Lean Built-Up Panel Assembly in a Newbuilding Shipyard

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The main shipbuilding assembly processes greatly influence the flow of interim products in a newbuilding shipyard. The panel assembly line is a major process located upstream of all the other shipyard assembly processes. In a previous paper, the application of lean principles enabled a balanced and smaller takt time along the workstations and yielded significant savings in man-hours. Although a panel consists of butt-welded steel plates with multiple fillet-welded longitudinal stiffeners, a built-up panel is this same panel fitted with longitudinal and transverse steel elements. Since there are many internal structural elements, the man-hours along a traditional built-up panel assembly line are multiple times greater than that of panel assembly. Therefore, it is necessary to analyze and map built-up panel assembly in an actual newbuilding shipyard. Using value stream mapping along with kaizen principles of continual improvement to determine the transformative steps to make the traditional built-up panel assembly line leaner. This enables significant man-hour reductions of about 60%, which yields remarkable cost savings to the shipyard.

Keywords: lean manufacturing; built-up panel assembly; value stream mapping; shipbuilding

1. Introduction

The built-up panel assembly line process is located downstream to the panel assembly process, and in most shipyards, half of all steel panels become built-up panels. It is very labor intensive since there are many steel elements that need to be joined in both longitudinal and transverse directions and there are both fillet and vertical welding jobs to be done. The joining of built-up panels to panels yields large three-dimensional blocks. Although in past papers (Kolich et al. 2017, 2015a) a lean value stream mapping methodology to transform panel assembly was developed, it makes sense to develop a methodology for the more complex and man-hour intensive built-up panel assembly process as well. The transformed built-up panel assembly process will further reduce bottlenecks in the shipyard and improve flow bringing down man-hours, which translates to critical savings for the shipyard.

2. Background

In a recent conference paper (Kolich et al. 2016), the lean transformation of built-up panel assembly was described on actual interim products from a real ship. Kolich et al. (2012b) developed a lean value stream methodology for preassembly steel processes in shipbuilding. The development of a value stream mapping methodology of preassembly steel processes in another paper (Kolich et al. 2014). The usefulness of mapping as a tool in lean manufacturing is very crucial before any system can undergo transformation to a lean one. Mapping enables the understanding of flow or lack of flow in the present state system. The possible wastes include excessive movements, transportation, defects, waiting, excessive storage, and unnecessary processing (Bicheno & Holweg 2000). On the elimination of these wastes and through the introduction of equal takt time between the workstations, a balanced flow of interim products will result in a more efficient production system. Liker and Lamb (2002) and Storch and Lim (1999) demonstrated how the application of lean principles to shipbuilding is very effective in improving flow. Pull systems replace push systems and the integration of one-piece flow with built-in quality...
Panel with longitudinal stiffeners + Micropanels = Built-up panel

Fig. 1  Panel plus micropans yields a built-up panel (Kolich et al. 2016)

Fig. 2  A typical CA micropanel
and just in time (JIT) further aids in developing a balanced system. The introduction of a slit system instead of cutouts in shipbuilding panel assembly further develops the practical steps that need to be taken to specifically implement the above-mentioned lean principles (Koenig et al. 2002) and (Okomoto 1997). The built-up panel assembly process requires further important technological implementations in order to reap the rewards of lean principle implementation. Since the micropanels include transverse as well as longitudinal members, a new technological innovation is presented in this paper, that would considerably reduce the man-hours of built-up panel assembly. The idea incorporates egg-box construction on an innovative adjustable jig matrix. Likewise, slit technology instead of cutouts is used (Kolich et al. 2011).

3. Built-up panel assembly analysis

The integration of butt-welded steel plates with longitudinal stiffeners is the usual definition of a shipyard panel (see Fig. 1). In Fig. 2 are micropanels, which consist of longitudinal and transverse steel interim products, also known as intercostal girders and solid floors (Eyres 2005). These steel substructures or micropanels strengthen the interim structure of the panel, which is a classification society requirement for complying with strength criteria for the entire ship structure. Therefore, the fitting of micropanels to a panel, which forms a built-up panel (see Fig. 1), has much influence in determining the total man-hours. Since the values are high, it would be logical to map the present built-up panel assembly process, thereby drawing up a new and improved process through the implementation of lean principles.

The difference between a panel designated with the letter P and a micropanel designated by three abbreviations (CA, CR, and MP) are that a panel is considerably longer, wider, and heavier up to 14 m in width and length. A micropanel is between 4 to 12 m in length, but no more than 4 m in width. Micropanels are further broken down into three groups using group technology at the shipyard analyzed in this paper. These include micropanels assembled along the semiautomatic assembly line, which therefore receive the symbol CA (see Fig. 2). The letter C in the abbreviation stands for computer, whereas the letter A means automated assembly line. These micropanels have only longitudinal stiffeners and therefore can be semiautomatically fitted and welded along the CA assembly line.

The next type of micropanels are designated CR, which stands for computer-robotically assembled micropanel (see Fig. 3). Along this assembly line, the robot uses a video camera to record the
tack-welded stiffeners (see Fig. 4). Metal active gas (MAG) welding technology joins the stiffeners completely to the panel. Finally, the designation MP stands for manually assembled micropanels, where workers do both the fitting and the welding manually. Typically, MP micropanels are more labor intensive due to the greater complexities of these substructures (see Fig. 5). The positioning of stiffeners in nonlongitudinal directions means that neither the CA nor the CR assembly lines are able to weld them, as is the case in Fig. 5 below. Even if most of the stiffeners are longitudinally or transversely positioned, the slightest discrepancy from this requires manual fitting, tack welding, and finally welding, which translates to high man-hours.

3.1. Workstations

According to a product work breakdown structure and also group technology principles (DFP) Manual 1999 and (Kolich et al. 2010a, b), it is necessary to define the work stations of all fabrication and assembly processes. In this way, it is much easier to map the flow of items and to collect data about the number of workers and machines at each work station. Likewise, it is therefore possible to develop an equal workstation takt time, which is necessary for any modern factory including a shipyard (Kolich et al. 2012a).

The panel assembly line has four workstations with a takt time of 4 hours at each workstation. The takt time for the built-up panel assembly line is 8 hours or roughly twice as much as the panel assembly line takt time. As a result, there is a relatively large build-up of panels in interim storage areas as in Fig. 6 below. Excessive storage is an enemy of lean manufacturing. Because valuable space is used, proper solutions can eliminate this storage. The application of the lean principle of JIT and a Kanban post with supermarket principle application will eliminate large storage areas. In a well-organized supermarket, the shelves are periodically stacked only when necessary depending on consumer demand. When demand is higher, there is more refilling of the shelves, and when demand is lower, there is very little stacking. This saves up space and eliminates the need for large storage areas in the supermarket. The same principle can be implemented in a shipyard.

In addition to excessive storage, the built-up panel process uses a relatively large number of workers per workstation because of the more complex configurations for fitting and welding of the internal structure. Although a typical panel P has a mass of 20 tons, the mass of a typical built-up panel is more than twice or up to 50 tons. An example of excessive processing are the collars and the lugs that need to be first centered and then fitted along the assembly line as in Figs. 7 and 8 below. The placement of collars before the fitting and welding of the transverse micropanels to the panel structure (Fig. 7). On the other hand, lugs or strength plates are tack welded after the positioning and welding of transverse micropanels (Fig. 8).

3.1.1. 1st workstation. A portal crane hooks up to the temporary orifice attachments that each panel has, thereby moving the panel to the first built-up panel workstation (see Fig. 9). Tracers mark...
positions of all micropanel positions. The fitting of collars is before the fitting of the micropanels. On fitting, the elements are tack welded. There are 16 semiautomatically assembled CA micropanels weighing between 79 and 4,437 kg. There are six robotically assembled micropanels CR weighing between 231 and 1,072 kg. Most of the assembly of the micropanels occurs at this workstation. Although the panel P weighs 23,968 kg, the total of the built-up panel is 51,975 kg or about 52 tons. This means that 28,007 kg of the weight are micropanels and secondary steel elements, thereby making up more than 50% of the total built-up panel weight.

3.1.2. 2nd workstation. Sliding rails transport the partially fitted built-up panel to the second workstation (see Fig. 10). The fitting of

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Fig. 7 Collar detail

Fig. 8 Lug detail

Fig. 9 Fitting of micropanels to the large panel

Fig. 10 Transporting of built-up panel to workstation no. 2

Fig. 11 Fitting of the rest of the micropanels at workstation 2
the rest of the micropanels takes place at workstation number 2 (see Fig. 11). After the tack welding of the micropanels by ship fitters, complete welding sequence instructions are prepared so that the welders can immediately finish off the job with final welds.

3.1.3. 3rd workstation. At workstation number 3, the welders use overhead hanging welding equipment to easily walk around the built-up panel and finally finish off all the welds. This is highly man-hour intensive (see Fig. 12).

3.1.4. 4th workstation. At the fourth workstation, the fitting and welding of ships equipment such as pipe hangers, ladders and cable trays takes place. Likewise, any lugs or collars are also finished off with final welds as necessary (see Fig. 13).

4. Lean manufacturing and value stream mapping

The aim of lean manufacturing application is to transform present assembly line processes to lean ones. Value stream mapping is a logical tool to apply first. Although the built-up panel assembly process explained above functions correctly, a value stream map will identify wastes and critical areas where there are bottlenecks. The five main lean principles are identifying value from the customer’s point of view, identifying flow, creating flow, creating a pull system, and acceptable quality. The seven wastes are transport, waiting, storage, mistakes, over processing, overproduction, and too much movement, both in workers and materials. Wastes take up valuable shipyard space, consume shipyard resources and spend workers energy unnecessarily.

Additional lean principles include JIT, and built-in quality as well as kaizen. Applying JIT will eliminate storage. In Fig. 6 shown earlier is an example of storage of panels, which takes up valuable space in an already limited area of built-up panel assembly. Likewise, built-in quality means that during interim product assembly the process itself insures that the product is in compliance to all dimension and design characteristics. Finally, kaizen or continuous improvements means that proactive thinking needs to replace complacency to present assembly systems. In this way, the shipyard will be competitive on a world stage, because anything that
reduces non-value added activities saves time and energy for the shipyard.

4.1. Current-state value stream map

Value stream maps start from the top left which represents the prior process or the supplier. In this case, it is the panel assembly line. The triangle represents interim storage of the panels (Fig. 6). The thick vertical line represents the pushing of panels from the panel assembly line to the triangle regardless of whether the built-up panel assembly line can start to process them any time soon. The broken horizontal lines represent pulling of the interim product downstream along the workstations (see Fig. 14).

A table that lists the takt time, number of operators’, number of panels per shift, and total number of man-hours, represents a workstation. The formula for calculating man-hours is number of operators at the workstation multiplied by the takt time at that workstation.

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\text{Man-hours} = DT \times O \tag{4.1}
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where DT is the takt time or duration time at the specific workstation, and O is the number of operators at that workstation. The multiplication of the two yields the man-hours.

The proper panel pulled from the stack of panels requires sorting with the use of a crane. At workstation number one, the panel is marked with positions for the micropanels, which are also stored nearby the workstation.

Tracers mark the positions of the micropanels with string and chalk equipment. The fitting of the micropanels to those same positions by ship fitters, who also do the tack welding. Therefore, in Fig. 14 the first workstation illustrates that the takt time is 8 hours, with four operators. Therefore, applying equation 4.1, there are 32 man-hours. Exactly one panel is processed at workstation one during this shift.

Fig. 14  Current state value stream map of built up panel assembly (Kolich et al. 2016)

Fig. 15  Detail of slit system (Kolich et al. 2012a)
At workstation 2, welders weld the micropanels, already fitted and tack welded at workstation number one to the panel. The existence of overhead welding machines means that the welders do not have to carry around the heavy equipment, and instead it is very simple to move using the consoles. The takt time is 7 hours, and the number of operators (welders) is four. Therefore, there are 28 man-hours. Again, only one panel during a shift is processed.

The takt time of workstation number three is 9 hours and there are six operators, who are mainly welders. There are therefore 54 man-hours. The panel is not finished in one shift, since the takt time is longer than a shift of eight hours. Finally, at workstation four, the takt time is 6 hours; there are five operators, which includes grinders, cutters, and quality control workers. This equates to 30 man-hours. A crane transports the completed built-up panel to an intermediate storage place indicated by the yellow triangle on the right side of the map. In the large block assembly hall, the built-up panel is pulled from the interim storage when necessary. Here, assembly with other panels in the large block assembly hall as illustrated on the far right and top of the value stream map in Fig. 14 below.

The value stream map illustrates that the takt times are not equal throughout the process, which means that flow is not balanced. The takt time per workstation is 9 hours, since the workstation assembly duration that lasts the longest dictates the takt times for all of the other workstations. Only when workstation number 3 completes its 9-hour cycle can it pull the interim product from workstation number 2. The unbalanced flow results in waiting at the other workstations, which is one of the wastes identified in lean manufacturing.

4.2. Future value stream map

The current state value stream illustrates what type of flow exists in the built-up panel assembly process. The main wastes are interim storage identified by the triangles and waiting because of unbalanced takt time between the workstations. Likewise, inherent system wastes include excessive transport with cranes. There are also defects, repaired at workstation number four, and as a result, there are excessive movements. The existence of collars and lugs results in excessive overproduction. The elimination of these wastes in a future improved built-up panel assembly system insures greater efficiency.

The present large cut out details in micropanels require lug and collar installment, which requires intensive man-hours to fit and weld because there are many of them. Likewise, the system cannot be semiautomated as a result. The use of slit technology...
explained (Kolich et al. 2016) results in the elimination of lugs and collars (see Fig. 15). According to the lean principle of kaizen, this will force the quality control department to integrate better quality with smaller steel deflections. The application of hybrid-laser arc welding as opposed to MAG welding lends to smaller energy usage, filler materials and therefore greatly smaller deflections (Kolich et al. 2015b). This complies with slit technology.

The creation of an adjustable matrix-jig workstation is necessary in order to reduce excessive movements and over-processing, shown by the kaizen burst in Fig. 16. The setting of the distances between the railings of the matrix-jig reflect the values received from detailed design drawings. The placing of the micropanels is also in accordance to the production drawings. Special vice grips hold the micropanels together, on which they are tack welded. On the removal of the vice grips, the tack welded egg-box structure is transported to micropanel jig station No. 2. The completion of all horizontal and vertical fillet welding of the internal egg-box structure means that it is ready to be sent to the first workstation. The sliding of the internal structure by a special horizontal pushing system ensures the precise alignment of the small clearances of the slits with the longitudinal stiffeners of the panel at the workstation. This is also shown by the kaizen burst “integrated micro-panel is slid through the slots” in Fig. 16 above. The micropanel structure is tack welded to the panel. On final welding at workstation number 2, the built up panel is finished. The total duration time of 5 hours is an 84% improvement over the 30.5 hours in the current system in Fig. 14 above. The 52 man-hours is a 64% improvement over the 144 man-hours of the previous system. This is a result of the elimination of wastes, such as storage, and replacing with a supermarket-kanban system. The incorporation of matrix jig stations yields fewer movements and eliminates over-processing during the assembly process.

5. Conclusions

The lean transformation of built-up panel assembly results in significant man-hour and duration time savings of about 60 and 80%, respectively. Every vessel consists of both panels and built-up panels in large quantities, and the justification for shipyard investment in introducing these new methods and technologies is very strong. The key improvements are due to the incorporation of adjustable jig-matrix assembly workstations where the micropanels are assembled together. Likewise, the use of a slot system instead of cutouts results in built-in quality and therefore the elimination of hand markings on the panel. This reduces valuable manual labor; thereby making the sliding of the micropanel structure through the longitudinal panels compliant with the lean principle of built-in quality. The structure is tack welded, and then transported to the next workstation. Final welding activities take place at the last workstation. The significant improvement of flow of material and interim products results in a transformed built-up panel assembly process that looks and behaves as an efficient factory. Outfitting of built-up panels is the next step. In a future paper, it would be logical to continue this lean analysis with modular ship outfitting of the built-up panel (Rubesa et al. 2011).

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