Lean IHOP Transformation of Shipyard Erection Block Construction

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The modern system of shipbuilding includes applying integrated hull construction, outfitting and painting (IHOP) of ship interim products, as opposed to the traditional manner of first constructing the hull blocks, then performing basic outfitting and finally painting, all separate of each other. Even though most shipyards apply some degree of integration of all trades during vessel construction, much work could still be better integrated. This paper analyzes and maps the present IHOP construction of a typical shipbuilding erection block in a real shipyard. Through the application of a Product Work Breakdown Structure (PWBS) and group technology, the degree of IHOP integration could be increased. This is demonstrated to be in compliance with the lean principles of improving flow and kaizen. The paper will suggest how the vessel construction could be become leaner through a value stream map, thereby decreasing both duration time and man-hours thus securing significant savings for the shipyard.

KEY WORDS: lean manufacturing, IHOP – Integrated hull construction, outfitting and painting, Product work breakdown structure, group technology, kaizen, shipbuilding

INTRODUCTION
The concept of integrated hull construction, outfitting and painting (IHOP) of ship blocks has existed for the past 40 years. However, the level of IHOP application differs among shipyards. There is still much rework and outfitting that is done on the slipway or in the dry-dock as opposed to during the assembly or pre-erection construction phase. The main aim of IHOP is to construct and outfit and paint ship blocks to a high degree while minimizing the outfitting tasks for later construction stages. This method greatly reduces shipbuilding production man-hours which yields major savings for shipyards.

The idea of IHOP derives from group technology. In the distant past, ships were built in the classic method with keel laying on the slipway followed by piecemeal steel construction with outfitting of ships equipment afterwards. Outfitting includes all equipment that is not an integral part of the hull structure such as equipment foundations, pipes, cables, hangars, ladders, pumps, valves, boilers, purifiers, evaporators, bus and switchboards, diesel generator sets, main engine and all of the ship systems including the wheelhouse electronics and navigation equipment.

The functional breakdown used by most commercial shipyards in the world was developed by the Ship Research Institute in Norway (Skipsteknisk forskningsinstitutt) and is most commonly known as the SFI group system for classification of all the parts of a ship, regardless of ship type. For instance, Group 1 represents the activities related to technical specifications, contract drawings estimations, purchasing activities. Likewise the costs related to the classification society, inspections, model basin testing, ship trials, and all of the fuel and lubrication that the shipyard must purchase while the ship is undergoing sea trials. Group 2 is the hull; Group 3 is equipment related to cargo handling; Group 4 is ships equipment which aids maneuvering, navigation, mooring and anchoring and much more. Group 5 is equipment for crew and passengers; Group 6 is all equipment including the main engine and its affiliations; Group 7 are systems related to auxiliary machinery spaces. Group 8 are ships systems. This vessel classification system is used in defining all ship drawing designs and enables communication within the shipyard and towards suppliers, classification society and the Customer. Whereas, the SFI classification system is very successful in the design phase, the development of the detailed production drawings requires the adoption of a Product Work Breakdown Structure (PWBS). While SFI defines the ships systems which pass through many blocks of a ship such as the ballast system, a PWBS philosophy engages the detailed design engineers to create drawings from completely finished 3D models and extract interim products. These interim products include panels, micro-panels, built-up panels, three-dimensional blocks and very large three dimensional blocks. Likewise, when properly done, it also includes the outfitting that is done while a section is still two-dimensional as opposed to three dimensional. The advantages in maximizing outfitting when an interim steel product is two dimensional will be demonstrated in this paper.

The complete assembly of an outfitted and painted block ready for erection to the slipway or dry dock is analyzed and mapped using a value stream mapping methodology developed in earlier papers (Kolich et al. 2012b, 2014, 2015a, 2016, 2017a, 2017b). The lean value stream mapping method is used to show the flow of interim products which are assembled similar to lego blocks. In the present system at the shipyard analyzed, very little outfitting is done on two-dimensional sections. The rest of the outfitting is done once a three dimensional block is already assembled which means that there are relatively high man-hours for the outfitting work because the access to overhead cranes is greatly diminished as opposed to the outfitting of two-dimensional sections. The aim of this paper is to demonstrate and explain how by shifting the outfitting works to an earlier
construction phase, the required man hours decrease while constructing the same interim product.

BACKGROUND
The concept of IHOP is described in earlier SNAME literature. (DFP) Manual (1999). The main idea is that there needs to be more overlapping of work and work done in tandem as opposed to first fully completing the steel assembly before moving to outfitting (Rubesa et al 2011). The idea is that it is more efficient to organize different trades to work together. The downside is that it requires a transformation of the engineering and planning offices into a very well developed PWBS system in the shipyard (Kolich et al. 2010, 2012a).

Shipyard value stream mapping of pre-assembly steel activities was performed in an earlier paper. It demonstrated how mapping present pre-assembly steel activities and using lean methods allows production engineers to develop a future more improved system which reduces man hours in this early shipbuilding phase. (Kolich et al. 2012b). Micropanel assembly was likely mapped using lean manufacturing techniques which resulted in improved micropanel assembly (Kolich et al. 2014). Similar treatment for panel assembly and built-up panel assembly likewise (Kolich et al. 2015a, 2016, 2017a, 2017b). The savings are significant 80% and 60% successively. Since there is a lack of IHOP value stream mapping, the idea for this paper is relevant in answering how to use a value stream mapping methodology to improve the next downstream production stage in shipbuilding which is large erection block assembly along with outfitting which in essence is applying value stream mapping to IHOP.

PWBS INTEGRATED WITH IHOP
According to the Design for Production Manual (DFP 1999) the following stages are defined (See Table 1), which industry generally accepts as a given. The first stage is sub-assembly which includes micropanel assembly. All steel elements are fitted and welded in a downhand position with readily available welding equipment and overhead cranes for shipfitters. See typical sub-assemblies such as micropanels that are semi-automatically assembled (Figure 1), robotically assembled (Figure 2), and manually assembled (Figure 3). Under unit assembly are the panels (Figure 4), built-up panels (Figure 5) and two dimensional sections (Figure 6). Three-dimensional sections (Figure 7) are a combination of micropanels. They fall under block assembly and it is necessary to use considerable overhead assembly in addition to downhand assembly, which increases the man-hours since it is more time consuming than just downhand assembly. Very large block assembly consists integrating a combination of panels, built up panels and two-dimensional sections and is also classified under block assembly. The fourth stage includes block erection on the slipway.

Table 1. Man-hour correlations to shipbuilding stage (DFP, 1999)

<table>
<thead>
<tr>
<th>Building Stage</th>
<th>Man-hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-assembly</td>
<td>1</td>
</tr>
<tr>
<td>Unit-assembly</td>
<td>2</td>
</tr>
<tr>
<td>Block assembly</td>
<td>4</td>
</tr>
<tr>
<td>Berth/dock assembly</td>
<td>8</td>
</tr>
<tr>
<td>Afloat</td>
<td>12</td>
</tr>
</tbody>
</table>

The conclusion that can be drawn from the above table is that it is best to do as much outfitting in the earlier stages. The more the shipyard waits for the outfitters to do their jobs, the more man-hours it will require. The next logical step is to perform a case study of the assembly and outfitting of a large erection block in order to identify how much outfitting is done and during which stage.

CASE STUDY ON A TYPICAL ERECTION BLOCK

The erection block analyzed in this case study includes many different types of interim products. CA stands for a micropanel assembled on the semi-automated assembly line (Figure 1). CR stands for robotically assembled micropanel (Figure 2). MP is the manually assembled micro-panel (Figure 3). P stands for a semi-automatically assembled panel (Figure 4). KP stands for built-up panel (Figure 5). S stands for a two-dimensional section (Figure 6) and T represents three-dimensional blocks (Figure 7). VT stands for a very large three-dimensional erection block (Figure 8). This very large erection block is made up by assembling all of the mentioned interim products together (Figure 9).

Fig.1 Semi-automatically assembled micropanel (CA)

Fig.2 Robotically assembled micropanel (CR)
Fig. 3 Manually assembled micropanel (MP)

Fig. 4 Panel (P)

Fig. 5 Built-up panel (KP)

Fig. 6 Two dimensional section (S)

Fig. 7 Three-dimensional Section (T)

VT01

Fig. 8 Very large three-dimensional erection block (VT) (3. Maj shipyard archive).
VALUE STREAM MAPPING
It is necessary to define the stream of flow of interim products during the drawing of a value stream map. Usually it takes up the shape of the letter U. From the top left the interim products that make up the large erection block include the ones mentioned above: panels, built-up panels, two-dimensional sections and three dimensional sections as well as all of the outfitting equipment such as pipes and electrical cables. A value stream map enables the identification of wastes of storage and transportation. Likewise, it also shows the workstations and the downstream flow of the interim products and how the different parts come together. As a result, it is possible to identify wastes and then eliminate them in the future improved value stream map.

Current state value stream map
In the current value stream map (Figure 10), there is much interim storage which is represented by a triangle. This means that once the interim products mentioned above are produced, they are sent to an interim storage close to where the very large block assembly will take place. The first activity is represented by steel block assembly, which essentially is the combining of the interim products of Figure 9 above, panels, built-up panels, two dimensional sections and three dimensional sections. According to Table 1, this represents the third stage of shipyard assembly which is block assembly. The takt time is 20 hours and there are 15 operators. Multiplying the two yields 300 man-hours. Likewise, the total mass is 148524 kg.

The next cell moving to the right is pipe hanger assembly and pipe fitting. The takt time is 24 hours and there are 20 operators which equates to 480 man-hours. There is a total of 2443 kg. Moving next to the right is steel equipment assembly which includes ladders, handrails, man-hole covers and other steel equipment of which there is 1386 kg. The takt time is 16 hours and 10 operators which yields 160 man-hours. The next two cells includes cable tray assembly and protective coverings in tandem. With the cable tray assembly there is a takt time of 8 hours and five operators for a total of 40 man-hours. For protective coverings which is installed in parallel with the cable trays, the takt time is 8 hours and there are three workers for a total of 24 man-hours. Finally, the anti-corrosive protection process has a takt time of 72 hours and three operators for a total of 216 man-hours. When everything is summed up, the duration time is 140 hours and 1220 man-hours.
It is necessary to identify and eliminate interim storage represented by triangles in Figure 10 (Liker and Lamb 2002). This is replaced by a Kanban supermarket system illustrated in Figure 11 below. The implementation of a Kanban in production enables the creation of a pull system (Bicheno and Holweg, 2000) where interim products are not stacked up in great quantities waiting to go downstream, but instead only the relative appropriate amount is produced which will not be stored for longer than a day. This means that space is not wasted. Likewise, workers from the upstream activities only produce interim products only one day in advance. Presently the situation in many shipyards which do not have Kanban systems have large stacks of steel plates, micropanels, panels, built-up panels and steel and other equipment instead of producing only smaller batches as is necessary for the upcoming week.

The next thing that the shipyard is doing is to enable better access for workers to assemble equipment onto the steel interim products. In table 1 it is clear that the man-hours decrease if we shift the outfitting to earlier stages. Presently, outfitting is performed in the block assembly stage, which means that a three-dimensional steel block has been constructed. This requires pipe fitters, steel outfitters and electricians to crawl through tight man-hole spaces and manually assemble all the pipes hangers and pipes, ladders and cable trays manually. This requires much excessive movement which is a waste identified in lean manufacturing. However, by doing the outfitting works during an earlier stage, the unit assembly stage, then the man-hours will be split in half. See table 2.

The steel block assembly is 300 hours for both present and future assembly as is anti-corrosive protection 216 man-hours for both present and future. However, the installation of pipe hangers and pipes, steel equipment such as ladders, protective coverings and cable tray assembly is halved due to moving the installation during an earlier stage, when the steel structures are two dimensional and open to much more efficient installation which requires much less movement of workers and also maximizes the access to overhead cranes and tools. The total man-hours is 868 man-hours in the future improved lean IHOP block assembly as opposed to 1220 man-hours in the current IHOP system. This is an improvement of 29% which is significant for shipyard efficiency and savings.

Fig.10 Value Stream Map of IHOP Large Erection Block Assembly
Table 2. Transformation of man-hours present vs. future state

<table>
<thead>
<tr>
<th>Shipyard activities</th>
<th>Present</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block assembly man-hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit assembly man-hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel block assembly</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Pipe hangers/pipes</td>
<td>480</td>
<td>240</td>
</tr>
<tr>
<td>Steel equipment</td>
<td>160</td>
<td>80</td>
</tr>
<tr>
<td>Protective coverings</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Cable tray assembly</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Anti-corrosive protection</td>
<td>216</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1220</td>
<td>868</td>
</tr>
</tbody>
</table>

One prerequisite is that the assembly of these outfitted units, which are two-dimensional means that accuracy control will have to be increased to a higher level. Presently during the flipping over of panels and built-up panels there is some leeway with regards to dimensional control. However, once the two-dimensional interim products become outfitted, the assembly techniques will need to be improved to eliminate damage and rework to the outfitting equipment.

In the current state, steel assembly includes 25% percent of IHOP construction while outfitting is 58% and 17% is anti-corrosive protection. On the other hand in the future improved state steel assembly is 35%; outfitting is 40% and anti-corrosive protection is 25%. The improvements in outfitting are significant since they are performed in the unit construction phase, when the interim products are two dimensional, and therefore the amount of energy and movements are significantly lower due to downhand work and ease of automation. The total man-hours decreases 29% from 1220 to 868 man-hours, which is significant when considering that if this is done for all the other ship erection blocks, the man-hour savings will result in reductions during the construction of the entire ship.

Fig. 11 Value Stream Map of the future state IHOP large erection block assembly
CONCLUSIONS.
Value stream mapping has proven to help reduce man-hours and improve the production efficiency of all shipyard activities. This includes pre-assembly steel activities and assembly activities from micro-panel assembly, panel assembly, built-up assembly all the way to and including IHOP. The main difference between IHOP and other assembly activities is that it includes steel assembly as well as outfitting activities. With reference to outfitting, the complexities increase significantly moving downstream due to the fact that outfitting in later shipbuilding stages requires intensive man-hours because the conditions require much movement and manual overhead work in small spaces where there is little or no access to cranes and virtually no possibility of automation. Therefore, by moving as much outfitting to earlier construction phases will result in smaller man-hours which is close to 30% as demonstrated in this paper.

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