed until the slab has fully reached its strength. This put the materials at stop and the queue time of the process increased. This contingency was not taken into account during the planning stage of adopting PT lab.

Reinforcement materials were subjected to a lot of waste in the initial stage. This was due to the adoption of Automated Reinforcement System using BIM due to unavailability of BBS Engineer. This method calculated the quantity of reinforcement by simulation and procurement was done based on that. But this led to shortage of reinforcement as in most of the structure excess reinforcement was provided.

Lack of supervision in most of the works led to the quality related problems.

Sufficient number of engineers and managers were not available or allotted even after a few months after the start of the project.

Procurement of materials were not done on time which delayed most of the activities. This was due to the unavailability of procurement engineer.

Initially most of the materials and orders made were made verbally only. There was no documented tracking of the orders made. This led to loss.

Wastage and shortage of materials were encountered. Materials were wasted at higher rate than allowed.

The site had 2 concrete batches that were also underutilized. The production capacity of the batching plant is 30m$^3$/hr but the output generated was only an average of 15-20m$^3$/hr. This was due to lack of proper maintenance of the plant. Similarly, the transit mixers of 6m$^3$ capacity generated an output of only 4.5-5 m$^3$/hr. The concrete that was transported in the mixer was not fully washed out which resulted in hardening of concrete inside the mixer drum that eventually resulted in less output.

There was a large amount of inventory held in between processes that needed much supervision and security from vandalism and theft.

The Post tensioning process was not carried out in a systematic manner. There were frequent handoff delays after RCC and Stressing of cables.

The meetings regarding the progress update with the workers and engineers were held only once in a week.

The intervention of an electric cable over one of the tower delayed its construction. This later on affected when all the workers had to be shifted to its completion at once which in turn delayed the ongoing activities.

4.2. Future State Map

As mention above Figure 3 shows the improved state map called the Future State Map which can be used to ascertain the elimination of wastes and improvement of the existing practices. The map shows the standard time with which the activities should be executed to achieve the desired pour cycle and improved cycle time. The work sequence and the information
passed will help to efficiently complete the process. With this the site managers can have a clear picture in execution.

4.3. Lean Suggestions and Process Improvements

As mentioned earlier, the pour cycle was possible to be achieved in 15 days with proper scheduling of the activities and maintaining persevering management techniques. Lean suggestions and implementations requires dedicative efforts and investment of time by the management to achieve continuous improvements. Work Standardization ensures quality of the work done. Kaizen measures, to attain the future state should be made as the primary target. OEE analysis can improve the productivity of the available machinery and equipments. To improve the productivity of the labours, First Run Studies can be implementing by recording the current process and making improvements the next time it is done. It also gives an opportunity of better interaction with the workers. Thus continual improvements can be achieved. VSM in this way helps to identify the root cause of all the bottlenecks that chokes the flow of the process and the encountered wastes.
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2. CSM of Least Duration – Pour Cycle 2

3. CSM of Intermediate Duration – Pour Cycle 1
4. CSM of Intermediate Duration – Pour Cycle 2

5. CSM of Longest Duration – Pour Cycle 1
As mentioned earlier, the pour cycle was possible to be achieved in 15 days with proper scheduling of the activities and maintaining persevering management techniques. Lean suggestions and implementations requires dedicative efforts and investment of time by the management to achieve continuous improvements. Work Standardization ensures quality of the work done. Kaizen measures, to attain the future state should be made as the primary target. OEE analysis can improve the productivity of the available machinery and equipments. To improve the productivity of the labours, First Run Studies can be implementing by recording the current process and making improvements the next time it is done. It also gives an opportunity of better interaction with the workers. Thus continual improvements can be achieved.

VSM in this way helps to identify the root cause of all the bottlenecks that chokes the flow of the process and the encountered wates.
Table 3 Future Improvements

<table>
<thead>
<tr>
<th>Work Standardization</th>
<th>Restructuring work process</th>
<th>Standardize work processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing Cycle time</td>
<td>Performing adjacent activities</td>
<td>Overlapping activities</td>
</tr>
<tr>
<td></td>
<td>Regular supervision</td>
<td></td>
</tr>
<tr>
<td>Managing Labour forces</td>
<td>Training for skilled craftsmen</td>
<td>Identify teams with multi-performing skills</td>
</tr>
<tr>
<td></td>
<td>Gradation of skilled labour</td>
<td></td>
</tr>
<tr>
<td>Improper planning</td>
<td>Long term planning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5S principle</td>
<td></td>
</tr>
<tr>
<td>Material Procurement</td>
<td>Timely basis of procurement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>JIT procurement</td>
<td></td>
</tr>
<tr>
<td>Under Utilization</td>
<td>Fully utilizing all resources</td>
<td>Planning of resources</td>
</tr>
<tr>
<td></td>
<td>Ownership on materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overall Equipment Effectiveness (OEE)</td>
<td></td>
</tr>
<tr>
<td>Progress Update</td>
<td>Daily Progress Report* (DPR)</td>
<td>Systems, Applications &amp; Programme* (SAP)</td>
</tr>
</tbody>
</table>

Note: *DPR – tracks all the ongoing process in the particular day
*SAP – computer based tracking system in which information is made available to all project members.

Table 4 Processes Improvements

<table>
<thead>
<tr>
<th></th>
<th>Least</th>
<th>Intermediate</th>
<th>Longest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pour</td>
<td>P1</td>
<td>P2</td>
<td>P1</td>
</tr>
<tr>
<td>Cycle time</td>
<td>35</td>
<td>41</td>
<td>46</td>
</tr>
<tr>
<td>Pour duration</td>
<td>16</td>
<td>15</td>
<td>31</td>
</tr>
<tr>
<td>Future State</td>
<td>C/T 24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improvement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% improvements</td>
<td>C/T 31.42</td>
<td>41.46</td>
<td>47.82</td>
</tr>
<tr>
<td>Pour</td>
<td>6.25</td>
<td>0</td>
<td>51.61</td>
</tr>
</tbody>
</table>

5. CONCLUSION

The following work has represented the usage of a highly engineered tool like value stream mapping for achieving a lean construction system on a residential project. The authors have built up the application of VSM in a floor production activity of a residential project and demonstrated an activity based process improvement that has been achieved by making the current state map depicting the existing process for the least, intermediate and longest durations that were encountered in the pour cycle. Various factors that impede the completion of the process were analysed for their root cause and based on the discussions made with project personnel and with the aid of other existing literatures a hypothesis for lean improvements are suggested. On sound implementation of these suggestions a desired future state can be achieved by the organization and this work can also be used as a stepping stone for future research in VSM.

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