Lean Methodology to Transform Shipbuilding Panel Assembly

Damir Kolich,* Richard L. Storch,† and Niksa Fafandjel*

*Naval Architecture and Ocean Engineering Department, University of Rijeka, Rijeka, Croatia
†Industrial and Systems Engineering Department, University of Washington, Seattle, Washington

The core competence of any medium-to-large sized shipyard includes the panel assembly line. Ship panels are the basic building blocks of well over 60% of the interim products of typical commercial ships. Therefore the improvement of the panel assembly process could greatly reduce the number of man-hours of all assembled panels, thereby yielding significant savings to the shipyard. Using a lean methodology to make kaizen improvements to traditional panel assembly lines will greatly reduce the costs in ship production. This means that shipyards, which are barely keeping earnings above costs, will be able to increase profits. Value stream mapping is a key way of determining how lean a production process is. The wastes in production assembly are readily identified as well as the takt time and the areas where there is push as opposed to pull. In this paper, a case study of a typical commercial shipyard, which builds a product mix of vessels is analyzed. The present state panel assembly line is mapped and then using lean tools and avant-garde technologies, such as hybrid laser arc welding, the new transformed panel assembly line is demonstrated to bring man-hour reductions of over 80%, so that a typical panel is assembled using 12 man-hours as opposed to the present 72 man-hours.

Keywords: value stream mapping; shipbuilding; one-piece flow; kaizen; hybrid-laser arc welding

1. Introduction

The core competence of virtually any medium-to-large sized shipyard includes a panel assembly line. Many times shipyard management takes for granted that the panel assembly line is just fine as is and therefore it is not necessary to make analysis to improve this core shipbuilding assembly process any further. However, since flat panels make up well over 60% of the building blocks of most commercial ships, any type of significant improvement to the panel assembly line will result in important cost savings for the shipyard.

Lean manufacturing is a concept that is used in multiple industries to improve the production processes by streamlining them. The techniques include applying the principles of value stream mapping. Once the value stream of the present production system is mapped, it is possible to readily identify the wastes. The identified wastes need to be eliminated for the future improved value stream map. Likewise it is necessary to have a balanced takt time between the processes. In addition, the lean principles of one-piece flow, kaizen, and just in time assembly need to be implemented.

2. Background

Storch and Lim (1999) introduced the concept of lean manufacturing to the shipbuilding industry and stressed the importance of flow as key to the lean manufacturing analysis system. Likewise, the application of group technology within a product work breakdown structure as opposed to an exclusively ship breakdown based on functions are some of the necessary fundamentals that need to be developed at any shipyard in order to be able to make lean improvements. The definition of lean shipbuilding further defines and applies the ideas of lean manufacturing from the automobile industry, especially the Toyota Production System with the two pillars of just in time and built-in quality (Bicheno & Holweg 2000).
Defining the value stream is stressed as are the seven wastes of overproduction, transportation, waiting, inventory, defects, over processing, and movement (Liker & Lamb 2002). With Koenig, Narita and Baba (2002) and Okomuto (1997), the idea about one-piece flow is well explained within the panel assembly process of the Japanese IHI shipyard. The underlying idea behind these papers is the need to improve the efficiency of core shipbuilding processes in order to be competitive in the unmerciful industry, where many European shipyards have seen bankruptcies and closures. The idea is that even though a shipyard may be technologically superior, by failing to apply a lean philosophy will eventually lead to noncompetitiveness on the world stage.

A lean methodology was made which applied the idea of the earlier papers and demonstrated through Gantt charts and through the comparison of different types of panel and built-up panel assembly methods in order to uncover the most efficient assembly method. Through the use of a Monte Carlo risk analysis technique, it was shown that the panel-block assembly method with the least amount of weld lengths and through the utilization of one-piece flow and one-sided welding of steel plates results in the fewest number of man-hours (Kolich et al. 2011b, 2012a). In another paper, a value stream mapping methodology of pre-assembly steel processes was developed. This demonstrated the application of lean principles in shipyard storage and production areas, where the system appears to function efficiently, could be further improved (Kolich et al. 2012b). In another paper, the value stream mapping method was adapted for micropanel assembly. With the use of clustering that derives from the data-mining field, it is possible to further simplify the present shipyard production processes and determine which production processes can be combined together, thereby reducing the amount of space taken up in the shipyard. This results in man-hour reductions of up to 50% (Kolich et al. 2014). Likewise, data mining to predict hybrid laser arc welding (HLAW) improvements is another argument for applying better technology to processes where there is a bottleneck which needs to be removed (Kolich et al. 2015b). Finally, the paper on optimizing interim product assembly using value stream mapping is another demonstration of using typical lean tools adapted for the shipbuilding industry (Kolich et al. 2015a).

3. Shipyard case study

The shipyard analyzed in this paper is considered a medium-to-large sized shipyard in the European theater of shipbuilding. It builds a product mix of vessels ranging from chemical tankers, asphalt tankers, and asphalt barges. It has picked up the niche market and delivers up to 31 barges a year, with the capacity for having a diverse shipbuilding program. Although the shipyard has decent production facilities that meet the needs of the production product mix program, it is necessary for it to improve its facilities in order to maintain and also increase its competitiveness. According to the SNAME Design for Production (DFP) Manual (1999), it is necessary to analyze the product mix of vessels and determine where improvements can be made. DFP principles can be adhered to make significant improvements (Kolich et al. 2010, 2011a). Even though the shipyard uses a degree of a product work breakdown structure, still much of the initial design is still based on functional drawings and functional breakdown when it comes to vessel price estimation.

The shipyard in question is in Europe and presently has a product mix program of chemical tankers and asphalt barges (Figs. 1 and 2) (Kolich et al. 2015a). It launches vessels from two slipways, which are serviced by an overhead gantry crane with a capacity of 300 tons lifting capacity. This means that the erection blocks are usually designed to be close to 300 tons in weight. The rest of the facilities are structured around steel storage and handling, steel prefabrication processes, steel fabrication processes, steel assembly, and outfitting. Then there is interim product assembly of panels, micropanels, and built-up panels in the subassembly hall. This assortment of interim products is combined to form sections, and finally the large blocks, which are erected on the slipway. There is a degree of integrated hull construction, outfitting, and painting performed in the assembly halls. This includes pipe hangers, pipes, and other types of steel outfitting such as ladders and ventilation ducts. The aim of the shipyard is to reduce the amount of outfitting processes after the erection phase. The typical ships are made up of the following characteristics in Table 1.

The purpose of this paper is to analyze and map the shipyard panel assembly process, upon which it will be possible to deduct the existing wastes and then with the application of lean principles and value stream mapping tools, draw up a new improved future
In order to properly map the assembly process, it is necessary to analyze the DFP (Design Feature Parameters) characteristics of typical panel interim products from a product mix, which includes seven typical panels of both the chemical tanker and the asphalt barge. These characteristics include assembly man-hours, mass, plate thickness, panel length, panel width, stiffener height, stiffener thickness, stiffener length, number of stiffener types, and the number of stiffeners (Table 2).

Although the two vessels above are significantly different from one another (Figs. 1 and 2) the application of group technology enhances the perspective of similarities between the interim products, which in turn allows for the mass production of panels that is treated in this paper. Likewise, a similar approach can be used for other groups of interim products such as pipes, modules, cable trays, ventilation, and more. Whether a panel is for a tanker or a barge does not affect the production workers on the panel assembly line. Similar assembly techniques are used for all steel panels.

Figure 3 depicts a chemical tanker panel, with four 12.5-mm-thick steel plates butt welded together. There are a total of 11 Holland profile longitudinal stiffeners. The total weight is 16.8 tons.

The panel above (Fig. 4) has five steel plates with an average thickness of 16 mm along with 14 longitudinal Holland profile stiffeners. This means that there are a total of four butt welds to be performed on both sides of the panel. As a result, the weight of 23.4 tons is greater than the panel in Fig. 3 as well (Table 1).

The panel in Fig. 5 is similar to Fig. 3. It has 4 butt welded 13-mm-thick steel plates and 11 Holland profile longitudinal stiffeners yielding a total weight of 16.8 tons.

Figure 6 is similar to Fig. 4, except that due to the greater dimensions of one of the steel plates, it is 100 kg heavier. They both have 14 stiffeners with the same thickness of 11 mm.

This panel (Fig. 7) is similar to Fig. 3 in weight, dimensions, and configuration.

Figure 8 is similar to Fig. 4 with regard to all the dimensions and the weight.

The panel in Fig. 9 is similar to Fig. 5. There are a total of four steel plates, which means three butt welds on each side. There are a total of 11 longitudinal stiffeners. The total mass is 16.8 tons.

### Table 1 Principal characteristics of the chemical tanker and asphalt barge (3. Maj Shipyard Archive 2010, 2015)

<table>
<thead>
<tr>
<th>Principal characteristics</th>
<th>Chemical tanker</th>
<th>Asphalt barge</th>
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<tbody>
<tr>
<td>Loa (m)</td>
<td>195.30</td>
<td>59.48</td>
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<tr>
<td>Lpp (m)</td>
<td>187.30</td>
<td>59.48</td>
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<td>B (m)</td>
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<td>H (m)</td>
<td>17.80</td>
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<tr>
<td>Tdesign (m)</td>
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<tr>
<td>Tscantling (m)</td>
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<td>—</td>
</tr>
<tr>
<td>Δdesign (dwt)</td>
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<td>2,400</td>
</tr>
<tr>
<td>Δscantling (dwt)</td>
<td>51,800</td>
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### Table 2 Interim product characteristics for both chemical tanker group 3450 and asphalt barge ring group 3510 (3. Maj Shipyard Archive 2010, 2015)

<table>
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<tr>
<th>Panel label</th>
<th>Man-hours</th>
<th>Mass (kg)</th>
<th>Plate thickness (mm)</th>
<th>Panel length (mm)</th>
<th>Panel width (mm)</th>
<th>Stiffener height (mm)</th>
<th>Stiffener thickness (mm)</th>
<th>Stiffener length (mm)</th>
<th>Stiffener no. types</th>
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<td>10,540</td>
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<td>260</td>
<td>11</td>
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<td>13</td>
<td>10,540</td>
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Fig. 4 Chemical tanker panel P111

Fig. 5 Chemical tanker panel P120

Fig. 6 Chemical tanker panel P121

Fig. 7 Chemical tanker panel P210

Fig. 8 Chemical tanker panel P211

Fig. 9 Chemical tanker panel 220
Figure 10 is virtually identical to Fig. 8 except for being slightly heavier due to small steel plate dimensional discrepancies in length.

Although the panels of the asphalt tanker have many similarities, it is helpful to analyze the panels of the barge, because the workers on the panel assembly line have an identical approach, which is in compliance with group technology and lean manufacturing.

The panel of Fig. 11 contains five steel plates butt welded together with 18 longitudinal stiffeners. The panel has a total mass of 10.6 tons.

The panel in Fig. 12 contains seven steel plates butt welded together. There are a total of 14 stiffeners and the total stiffener length is 177 meters. The total panel weight is 9.99 tons.

This panel Fig. 13 contains three steel plates butt welded together with a total mass of 6.1 tons.

The above panel in Fig. 14 contains two steel plates with a total mass of 2.6 tons, which is logically lighter in weight because of the smaller number of steel plates.

The panel in Fig. 15 has two steel plates with a total mass of 2.3 tons, which is lighter than the previous panel (Fig. 14) due to the smaller thickness of the steel plates.
The panel in Fig. 16 consists of three steel plates and seven longitudinal stiffeners with a total weight of 6.1 tons.

The panel of Fig. 17 consists of a total of two steel plates with and seven longitudinal stiffeners giving a total weight of 2.6 tons. Figure 17 has a similar weight and configuration as Fig. 10 above. Although Fig. 17 has seven stiffeners and Fig. 14 has six, the total length of the stiffeners is the same (Table 1).

The panel in Fig. 18 consists of two steel plates and six stiffeners with a mass of 2.3 tons as Fig. 15.

4. Value stream mapping

Applying the lean principle of kaizen goes hand in hand with further development of DFP principles along with the need to institute and apply lean principles in the production system. The lean principles of determining the value stream and mapping it in order to determine where there is waste are one of the first steps in making the production process more efficient. A logical place to begin this value stream mapping is the panel assembly line since between 60% and 80% of the vessels’ interim products constitute flat panels.

The key value stream mapping symbols include identifying the supplier and customer, which uses the symbol to the top left of the value stream mapping legend of Fig. 19. Then it is necessary to identify where there is interim storage. The interim storage is represented by a triangle. Then there is a push arrow as seen in the legend. A thin straight line with an arrowhead represents manual information. A zigzag thin line represents electronic information. The kaizen improvement burst represents an irregular
figure within, which is placed descriptive text of the necessary planned improvement within the future improved value stream map. The withdrawal kanban looks like an index card and represents the instructions, which dictate to the production when to remove interim products from the supermarket to the next production process. The kanban post indicates a location where the withdrawal kanban exists. The kanban pull signal demonstrates the signal that comes from the next downstream process when it is ready to receive the next interim product. The pull arrow indicates the movement of the interim product to the downstream process. Finally, the process boxes have a title and indicate whether the process is a nonvalue added process or a value added process. The data box indicates the takt time of the process, the number of operators, the number of interim products per shift, and the man-hours.

4.1. Current state

The value stream map is always read from left to right (Fig. 20). At the top left corner is the supplier or in this case the internal predecessor of the production system. The steel plates prior to arriving to the panel assembly line have been sorted, labeled, heated, grit blasted, primer covered, and then cut to the necessary specifications ready to be assembled at the panel assembly line. However, the steel plates are stacked at an interim storage area in the consecutive order necessary to be assembled at the panel assembly line. Afterward, the panel is turned over to have the same seams on the other side butt welded in order to complete the panel butt-welding cycle. The shipyard uses two-sided welded technology as opposed to one-sided welding technology, which results in quality welds. However, if the shipyard were to transform to one-sided welding technology, it would result in less movements, a smaller duration time and therefore fewer man-hours, thus greater saving. Because of this requirement to turn the panel to the other side, the ceiling at workstation number 2 is higher than at the other workstations where there is no need to flip the panel over anymore. At workstation 3, the positions of where the longitudinal stiffeners need to be added are marked with string and chalk technology manually. Then those positions are grinded down until the primer paint is removed and the steel finish is visible. In this way, the stiffeners get welded with greater speed and better quality, thus improving efficiency. Once this is done, at workstation number four the first longitudinal stiffener is centered on the corresponding freshly grinded position. Then hydraulic pins press down on the first stiffener and again double-sided submerged arc welding technology is used to weld the stiffener to the panel. This is repeated until all of the stiffeners are welded to the panel. Please note that due to the use of the hydraulic pins, it is not necessary to first tack weld. The tack welding step is eliminated thus saving time, energy, and decreasing the number of motions. The takt time is usually determined by the fourth workstation, which is defined as the bottleneck station. This is due to the fact that there are usually between 6 and 18 stiffeners with total welding lengths ranging between 17 and 183 meters (Table 2).
The formula for calculating the assembly duration time of the first panel is as follows:

\[ DT_{\text{Total}} = DT_1 + DT_2 + DT_3 + DT_4 + DT_5 \]  

(4.2)

The man-hours are calculated by multiplying the duration time of each process with the number of operators. Therefore, the following calculation is pertinent: (4 hours \( \div \) 5 operators) + (4 hours \( \times \) 4 operators) + (4 hours \( \times \) 5 operators) + (4 hours \( \times \) 4 operators) = 72 hours. See equation (4.3).

\[ \text{Man-hours}_{\text{Total}} = DT_1 \times O_1 + DT_2 \times O_2 + DT_3 \times O_3 + DT_4 \times O_4 + DT_5 \times O_5 \]  

(4.3)

where \( DT_{\text{Total}} \) is the total duration time, \( DT_{1-5} \) are the individual process duration times, and \( O_{1-5} \) are the number of operators.

### 4.2. Future state

The transformation of the current state starts by analyzing where there are wastes. For example, the triangles represent waste and need to be replaced with a kanban supermarket system of handling interim products among the processes. Likewise, it is necessary to analyze where is push and replace it with pull. Presently at the shipyard, the steel plates are stacked in big piles. As a result, the steel plates start to corrode and even develop deformations. Therefore, the assembly of these steel plates along the panel assembly line means that there will be problems in leveling the steel, which translates to extra hours of rework and even increases the takt time of the panel assembly process. The kanban works in a similar way to modern supermarkets. For instance supermarkets place enough items as is demanded by customers for that day. However, in case more items of a particular product get used up, then the supermarket has a kanban card, which specifies when the minimum amount of a specific item has been achieved. Then the employee responsible for restacking the items brings the amount written on the kanban card. The same is with the panel assembly line where steel plates are restacked only when a minimum number have been used up. Therefore, the stacks of many steel plates will be eliminated in the future transformed state. This means that there will be more room in the shipyard and less deterioration of steel plates.

The principle of one-piece flow means that instead of assembling all of the steel plates together into one big plate as is done in most shipyards, each unit plate comes under a specially designed gantry, which has the computer information as to placing the exact number of stiffeners onto the unit plate. Since each unit plate does not have more than four stiffeners due the width constraints, it is economically viable to fasten, and weld all of the stiffeners simultaneously using submerged arc welding or even HLAW technology. On the other hand, mounting and welding up to 15 stiffeners on the traditional panel assembly line simultaneously is not economically or technologically viable, because that would require a much larger gantry with up to 15 automated welding machines. This requires a costly solution for investment as well as more space. Using the one-piece flow principal and creating a balanced takt time means that it is necessary to update the technology without doing “overkill” as would be the situation with the large traditional panel assembly line. Therefore, on the first workstation, the three to four stiffeners are tack welded simultaneously. There is only one operator. Afterward, the unit plate with tack welded stiffeners is sent to workstation 2 where it is automatically welded. Likewise, there is only one operator who controls and supervises the operation. At workstation 3, there is where the width of the assembly increases in order to accept more stiffened unit
The takt time is 1 hour per work station. At the third work-station, the first unit panel is positioned such that the other three stiffened unit panels can be butt welded as they arrive from work-station 2. Therefore, the man hours are $3 + 3 + 3 + 3 = 12$ man-hours. The duration time is 6 hours, which is a 62.5% decrease from 16 hours. Likewise, the man-hours are 12 hours, which is an 83% decrease from 72 hours. The savings are considerable and justify undertaking a transformation. In addition to man-hour and duration time improvements, there are also space savings, since instead of four work stations there are three. Likewise, the first two work stations have a decrease in width to 1-unit steel plate as opposed to 5-unit steel plates (see Fig. 21).

### 5. Discussion and conclusion

The value stream mapping transformation results in a panel assembly process where there is one-piece flow, pull, balanced flow, and an equal takt time. In addition, the advancement of the welding technology from classic metal active gas welding to HLAW means that excessive movements are eliminated. It is not necessary to turn the panel onto the other side to get welded since HLAW butt welds on one side. The penetrations of HLAW are deep and quality enough so that it becomes unnecessary to turn over to the other side to weld. The stiffening of unit steel plates as opposed to large welded steel plates is much more practicable from a technological point of view. Simultaneously up to four stiffeners are welded to each unit plate, resulting in a stiffened unit panel.

Once the second unit panel is assembled at workstation number two it is butt welded using HLAW technology at the third workstation. The third and fourth unit panels are consecutively butt welded together resulting in a large stiffened panel.

From the earlier figures showing the differences between panels of the chemical tanker vs. the asphalt carrier barges, the transformed 1-piece flow panel assembly line lends itself well to meeting the needs of both types of ships. For instance, the panels of the barge consist mostly of two steel plates, which means that the duration time would be 4 hours, whereas the assembly duration time of the chemical tanker panels would be six man-hours. This is a drop of 62.5% in duration from the present day 16 man-hours. The man-hour savings is 83% from the original 72 man-hours yielding 12 man-hours. This is significant because the one-piece flow lends itself to better and more economical automation of the entire process. The stiffened panels would be well on their way to the next downstream process of built-up panel assembly, which will be treated in a future paper.

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