VALUE STREAM MAPPING METHODOLOGY FOR PRE-ASSEMBLY STEEL PROCESSES IN SHIPBUILDING

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Abstract. Value stream mapping is used to identify the wastes in industrial processes of many industries such as the automotive and aerospace. In order to remain competitive in the shipbuilding industry it is necessary to continually work on reducing waste in production processes. A clear-cut methodology for shipbuilding is lacking. Since steel makes up the most significant weight composition of commercial ships, shipyard steel processing is analyzed in this paper. A methodology for value stream mapping the current state and a future improved state is presented through a case study of an actual shipyard. The man-hour savings are demonstrated as 33% in the future improved state.

Introduction
The value stream mapping method is actively used in many industries such as the automobile and aerospace industries in order to make production more efficient by reducing unnecessary waste which results in dramatic savings for the companies involved [1], [2]. Since steel makes a significant portion of building commercial ships, making the starting processes related to steel storage and processing efficient as possible is very important. Making the steel processes lean is necessary for the logical downstream flow of materials leading to the assembly processes. Whereas there is treatment of lean manufacturing in the shipbuilding industry, analysis of the pre-assembly steel processes from a lean perspective is lacking. This paper analyzes the pre-assembly steel processes of an actual shipyard. Then the processes are mapped utilizing a value stream mapping methodology. These mapping techniques include analysis of the manufacturing flow of the current state in the shipyard and allow for the mapping of a future improved state.

Background
The ideas of lean manufacturing exist for over two decades since its introduction by Womack, Jones and Roos to the West in their book The Machine That Changed The World. The five main principles of lean manufacturing include specifying value from the customer’s point of view, identifying the value stream, creating flow in all processes, pull, and perfection or acceptable quality. Value stream mapping is a clear-cut method for implementing all of these five principles. Another integral aspect of value stream mapping is the elimination of waste. The seven wastes are overproduction, transport, waiting, inventory, defects, over processing and excessive movement. Likewise creating a Just in Time (JIT) flow of interim products throughout the manufacturing process, with built in quality, will enable and enhance the flow and create a value stream which eliminates non-value added activities as much as possible.

The treatment of lean manufacturing in shipbuilding was first prominently covered by (Storch, 1999) and (Liker, Lamb, 2002) [3], [4]. Other works include the development of a lean manufacturing methodology in shipbuilding in the panel and built-up panel assembly lines where the lean concepts of one piece flow, Just in Time and built-in quality are integrated in order for a lean transformation to occur [5]. Likewise 5S which includes sustaining, sorting, straightening, shining and standardizing leads well to improving flow. In addition to constantly analyzing how to reduce and eliminate waste, kaizen another important principle of lean manufacturing is in compliance with producing future improved value stream maps since it forces management to analyze how to constantly improve the production process.

Case Study
There is much theoretical treatment on lean manufacturing and value stream mapping. A practical way of understanding how to implement the method in a real manufacturing setting is necessary for shipyard lean transformation. The pre-assembly steel processes in a shipyard are analyzed in this case study. The pre-assembly processes include receiving of steel plates, whereby the steel is removed by magnetic cranes and stacked in an interim storage area. Then the steel plates are sorted and labeled into other piles depending on whether they will undergo leveling or not. Steel plates arrive from the factory labeled with the shipyard name, the new building number, the classification society that certified the steel, steel plant initials, grade of steel, the batch number and dimensions [6]. Once the shipyard workers start the sorting process, then each plate is again labeled manually with the group number, and the technological phase.

For this case study the processing of 40 steel plates is analyzed as a realistic number of steel plates which could be processed by the shipyard downstream processes on a daily basis. The unloading of the steel from the wagons and stacking in new positions in the interim storage 1 (ISP1) takes 4 minutes per plate for a total of 160 minutes. Then the steel is sorted and labeled manually onto new technological positions in interim storage 3 (ISP3) for a total of 200 minutes [7].

Steel Stockyard Activities
Steel plates and profiles arrive at the shipyard often in wagons transported by train. They are unloaded from the wagons by use of cranes onto large temporary piles since there are time constraints on the wagons. Afterwards the steel plates are sorted and labeled into other piles depending on whether they will undergo leveling or not. Steel plates arrive from the factory labeled with the shipyard name, the new building number, the classification society that certified the steel, steel plant initials, grade of steel, the batch number and dimensions [6]. Once the shipyard workers start the sorting process, each plate is then labeled manually with the group number, and the technological phase.

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Leveling, Grit blasting and Primer Coating Activities

Steel plates that were deformed during transport and movement need to be leveled. Usually steel plates that are thinner than 8 mm are the ones that need to be leveled at the shipyard. Approximately 4 plates or about ten percent of the steel plates undergo the leveling process and are stored in interim storage of plates 2 (ISP2) by the magnetic crane. Then the transverse transporter 1 (TT1) moves the deformed plates to longitudinal transporter 4 (LT4) which takes 5 minutes per plate or a total 20 minutes. The actual leveling process lasts 7 minutes per plate or 28 minutes. The leveled steel plates then leave by way of the longitudinal transporter 5 (LT5) back to longitudinal transporter 4 (LT4) and then to interim storage 3 (ISP3) with the other steel plates that did not need to be leveled. The entire cycle of the leveling of 4 steel plates from ISP2 to leveling and to ISP3 lasts about 48 minutes.

Steel needs to be grit blasted in order to prepare the surface for primer application according to the standard Swedish SA standards. Prior to grit blasting it is necessary for information about each steel plate to be inputted into the automated system which takes 5 minutes per plate. Each steel plate is first heated to around 50 degrees Celsius. The pre-heating of the steel is required in order to shorten the drying time upon primer application. Grit-blasting is performed in order to remove rust and impurities on the surface of the steel. Centrifugal blasters are frequently used as is the case of the shipyard analyzed.

The shop primer is applied afterwards in order to protect the steel from corroding during the upcoming assembly processes. Common shop primers include epoxy based or zinc-silicate based primers. Anti-corrosion protection and the weld-ability of the steel are necessary to be compliant to the downstream welding activities that still wait. This process of heating, grit-blasting and primer coating are well automated processes which last 5 minutes per plate. Afterwards the steel plates are again labeled which takes about 2.5 minutes per plate, and then sent to interim storage of plates 4 (ISP4) [7].

Steel Cutting and Forming for Assembly

After the steel plates have been sorted, leveled, heated, grit-blasted and coated with shop primer, the next downstream processes include steel cutting and forming. Various technologies exist for cutting steel plates. This includes oxygen-acetylene flame cutting which is most commonly used due to its flexibility for edge preparation, plasma cutting which is limited to 20 mm steel plate thicknesses, and laser cutting. Mechanical shearing is used for cutting thinner plates. Forming and bending of steel is performed by workers integrating the use of wooden molds and mechanical G and H presses, and bending machines. After these processes are completed, the steel is finally ready for being fed to the automated panel and micro-panel assembly lines.

Value Stream Mapping

The above information is necessary in order to map the pre-assembly steel processes of the present state. The future state can be mapped upon analysis of the present state and integrating lean tools. The use of value stream mapping symbols using Microsoft Visio 2007 is practical. Likewise, the authors used new symbols not available in the program to make the map more adaptable for shipbuilding (See Figure 1).

Current State

Value stream mapping the present state is shown in Figure 2. Every map is read from the left to the right. At the top left is the supplier of steel plates. The steel plates are shipped by wagons to the shipyard, where they are moved to interim storage (ISP1). Afterwards the steel is again moved to other interim storage ISP2 and ISP3 depending on whether it needs to be leveled or not. Then the steel that is sorted and labeled in ISP3 gets transported again to the steel plate reader for grit blasting and then to the automated steel heating, grit blasting and primer coating process. Finally the steel is again transported to another intermediate storage area ISP4. The value stream map illustrates that the steel is pushed between each process. Likewise there is much intermediate inventory, represented by the yellow triangles, as well as excessive movement. During the steel movement process, there are many non-value-added processes represented by the processes in black boxes. The total duration time which is represented by adding up the timeline segments (160 + 200 + 200 + 50) = 810 minutes as in Eq. (1) are calculated by the “conventional process method” [8]. The man-hours are calculated by multiplying the duration time of each process with the number of operators: (2.7hrs x 2 operators) + (3.33 hrs x 2 operators) + (3.33 hrs x 2 operators) + (.833 hrs x 2 operators) = 27 man-hours. See Eq. (2).

\[
\text{DT}_{\text{Total}} = \text{DT}_1 + \text{DT}_2 + \text{DT}_3 + \text{DT}_4 + \text{DT}_5
\]

\[
\text{Man-hours}_{\text{Total}} = \text{DT}_1 \times \text{O}_1 + \text{DT}_2 \times \text{O}_2 + \text{DT}_3 \times \text{O}_3 + \text{DT}_4 \times \text{O}_4 + \text{DT}_5 \times \text{O}_5
\]

where: \(\text{DT}_{\text{Total}}\) is the total duration time, \(\text{DT}_{1,2,3,4,5}\) are the individual process duration times and \(\text{O}_{1,2,3,4,5}\) are the number of operators.

Fig. 1 Value Stream Mapping Legend of Steel Processing [6], [9], [10]
Future Improved State

For moving to the future improved state, it is necessary to improve flow and eliminate the waste of inventory (yellow triangles) and have the steel pulled from the steel supplier to the steel cutting and forming for assembly. This is done by having production control forecast requirements to the steel manufacturer, who would no longer deliver steel in one big lump shipment, but instead create a kanban supermarket like system, where the steel is delivered incrementally as needed (See Figure 3). The local shipyards in Croatia could make contracts with one steel manufacturer and have milestone payments as well as intermediate batch deliveries which will result in regular steel deliveries which will decrease the storage space necessary. Likewise the steel dimensions should be standardized according to design for production principles in order to simplify the handling of the steel further. This will be more economical for the shipyard and is also compliant with the steel manufacturer because in this way there will be constant steel production for all the four major shipyards as well as regular milestone payments to the steel manufacturer. In addition, the quality of steel will be better maintained, because steel plates usually get deformed and start to rust when there are large inventories lying around on the open for long periods of time.

The kanban post in conjunction with the withdrawal kanban and the kanban pull signal represent the situation where the worker in the shipyard steel stockyard signals to the steel manufacturer who has set up intermediate storage in a practical industrial area close to the shipyard for the next batch of steel to be delivered once the previous batch is on its way to completion (See Figure 3). Likewise the steel is no longer unloaded onto big stacks of steel plates but is instead immediately sorted into few smaller batches and is immediately sent on to further treatment with minimal storage. The OXOX represents load leveling or balanced flow, which is necessary in order to follow an equal takt time with the downstream processes. Steel plate reading for the grit blaster; steel heating, grit blasting and painting; and labeling and transporting to the kanban post all follow an equal takt time of 5 minutes.

The duration time is calculated using the group technology method [8]. The number of processes has been decreased from five to four. Likewise the takt time is set at 5 minutes per plate. The first plate takes \((5 + 5 + 5 + 5 + 5) = 20\) minutes to process, Eq. (3). The rest of the 39 plates take \((39 \times 5) = 195\) minutes to process, Eq. (4). Therefore the total duration time for all forty plates calculated by the “group process method” is 215 minutes, Eq. (5) which is a 73 percent improvement over the conventional process method which pushes material instead of pulling. Likewise the man-hours are 3.58 hours \(\times 5\) operators = 17.91 or about 18 man-hours Eq. (6) which is a 33 percent improvement over the current state.

\[
DT_{\text{PLATE}} = T \times P
\]  
(3)

\[
DT_{\text{PLATES 2-40}} = NP-1 \times T
\]  
(4)

\[
DT_{\text{PLATES 1-40}} = (T \times P) + ((NP-1) \times T)
\]  
(5)
where: \( T \) is takt time, \( P \) is the number of processes, \( NP \) is total number of plates, \( DT \) is duration time and \( O \) is number of operators.

\[ \text{Man-hours}_{\text{Total}} = DT \times \text{plates} \times O \times \text{TOTAL} \]  

\( (6) \)

**Conclusion**

The value stream mapping methodology for the pre-assembly steel processes requires performing a case study and identifying all processes, their duration times, and number of operators per process. Then a value stream map using lean symbols and terminology can be created. Keeping in mind the lean principles of flow, pull, and perfection, as well as the wastes of excessive transport, movement, and inventory which leads to defects, should allow for a new improved map to be created. With the new map, there is no need to change the infrastructure of the shipyard. The key differences are that steel should not be piled up as is done in the current state but should be brought to the shipyard in batches as requested by the kanban post between the supplier of steel and the shipyard stockyard which results in minimal inventories at manageable levels. Finally, the application of group technology is compliant with lean manufacturing and creating future improved value stream maps which decrease man hours and duration times significantly.

For a future case study and value stream mapping analysis, the authors recommend value stream mapping the rest of the downstream processes which includes steel cutting and forming, panel assembly, outfitting and block assembly, and determining the optimal takt time between all shipyard processes. The integration of the IHOP concept (integrated hull construction, outfitting, and painting) with lean manufacturing and group technology principles will be pertinent in making dramatic savings in both man-hours and duration times, which results in competitive shipyards.

**References**