LEAN ZAVARIVANJE U BRODOGRADNJI

LEAN WELDING IN SHIPBUILDING

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Sažetak: U radu su opisana osnovna načela *Lean* proizvodnje, koja se uspješno primjenjuju za unapređivanje suvremenih proizvodnih procesa. Razmatrana je mogućnost primjene *Lean* načela kod postupaka zavarivanja u brodograđevnoj industriji, posebice kod izrade dijelova brodskog trupa. Izneseni su preduvjeti za primjenu načela *Lean* proizvodnje kod zavarivačkih radova u brodogradnji. Također, komentiran je i odnos *Lean* proizvodnje s drugim metodologijama unapređivanja kvalitete, kao primjerice *Six Sigma* metodologijom.

Abstract: In the paper, the *Lean* principles and approaches, used in modern manufacturing for process improvements, are firstly described. Possibilities of application of *Lean* principles to welding processes in shipbuilding industry, especially in production of assemblies and subassemblies of ship hull, are evaluated. Prerequisites for method application in shipyard welding operations are examined and explained. Interaction and correspondence with other quality improvement methodologies, such as *Six Sigma*, is presented.

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1. INTRODUCTION

Recently, there are many examples of successful applications of production improvement methodology know as *Lean* manufacturing or *Toyota Production System*, *TPS*. *Lean* manufacturing evolves as an answer to production problems experienced in mass production practice, mainly in automobile industry in US. At the time, mass production is characterized by large overproduction and excess inventories which are pushed through production processes. Production is inflexible, usually producing one type of products in huge quantities. To overcome mentioned problems, and in the same time enabling flexible production of needed products, in quantity and quality, on time when they are needed, *Lean* manufacturing is developed.

Soon, achievements and benefits of *Lean* manufacturing in automobile industry became of interest to other industries, such is shipbuilding. Shipyards that introduced *Lean* manufacturing can provide several examples of successful *Lean* principles application in shipbuilding processes. In this paper, *Lean* principles as well as possibilities of application are examined on welding processes in ship hull construction.

2. MAIN *LEAN* PRINCIPLES

Lean manufacturing principles provide a way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively. In short, *Lean* manufacturing is *Lean* because it provides a way to do more and more with less and less – less labor, less equipment, less time, and less space – while coming closer to providing customers with exactly what they want. *Lean* manufacturing is based on five main principles [1]:

- Value for specific product should be precisely specified.
- The value stream for each product should be identified.
- Value flow should be made without interruptions.
- The customer should pull value from the producer.
- Production perfection should be persuaded continuously.

2.1. Product value

A key *Lean* principle is to understand the nature and degree of value that the market demands in order to avoid incurring costs not justified by corresponding increases in market value.

Exactly knowing the product value on market, as well as component of product value enables specification of value flow. The value flow is a path of product through production on which a value is added for certain product. Knowing value flow or value stream, it is easy to differentiate between activities that add-value and activities that doesn't add value to product.

2.2. Identification of the value stream and removal of inessential operations

In *Lean* manufacturing it is necessary to define true value stream for every product and to eliminate non-value added activities, which are usually divided into following seven categories, also known as *Seven wastes* in manufacturing [2]:

- Overproduction - producing more than the customer will buy which leads to excessive inventories.
- Waiting – excessive time waiting to proceed to the next step in the process, or idle time.
- Transportation – the unnecessary movement of material or product.
- Over-processing – unnecessary of inefficient operations.
- Inventory – excess inventory of parts and materials before they are required.
- Motion – non-value added movement of workers and equipment.
- Producing defective products – excessive defects and rework of materials, labor and overhead.

In the shipbuilding, production process improvement, for example, can be approached by:

- Increasing the speed of essential process steps.
- Eliminating unnecessary process steps and waiting time.

For the essential process steps that are to be speeded up, the idea is to reduce net working time by increasing the speed of physical production. Depending on the case, this is done via improved facilities, tooling, work methods, or other means.
Examples of eliminating inessential operations:

- Improvements in accuracy control to eliminate processing required due to extra material at the block joint.
- Training of multi-skilled workers to minimize idle time.
- Development of composite outfitting drawings to eliminate rework in engineering and production.

It can happen that a discrete shipyard process improvement will simultaneously increase the speed of an essential process step and also eliminate some other operations and/or idle time.

2.3. The value flow

The *Lean* ideal here would be continuous one-piece flow of intermediate products rather than batch production.

In shipbuilding industry this is achieved to some extend. In shipyard production, flow is based on blocks. Production processes are carried out block by block. So, although exceptions exist for plate nesting and for certain small standard components, the process is organized largely along a flow rather than a batch paradigm.

2.4. The customer pulls value from the producer

In essence of *Lean* manufacturing is that product should be produced only when customers needs it. In that relationship, customer is not only the final user of products, but customer is

each process in production chain which gets supply of materials and semi-products from its predecessor. Therefore, customer-supplier relationship should be established within production processes. When user of products or last customer in production chain pull the product, each production process is triggered to produced needed product.

Ship production is driven by pull at the top but by fixed schedules at lower levels. At the top level, the shipyard's production is based on the pull concept, as the shipowner's order pulls the final product and the shipyard is contractually obligated to deliver. It is not possible to start erection before the previous ship launches. There is thus a pull-style physical constraint preventing over-production at the uppermost level stages [3].

2.5. Continuous pursuit of perfection

One of the most important benefits achieved by *Lean* manufacturing is improved quality. The quality benefits comes because of the shorter feedback loops when the steel cut in a morning is actually assembled into a block in the afternoon same day, instead of weeks latter. With large batches of inventory many quality problems are hidden and only become visible when the downstream customers (e.g. the block assemblers) try to use the material and it does not fit. By this time the same problem have been made on many other plates or profiles and they are all somewhere in the pipeline [4].

Lean manufacturing emphasizes the efficient use of resources that shortens lead times and decreases costs by eliminating all non-value waste.
Also, it is critical to understand that no level of performance is ever good enough, and that there is always room for improvement. The main goal is to eliminate the root causes of variances while improving performance in periodic leaps that never end. Continuous flow and perfect quality were achieved together, after rigorous root-cause analysis and corrective action.
By clearly understanding these principles and tying them all together, managers can make full use of *Lean* techniques and maintain a steady course.

3. *LEAN* IN SHIPBUILDING

Lean focuses on the removal of waste so that all processes in the total system add value from the customers' perspectives. Although *Lean* was first developed in the automobile industry, it has been successfully applied in all industries by varying the tools used in its implementation.

The selection and application of specific *Lean* tools in shipbuilding will depend upon how the ship is designed. Ships, of course, needed to be designed for ease of manufacture and should be based on standardized modules [5].

In *Lean* manufacturing waste is anything that adds to the time and cost of making a product but does not add value to the product form the customer's point of view. Value-added activities transform the product into something the customer wants. In manufacturing this is generally physical transformation of the product to make to conform to customer expectations. Figure 1. shows a simplified version of the steps required to make a steel subassembly. Only the activities shown in dark gray add value. By add value it is meant that

they transform the product physically toward something the customer wants. The light gray activities are waste – they do not add value form the customer's perspective.

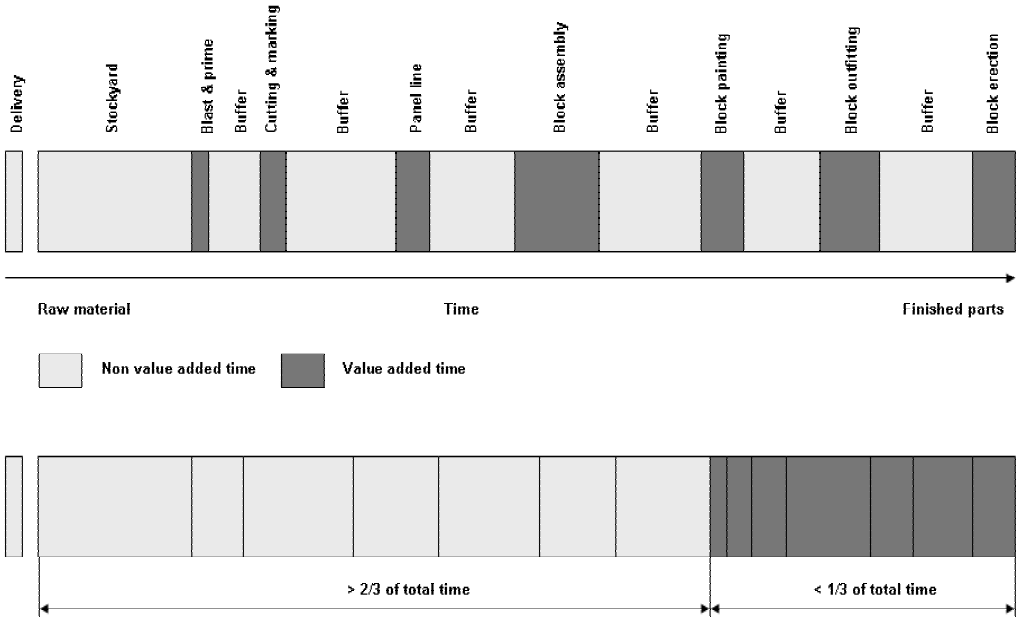

Figure 1. Elements of product lead time

To make the overall system more efficient, mass production thinking attacks the efficiency of value-added activities, for example cutting the steel. The total benefit of reducing the cycle time of value-added activities amounts to a small portion of overall lead-time, because value-added time is a small portion of total lead-time.

The *Lean* principles used in shipyards include Just-In-Time deliveries; *Lean* flow using takt time; staged materials; dedicated process lanes for major processes, such as built up profiles, subassemblies, flat blocks and curved blocks; build in quality; visual control; and people systems such as continuous improvement, multi-skilled workers and multiple machine/task assignment [4].

Successful application of *Lean* principles also brings high level of flexibility to production enabling shipyards comfort of producing different kind of vessels with all activities needed to change type of production performed in shortest possible time with the lowest possible costs. Thus, flexibility in modern shipbuilding become highly desirable features since new ships are large sophisticated products, typically launched as one-of-a-kind or in very short series [6]

When starting to implement *Lean* manufacturing it is usually good practice first to train personnel who will participate in *Lean* projects, and than immediately start with identification and removing of waste away from production lines. Also, application of 5S method is recommended prior to *Lean* manufacturing application, to organize tools and materials and develop visual tracking board to track key measures visually along side of lines.

Although, application of *Lean* manufacturing in shipyard should start on pilot lines, and than spreading to whole shipyard, full benefits from *Lean* are achieved when *Lean* principle are

applied not only on organization (shipyard) itself, but also along whole value stream, including first tire suppliers, second tire suppliers, and so on.

4. *LEAN* WELDING

Incorporating *Lean* manufacturing principles into welding operations offers a number of desirable benefits.

First, welding is often perceived to be an operation that is difficult to measure from a productivity standpoint. While numerous time studies could be conducted in an attempt to quantify the amount of time needed to produce a weldment, it is difficult to factor all of the variables, such as material irregularities, fit-up variations, and cleanliness of parts, which can have a direct effect on welding productivity.

Welding quality and productivity can be affected dramatically by both prior and subsequent operations.
For example, the joint fit-up and exact joint geometry can vary significantly, even when they are controlled within accepted tolerances. This causes difficulty when accurately prediction of the amount of time required to produce a given weld is attempted.

If welding is not done according to certain specifications, the as-welded properties of some components may be undesirable for subsequent operations, such as machining. Situations such as this make it very difficult to include welding in a production system that relies on the uniform flow of components, as they do in a *Lean* manufacturing environment.
The only way in which *Lean* manufacturing can be applied to welding operations that included welding is to ensure that all the prior operations that could influence the welding quality or productivity are studied and controlled carefully so the components presented to the welding cell are as uniform as possible. Likewise, the welding operation must be controlled to a degree that the resulting condition of the weld metal and weldments is as uniform as possible so subsequent operations are not adversely affected.

Consider much more that what is happening in the welding cell itself. While an initial study may show that the welding operation is the bottleneck for the overall manufacturing process, it is critical that the operation be carefully examined to ensure that the reduced productivity is not the result of inadequately controlled prior operations.

To apply *Lean* manufacturing ideas effectively, the overall operation must be studied carefully so that truly wasteful steps are eliminated and those that add value to the product are controlled carefully.

What manufacturers really want is flexibility. *Lean* manufacturing work cells must be adaptable to a mix of products. Robotics are particularly suited for *Lean* manufacturing since a successfully integrated manufacturing work cell has many of this concepts designed in from the planning stage.
Desirable approach to *Lean* welding can be through takt time planning, which enables that all parts of the process move in synch. That allows for flow production, which makes optimum use of resources.

Individual blocks are scheduled so that they will be completed just in time to construct grand blocks, which will be complete just in time for final ship construction in dry dock. All individual components for the block are cut and shaped and welded in kits that arrive just in time for block construction.
Takt time planning requires that all blocks have been designed and scheduled to be completed within the takt time. The way that moving time was determined was by calculating takt times and then designing the process so it could deliver blocks within that takt time.

The yard worker should be focusing on value-added work and materials and tools should come to the worker well presented for performing the work. An example – hanging welding units so they can easily be found and are right where the operator needs them to do welding work.

One simple example of value stream and non-value added activities in welding can be explained on panel production line.
To be able to gain leanness of production process it is necessary at the beginning to define value stream flow, and visually represent value making process. It is usually simple diagram as is shown on Figure 2., as an example for panel production line value and information stream flow.

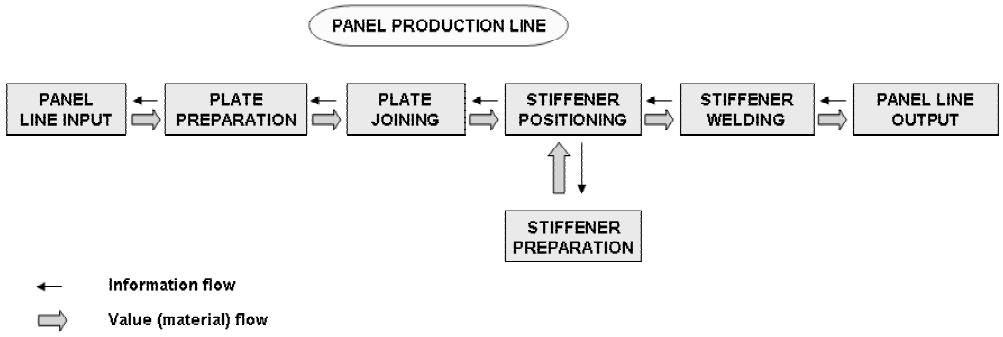

Figure 2. Panel production line value and information stream flow

Although, panel line represents one of best *Lean* organized welding processes in shipyard, there are also plenty of room form improvements. In general, panel lines are organized in conveyor manner, enabling one-piece flow. The next element can go forward only when preceding element has been moved, leaving empty space. This *Lean* principle is best accomplished, while other principles, like Pull or Kanban system, Just-in-time with other processes, including takt time specification, and elimination of waste, before all, are almost unknown. Those are point where can be much done and major benefits can be gained.
Two main directions for improvements can be:

- removal of non-value added activities, such as storage, marking, cleaning, etc.,
- improvement in performance of value added activities.

Second set of improvements usually involve significant resources and investments in new equipment, so the best approach is to level complete panel production line applying uniform takt time, and to make effort to remove all unnecessary non-value added activities and to minimize necessary non-value added activities such is transport.

As an example, on Figure 3. is shown a detailed diagram of panel production line with defined value-added and non-value added activities. It is obvious that some of activities marked as non-value added are necessary, but they should be evaluated and minimized as much as possible.

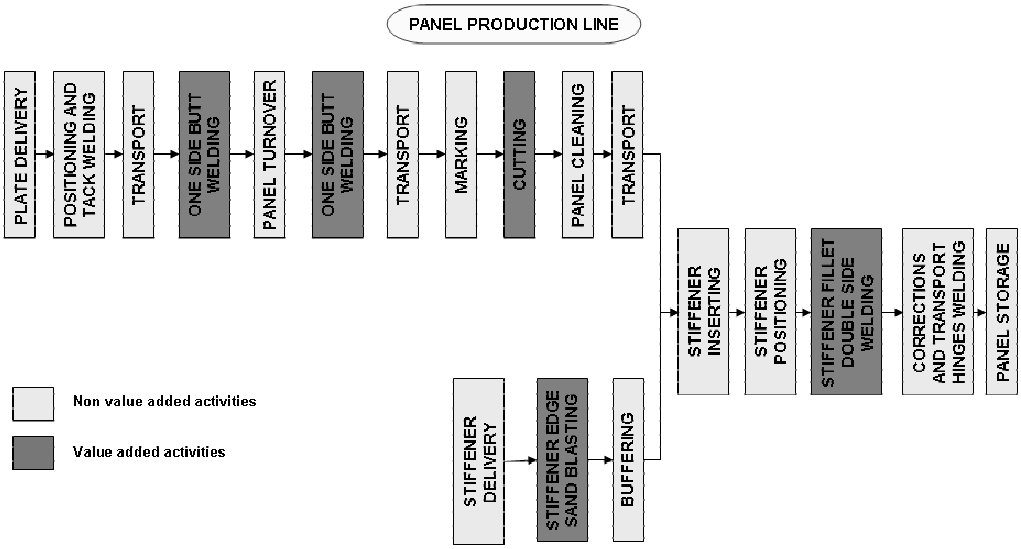

Figure 3. Panel production line value added and non-value added activities.

5. *LEAN* AND SIX SIGMA

The main emphasis of Six Sigma is the application of statistical tools in a disciplined manner, which requires data-driven decision-making. Six Sigma is about controlling processes to get the desired results. The target process can be any process critical to customer satisfaction and bottom line benefits [7].

One of the most powerful tools that Six Sigma offers to an organization is a structured approach to problem solving. A project's success depends on the careful planning and completion of each phase.

In the past several years many organizations realized that *Lean* and Six Sigma methodologies compliment each other. The integration of *Lean* and Six Sigma provides a rapid process improvement strategy for attaining organizational goals. When separated, *Lean* manufacturing cannot bring a process under statistical control, and Six Sigma cannot dramatically improve cycle time or reduce invested capital [8]. Together, synergistic qualities are created to maximize the potential for process improvement.

Shipbuilding is a distinct manufacturing industry. Unlike other manufacturing industries, shipbuilding does not produce mass quantities of its. It usually builds one ship for a long period of time, and most ships are different than the one before it. Also, the scale in which it must be built is unprecedented compared with other industries. These are the largest moving structures built in the world. However, one thing does make it alike most other manufacturing

industries – shipbuilding is a systematic process. In this way, each ship may be unique but is built using the same processes as its predecessors. This enables *Lean* Six Sigma to be effectively applied to shipbuilding and to produce significant gains in process performance.

6. CONCLUSION

Lean manufacturing is a philosophy, a way of thinking, not a set of individual tools. Moreover, *Lean* manufacturing requires an enterprise-level view of the value stream- from raw materials to the finished ship delivered to the customer. *Lean* production is a philosophy but what is most important is the process of involving associates in reducing the production flow by eliminating waste. If people are solving problems and continuously driving out waste then *Lean* manufacturing is alive and well.

There is every reason to believe that the *Lean* scenarios that have played out in other industries over the years will be duplicated in shipbuilding processes, including welding as a one of most important production process in ship hull production. Typically, when one company or one national industry commits to *Lean* principles and practices, competitors who do not become *Lean* are in trouble. They find themselves losing market share, profits and even the business itself. Together, *Lean* and Six Sigma are capable of improving the performance of shipbuilding processes and cultivating a culture o continuous improvement.

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