Optimizing Shipyard Interim Product Assembly Using a Value Stream Mapping Methodology *

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Author name(s): Damir Kolich¹ (AM), Richard L. Storch² (M), Niksa Fafandjel¹ (M)

1. University of Rijeka, Naval Architecture and Ocean Engineering Department, Rijeka, Croatia.
2. University of Washington, Industrial and Systems Engineering Department, Seattle, WA, USA.

Value stream mapping is used to analyze and improve the production flow in many industries, which includes the airplane and automobile industries worldwide. The shipbuilding industry has adopted lean manufacturing techniques. However, the amount of value stream mapping application in the shipbuilding industry is still relatively sparse due to the large variety of interim products and ship types. The aim of this paper is to analyze the interim products of a typical sized commercial shipyard with a product mix of chemical tankers and asphalt barges to demonstrate how a lean transformation can be performed using a shipyard value stream mapping methodology. The case study maps the typical panel assembly lines of the shipyard and demonstrates the differences between the ship type interim products and using the lean manufacturing methodology developed by the authors to demonstrate how to define and adjust the production facilities using both lean and group technology techniques to create an improved production line which is demonstrated through a future improved value stream map. The main criteria for analyzing and comparing production improvement is through man-hours and duration time. The future value stream map has improvements of up to 50 percent, which demonstrates the importance of adopting a value stream mapping methodology for shipyards aiming to improve world competition by decreasing production costs, while maintaining and/or improving quality of the ship building blocks.

KEY WORDS: value stream mapping, lean manufacturing, group technology, shipbuilding.

NOMENCLATURE
Optional, but do not use unless it is necessary. If used, place in alphabetical order, followed by any Greek symbols.

INTRODUCTION
The automobile and aircraft manufacturing industries have been applying lean principles to improve their production and reduce costs for over two decades. The shipbuilding industry has in comparison taken relatively miniscule steps in comparison. The reason why is that whereas Hyundai Corporation produces 6000 automobiles a day, it produces 60 ships a year. Therefore, since no two ships are exactly the same, the method of applying lean manufacturing principles in production of ships is not readily apparent. Principles of group technology and design for production methods, which have been more readily applied in shipbuilding, can be complemented with lean manufacturing principles adapted for the shipbuilding industry. Whereas in the automobile industry there is much repetition during the manufacturing of thousands of exactly the same types of cars, in shipbuilding the actual building blocks that make up a ship can be analyzed and grouped in such a way so as to apply lean manufacturing ideas. For instance a regular sized 220-meter long vessel consists of up to 10000 interim products. The interim products can be grouped together which in turn allows for lean analysis and transformation. The authors’ of this paper have analyzed a case study of the steel assembled interim products, particularly panels and micropannels. A value stream map of the present state was made. Then by demonstrating the application of lean techniques, a future value stream map of the key production systems in the shipyard is transformed and demonstrated in a future value stream map. The key criteria for measuring a production system are duration time and man-hours. Particularly by reducing the man-hours of each interim product assembly by a significant percentage, it becomes justifiable to approach the transformation of the production systems in a shipyard so as to apply lean, which in turn reduces man-hours and therefore cost. Therefore, the shipyard can become more competitive and justify a constant analysis through case studies that result in production cost reduction. Storch and Lim (1999) explain the importance of applying lean manufacturing techniques in the shipbuilding industry in order to improve the competitiveness of the industry.

BACKGROUND
Value stream mapping is a lean manufacturing technique used to accurately depict the flow of materials and information in a production system according to Bicheno and Holweg (2009). The purpose is to illustrate what type of flow the production has, as well as to readily identify the value adding and non-value adding activities. In this way it becomes possible to concentrate on reducing certain wastes such as excessive movement, transport, redundant operations, waiting, and excessive inventory which all contribute to a less than stream-line production system according to Liker and Lamb (2002). For instance whether the specific assembly line under analysis works based on a push system or a pull system or a combination of the two. The workstations are identified and the takt times are
listed for each workstation. Research in value stream mapping of production systems has been performed in various industries. However, they are still relatively lacking in the shipbuilding industry with the exception of some works such as value stream mapping of the pre-assembly steel processes in a shipyard (Kolich et al. 2012) and value stream mapping of micro-panel assembly (Kolich et al. 2014).

SHIPYARD CASE STUDY

In order to demonstrate the methodology for value stream mapping an actual shipyard production program is analyzed. The shipyard analyzed in this paper is a medium-sized shipyard that produces vessels up to 260 meters in length. The vessel types include chemical tankers, asphalt carriers, asphalt barges, and crane barges.

At any time two different vessels are being built using the same production facilities, as was the situation with the case study from the Design for Production Manual (1999). The vessels analyzed in this paper include chemical tankers and asphalt barges. The parallel middle body makes up the longest single part of each vessel with much repetitive characteristics between the interim products. For instance, the panels are primarily flat. Likewise, the dimensions do not vary drastically. Therefore, it is realistic to first approach value stream mapping of the interim products that make up the parallel middle body. In the case of the crane barge, the entire length of the vessel is considered a parallel middle body. Therefore, by analyzing one erection block, it is reasonable to assume the same characteristics for the other blocks.

Chemical tanker and Asphalt barge

The chemical tanker is a 49000/51800 deadweight tanker for the transport of oil, oil products, and chemicals. On the other hand, the unmanned oil asphalt tank barge is a completely different type of vessel based both on dimensions and purpose. The principal characteristics are in Table 1.

Table 1. Principal characteristics of both the chemical tanker and the asphalt barge manufactured in the same shipyard

<table>
<thead>
<tr>
<th>Principal Characteristics</th>
<th>Chemical tanker</th>
<th>Asphalt barge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loa</td>
<td>195.30 m</td>
<td>59.48 m</td>
</tr>
<tr>
<td>Lpp</td>
<td>187.30 m</td>
<td>59.48</td>
</tr>
<tr>
<td>B</td>
<td>32.20 m</td>
<td>16.00 m</td>
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<tr>
<td>H</td>
<td>17.80 m</td>
<td>4.60 m</td>
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<tr>
<td>T&lt;sub&gt;design&lt;/sub&gt;</td>
<td>12 m</td>
<td>3.35 m</td>
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<tr>
<td>T&lt;sub&gt;scantling&lt;/sub&gt;</td>
<td>12.5 m</td>
<td>------</td>
</tr>
<tr>
<td>Δ&lt;sub&gt;design&lt;/sub&gt;</td>
<td>49000 dwt</td>
<td>2400 dwt</td>
</tr>
<tr>
<td>Δ&lt;sub&gt;scantling&lt;/sub&gt;</td>
<td>51800 dwt</td>
<td>------</td>
</tr>
</tbody>
</table>

It is clear that both the chemical tanker and the asphalt barge are completely different vessels. Whereas the chemical tanker is almost 200 meters in length, the asphalt barge is a fraction of its length while being more rectangular in shape and unmanned as well. See Figures 1 and 2. A table of the typical panels of both the chemical tanker and asphalt tanker are created (See Table 2). The relevant characteristics are mass, steel plate thickness, panel length, panel width, stiffener height, stiffener thickness, stiffener length, number of stiffener types, number of total stiffeners, and finally the man-hours necessary to assemble the panel.

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**Fig. 1** Profile view of 49000/51000 dwt oil tanker for unmanned oil products and chemicals 2400 dwt unmanned oil asphalt tank barge

**Fig. 2** Profile view of 2400 dwt unmanned oil asphalt tank barge

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Kolich, Storch, Fafandjel Optimizing Shipyard Interim Product Assembly Using a Value Stream Mapping Methodology
Table 1. Interim product characteristics for both Chemical tanker and Asphalt barge

<table>
<thead>
<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>
<th>No. stiffeners</th>
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<td>24162.4</td>
<td>16</td>
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<td>11050</td>
<td>370</td>
<td>13</td>
<td>132600</td>
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<td>27472</td>
<td>15.5</td>
<td>15000</td>
<td>11050</td>
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<td>154700</td>
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<tr>
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<td>104</td>
<td>23967</td>
<td>16</td>
<td>12000</td>
<td>11100</td>
<td>370</td>
<td>13</td>
<td>133200</td>
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<tr>
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<td>112</td>
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<td>15</td>
<td>15000</td>
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<td>24482</td>
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<td>155400</td>
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<td>23398</td>
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<td>13250</td>
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<td>8</td>
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<td>11200</td>
<td>160</td>
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<tr>
<td>B_P110</td>
<td>53.5</td>
<td>7235</td>
<td>9</td>
<td>14000</td>
<td>6540</td>
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<td>77080</td>
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<tr>
<td>B_P120</td>
<td>56.5</td>
<td>1957</td>
<td>7</td>
<td>7000</td>
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<td>B_P210</td>
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<td>7</td>
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<td>7.5</td>
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<td>150</td>
<td>10</td>
<td>36400</td>
<td>1</td>
<td>8</td>
</tr>
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</table>

The key to understanding the difference and the similarities for the two vessels above is by analyzing the building blocks otherwise known as interim products, and through the use of group technology to group those interim products based upon general similar physical and qualitative characteristics.

Figure 3. depicts a chemical tanker panel, which has four steel plates butt welded together that are 16 mm thick, along with 12 Holland profile longitudinal stiffeners. The total weight is over 24 tons.
The above illustration (Fig. 4) is similar to Fig. 3 except that it has five steel plates and 14 longitudinal Holland profile stiffeners. Likewise the weight increases to 27.4 tons (See Table 1).

**Fig. 5: Chemical tanker panel P120**

This panel above (Fig. 5) is more similar to Fig. 3 than to Fig. 4, since it also has 4 steel plates and 12 Holland profile longitudinal stiffeners, with a total weight of less than 24 tons. The slightly smaller weight is due to the additional openings that it has.

**Fig. 6: Chemical tanker panel P121**

The figure above is similar to Fig.4 except for having a slightly greater mass of 100 kg, due to the greater dimensions of one of the steel plates. Otherwise the type and numbers of stiffeners are exactly the same.

**Fig. 7: Chemical tanker panel P210**

This panel (Fig. 7) is similar to Figure 5 except for having one extra flat bar which explains the greater weight of 200 kg.

**Fig. 8: Chemical tanker panel P211**

Figure 8 is similar to Figure 5 except that the steel plates have 15mm thickness as opposed to 16 mm thickness, which despite having an extra stiffener still has a smaller weight.
The above figure is similar to Fig. 7 except for the fact that it has two more cut-outs which explain the slight difference in weight between the two panels.

### Fig. 10: Chemical tanker panel P221

This figure is virtually identical to Fig. 8 except for a slight difference in weight due to minor dimensional discrepancy in length.

Moving on to the asphalt barge panel analysis.

### Fig. 13: Barge panel 010

The barge panel 010 (Fig. 1) illustrates a panel with 7 steel plates butt welded together and then turned around and butt welded on the second side, along with 18 flat bar stiffeners welded at workstation 4. It is among the heavier barge panels at around 12.5 tons.

### Fig. 14: Barge panel 020

The panel of figure 14 has 7 steel plates, 17 flat bars as well as two manhole openings, which translates to a smaller weight of 10.6 tons. The butt welding is somewhat more labor intensive due to AH 32 grade steel of the manhole openings which is justification for the extra man-hours.
Fig. 15: Barge panel 110

The above panel consists of 4 steel plates with 7 flat bar stiffeners. The weight is 7.2 tons.

Fig. 16: Barge panel 120

Figure 16 consists of 2 steel plates and 6 flat bar stiffeners with a weight about 2 tons.

Fig. 17: Barge panel 130

Figure 17 consists of a panel with 2 steel plates, 7 flat bar stiffeners with a weight of 2.6 tons.

Fig. 18: Barge panel 210

Barge panel 210 is heavier due to its greater dimensions. The steel plates and the flat bar stiffeners are thicker. Likewise there are 4 steel plates, which translate to a total panel weight of 7.2 tons.
The above panel contains two steel plate with 7 flat bar stiffeners and has a weight of about 2 tons, similar to figure 16.

The above figure contains 8 flat bar stiffeners with two butt-welded steel plates, which combined together gives a mass of about 2.6 tons.

Value Stream Mapping

In order to accurately describe the panel assembly line of the shipyard in the case study, the authors’ have decided to implement the techniques of value stream mapping. First it is necessary to understand the essential tools used for mapping a manufacturing system such as the panel assembly line (See Figure 21). The supplier is identified as the steel plates, which have been pre-fabricated in earlier shipyard processes explained in Ship Production (1995). The details of this process have been treated in earlier works (Kolich et al. 2012, 2014). Since usually these processes involve fabrication, which includes cutting, and making the necessary holes, it is found that the there are little if any bottle necks. However, as production moves downstream the bottleneck and decrease of balance in production is more prone. Therefore, the first major assembly process in virtually any shipyard is the panel assembly process. There is much room for improvement in most shipyards, which justifies the analysis of the panel line assembly process.

The first symbol represents the supplier on the left of the map. The interim storage, which every shipyard has, is represented by a yellow triangle. The push arrow is green whereas a red arrow represents manual information. A zig-zag style arrow represents electronic information. A yellow object with many points represents the continuous improvement or kaizen burst. The curved black arrow illustrates physical pull. The withdrawal kanban is represented by a card, since it has all the information about the specific interim product with regards to elements that make it up, and exactly when each new part needs to be added and at which workstation. The purpose of kanban includes setting up a post where attention is made to a critical part of production where there is otherwise a type of bottleneck being developed. The idea is compared to a modern day supermarket which has items stocked on the shelves of the store. However, well-run supermarkets usually do not have all of their items on the shelves due to space restriction. As soon as customers remove and buy items from a rack, there is a minimum number on the kanban card, which alerts the personnel to restack the shelves with items before the inventory reaches zero. However, since it is hard to predict exactly when and how much customers will purchase on a given day, the kanban posts allow for the employees to react when a certain minimum is reached. Then the shelves are restacked until again the customers buy them. An anti-kanban system would stack many items and then restack it perhaps weekly or monthly, regardless of whether the customers have bought more or less of the item in question. The situation in the shipyard is that the built-up panel process often results in bottle-necks between the panel assembly and built-up panel assembly processes. Therefore, a kanban post and the supermarket shelf system is designed to reduce inventory since extra large storage in a shipyard or in any production facility is considered an enemy to smooth and balanced production, which not only takes up space but creates a cluttered atmosphere where workers begin to loose track of the work to be done. Likewise it also becomes more difficult to detect defects in the interim products as they begin to stack up in excessive amounts. This over excessive stacking of interim products is a result of a push
A push system does not follow the natural flow throughout the production process and therefore creates bottlenecks, which can be metaphorically compared to the creation of a swamp during production. A swamp represents a lack of flow and a big stack-up, which is necessary to avoid in every production system.

**Value stream mapping the present state**

Value stream mapping the present state in the shipyard requires using the legend depicted in Figure 21 and in analyzing the panel assembly line during the assembly of typical shipyard panels. It comes in handy to analyze the interim products of the two ship types.

As mentioned earlier, the panel assembly process in the present shipyard facility configuration retrieves plates that have been pre-fabricated during the earlier processes of sand-blasting, primer coating, and labeling. Then during the fabrication process gas-acetylene cutters cut the steel plate, which is also known as nesting. Afterwards, the prepared steel plates are stacked in an interim storage area ready to be assembled into panels. A cell, where the typical takt time is four hours, represents the first workstation. This includes tack welding and then butt-welding up to 5 steel plates together on one side. Then the steel panel is turned over and transported to the second station where it is welded along the butt seams on the opposite side of the panel. At station three the positions of the longitudinal stiffeners are marked and there is also much grinding work of the welds, as well as the addition of lifting pads in addition to other details such as cutting of necessary holes and markings. The takt time is also four hours. Finally at station 4 the longitudinal stiffeners are added and welded to the panel to create a stiffened panel. Usually Holland profiles are used as the stiffeners. However, there are also flat bars as on the barge on the other hand.

There are four cells in Figure 22, which represent the four workstations used during panel assembly. The takt time for all four stations is determined by the most time consuming workstation of welding stiffeners, which is station 4. This is because each longitudinal stiffener is separately welded.
Value stream mapping the future improved state

Upon analysis of the present state it is necessary to identify where there are wastes and non-lean activities. Since the takt time is fairly long per workstation, four hours, it is necessary to apply the lean principle of one-piece flow. The configuration at IHI shipyards in Japan uses one-piece flow in its panel assembly and is considered a lean shipyard according to (Koenig, 2002). Therefore one of the key transformations of the panel assembly line would be to apply one-piece flow. This is done by butt-welding all four or five plates simultaneously, but by immediately tack welding up to 4 or 5 longitudinal stiffeners simultaneously to each plate at the first workstation. Then likewise welding the longitudinal stiffeners to the steel plate at workstation 2. At workstation 3, once the second unit panel arrives then the unit panels are welding together consecutively using one sided hybrid laser arc welding technology, which is proven to be more efficient than the standard gas arc welding used at the shipyard. The lean method requires technology upgrading with the welding method. Likewise it is necessary to configure the equipment to simultaneously weld the stiffeners.

The key change is the concept of one-piece flow. Most Western shipyards, even those that have state of the art technology still do not apply one-piece flow. Instead, first big panels are butt welded together upon which the stiffeners are then welded. However, one-piece flow goes well with a product mix production program at a shipyard. In the situation with this case study, the larger and smaller panels receive the same initial treatment. It is only workstation three which determines the ultimate final size of the panel, because at workstations one and two, the panels are still unit panels. For instance the Chemical tanker panels (See Figures 3-10) all consist of between 4 and 5 steel plates and between 12 and 14 longitudinal stiffeners. For instance if we analyze Figure 10, panel P221, there are four steel plates and thirteen stiffeners. Presently it takes 113 man-hours to assemble the entire panel with stiffeners, before it moves on to the built-up panel assembly. However, with the new transformed production configuration, it takes 15 man-hours which is roughly a 700% improvement. The number of man-hours drastically reduces. Likewise the duration time reduces from 16 hours to 6 hours, which is a 260% improvement.

The combination and integration of a kanban post along with a kanban withdrawal card along with a supermarket like system eliminates excessive build-up of panels entering the built-up panel assembly area. Finally, the kaizen bursts emphasize the improvement of one-piece flow as well as organization improvements in order to have a production system which pulls the production to make exactly what is necessary when necessary which is in accordance with the lean just-in-time principle. In this way, the bottlenecks between the panel assembly and built-up panel assembly are eliminated. The flow of materials and finished interim products becomes balanced, which eliminates the peaks and troughs in production. Neither will the workers be overworked nor will they have idle time. Every task will be better defined.

![Value Stream Mapping Diagram](image-url)

Fig. 23: Future state value stream map

Kolich, Storch, Fafandjel Optimizing Shipyard Interim Product Assembly Using a Value Stream Mapping Methodology

9
CONCLUSIONS
The case study of the commercial shipyard shows that a product mix is also conducive to production and can be production friendly if the interim products of panel assembly are analyzed and mapped in a value stream. The resulting value stream map allows us to identify where there is pull and what the takt time is. Using the lean tools developed earlier from other industries and from pioneering work in value stream mapping of shipbuilding processes, it is possible to draw improvements and create a pull system when combined with a kanban supermarket integration and the transformation of the facility to enable one piece flow, it is possible to create a future improved value stream map. The resulting improvements can be up to 700% improvement in decreasing man-hours and 300% improvement in duration time.

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