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edited by
Elio Padoano
Franz-Josef Villmer
Elio Padoano
University of Trieste
Pordenone, Italy
padoano@units.it

Franz-Josef Villmer
Ostwestfalen-Lippe University of Applied Sciences
Lemgo, Germany
franz-josef.villmer@hs-owl.de

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Department of Production Engineering and Management
Ostwestfalen-Lippe University of Applied Sciences, Lemgo (Germany)

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VALUE STREAM MAPPING TO MEET THE NEEDS OF MULTIPLE INDUSTRIES

V. Stanich¹, D. Kolich², N. Fafandjel²
¹Shipyard 'Brodosplit', Split, Croatia
²University of Rijeka, Faculty of Engineering, Rijeka, Croatia

Abstract
Shipyards in Europe, in order to maintain continual production of all of its facilities, must analyze ways to use the present production systems for the assembly of interim products for vessels as well as other types of industrial constructions. In the case of the shipyard analyzed in this paper, which has produced various types of vessels, the management is open-minded about meeting the needs for the civil engineering construction industry as well. The authors’ of this paper have analyzed the process of assembling interim products of a subsea construction for Venice using a value stream map (VSM). Applying lean manufacturing principles, the present lines of production are explained and certain realistic enhancements are drawn up and illustrated in a future improved VSM. Whereas, the present system will produce products which meet the quality and duration times of the customer, the new proposed system, illustrated in a future VSM, will decrease the non-value added activities as well. Therefore, the conclusion is that the VSM methodology developed in this paper will enable a shipyard to meet the needs of various industries and be competitive in quality, cost and delivery.

Keywords:
Value stream mapping, lean manufacturing, panel line assembly, civil engineering, shipbuilding

1 INTRODUCTION

Shipyards strive to improve the effectiveness and efficiency of their production processes in order to deliver quality products on time. Applying the principles of lean manufacturing to a production system is a significant way to improve the manufacturing efficiency of any type of manufacturing facility, including shipyards [1]. One specific tool that is used is value stream mapping (VSM) which is an illustrative display that readily identifies where waste occur in the production process. VSM visually displays all of the activities and identifies them as value added or non-value added. It can be used to map the assembly of interim products or an entire product from the beginning to the end of the process. Lean manufacturing principles demonstrate tools that can be used to assist in the identification and steady
elimination of waste such as excessive use of manpower, inventory and time. It becomes very important for companies which wish to produce a quality product in both an efficient and economic manner [2]. The implementation of VSM on production of a subsea protection construction for Venice is the subject that is analyzed in this paper.

2 BACKGROUND

The principles of lean manufacturing were originally created and developed by the Toyota Corporation as a process to eliminate waste during the manufacture of automobiles [3]. According to Shook [4] value stream mapping has four steps:

1. Determine the product families,
2. Create the current-state map,
3. Develop the future-state map,
4. Determine the plan for implementation of the future state.

With the creation of a VSM, visualization is enabled, which creates the ability to see where, when and how information, materials and interim products flow through the production assembly process. This in turn allows for the recognition of waste. Therefore in a future VSM at least some of the waste can be eliminated depending on whether the waste can easily be eliminated. Value stream mapping can be defined as the simple process of directly observing the flows of both information and materials as they occur, visually summarizing them, and then envisioning a future state with much better performance [5]. The VSM process involves identifying all of the waste in the value stream and then taking steps to eliminate them [4]. Optimization of the subsea protection construction for Venice process means working on the bigger picture and improving the whole flow and not just optimizing small pieces. With value stream mapping a common language for production process is created. The five main lean activities 5S are: sort, separate, shine, standardize and sustain.

3 CASE STUDY

In shipbuilding production process, both value-added and non-value-added activities are listed: value-added activities – welding, forming, machining, processing, assembling and painting. Non-value-added activities include scrapping, sorting, storing, counting, moving, and documentation transfer [6, 7]. To implement a VSM of the production of subsea protection construction for Venice in a shipyard surrounding, it is necessary shipyard lean transformation. Value stream maps should be representations of the actually
process flow instead of supposed; therefore it causes chances for development and recognition. Also it shows accurately the steps of process activates to complete timing of stages in production process.

The goals of this article is to demonstrate how lean manufacturing tolls, when used appropriately, can help the shipbuilding industry to eliminate waste, have better control, better product quality.

3.1 Problem description and approach

The shipyard produces roll-on roll off passenger (ROPAX) vessels, tankers, bulk carriers and heavy lift vessels. However, since the shipbuilding market is undergoing a type of crisis, where few owners are ordering large series production of vessels, the shipyard management is open minded about meeting the needs for civil engineering construction industry, while making maximum use of present shipbuilding facilities.

Subsea protection construction popularly called Venice protection doors will protect the Venice harbor against high tide and the raising of the sea level and flooding of the city.

The construction will be flooded and will rest on the sea bottom during the low tide season, not getting in the way of maritime traffic or anything else. However, during the period of high tides during the fall and winter, the seawater will be pumped from the watertight construction. This will result in the de-ballasting of the doors which in turn will thereby move to the vertical position. The height of the doors, while in the vertical position, will be more than enough to protect both the harbor of Venice and the city itself from flooding.

Subsea protection construction simulation is illustrated in fig. 1.

The interim products that make up the subsea protection construction for Venice have similar characteristics to the interim products of a ship. These include large panels, micro panels, transverse structural elements and outfitted components. There are some special positions that need to be machined, pre-heated and grinded, and the whole production process is very demanding for the shipyard to fulfill all of the requirements that are needed to satisfy the tender obligations.

In case of production and receptiveness of similarities of ship structural elements and subsea protection construction elements in the same shipyard facilities, it is possible to reap advantages of repetitiveness in the assembly of ship interim products.
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Therefore it is possible to analyze implementation of the VSM in the production of subsea protection construction. In the case study treated in this paper, the subsea construction includes a typical module of the dimensions: abt. 21m long, 4.6m height and 18.6m width. This in turn is broken down into technological interim products which can be assembled in different production lines at the shipyard. These interim products include 7 semi-automatically assembled large panels, 10 semi-automatically assembled medium panels, 27 automatically assembled micro panels and 90 manually assembled micro panels in the shipyard downstream processes. The total weight of assembled construction is about 290 metric tons and the shipyard plans to deliver one module monthly in next few years for a total of about 50 modular pieces of the same subsea protection construction that will satisfy the needs of the Venetian harbor.

As comparison to the production of the subsea construction, it will be presented production times for typically ship hull double bottom structure of the heavy lift vessel, which was the demanding product assembled in the shipyards workshops before starting the building the Venice subsea protection construction. Double bottom hull block dimensions are: abt. 26.5m long, 26m width and 2.15m height. The interim products include 5 semi-
automatically assembled large panels, 122 automatically assembled micro panels and 32 robotically assembled micro panels in the shipyard downstream processes. Total weight of assembled hull block is about 300 metric tons. Comparison of processed materials of heavy lift double bottom and subsea construction is presented in fig. 2.

![Pie charts showing processed materials comparison](image)

Figure 2: Comparison of processed materials.

Basically, there are differences between two processes, on the double bottom there were all automatic welding processes, while on the Venice subsea construction there was a good number of manually welded structural elements.

### 3.2 Production workflow

The shipyard workflow working hour is organized in daily shifts of 8 working hours. The month shipyard work period is 21 days, means 5 working days per week. Occasionally in case of short delivery timing, the daily working schedule is organized in two shifts of 8 hours working time in each shift.

The production of one subsea construction monthly is realistic and is in compliance with the construction delivery plan. In this paper, there is presented the second phase of assembly of the subsea construction, also double bottom hull block assembly process, after previously finished processes: plate and profiles delivery and storage to the yard, sorting, grit blasting and corrosive protection, labeling, cutting, leveling, and preparation of the plates edges for further assembly and welding.

The common pre-assembly process in shipyard semi-automatic welding workshop starts with panel line welding, where the first step is welding of the several plates in the large panel. For transverse gantry crane removing profiles from interim storage (IS1) (fig. 5) and lowering them on the panels for automatic welding process. Semi-automatic pre-assembly welding workshop consists of a number of different semi-automatic, robotic and manually welding machines, which work independently or are manually...
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operated by workers, but each machine works on a different task separately and simultaneously.

After welding the profiles on the panel, the stiffened panel is transported with conveyor rollers to the next production step, which is welding of the transversal structural elements pre-assembled on the automatic and robotic welding machines. Welding of the transversal structural element as stiffened frames is done on the semi-open hull block welding line. There are welders, grinders, fitters and repairers. Near the semi-open hull block line, especially for this project, a manually micro-panel welding line is organized. The line is supported with workshop gantry cranes and transportation vehicles. For this purpose, to organize the manually welding line, welders from other shipyard areas are relocated and organized in line, unlike conventional shipyard downstream process. After finished automatic, robotic or manually welding of the micro-panel, gantry cranes transport the micro-panels on the semi-open hull block/construction welding line (fig. 5).

On the semi-open block welding line semi-opened block is completed with transversal and longitudinal structural elements previously finished on the supported automatic, robotic and manual welding lines. After finishing the pre-assembly of the semi-opened construction, structure is transported by gantry crane on the interim storage (IS2) (fig. 5). Assembly of the construction is done in the pre-outfitting workshop and transported with transporters to the interim storage (IS3) (fig. 5) where it will be prepared after corrosive protection for loading on the interim storage (IS4) (fig. 5) as preparation for delivery on the transportation barge (shipyard activities 2015). In parallel, according to integrated hull outfitting and painting (IHOP) principles, the fabrication of pipes, passes, lifting lugs and special steel pieces that need to be pre-heated and grinded has to be completed. These pieces are removed from the pipe fabrication workshop to a separate workshop; specialist workers for these steel types are not permanently positioned in the standard pipe workshop. Instead of moving workers, the necessary special steel element that need to be specially heat treated are removed between the two workshops. On the assembly line, there are steel plate welders, grinders, repairers, fitters and pipe welders.

Assembled construction will be transported to the Venetian harbor (fig. 5) while ship hull block (fig. 4) will be transported to the erection area.

4 VALUE STREAM MAPPING (VSM)

In preparation of value stream map (VSM) the logical and simple step is the grouping of interim products. The first step is the selection of the product family. The second step is the current state mapping in order to understand how the process currently operates. It is the foundation for the development of the future improved state [2]. In the future state the aim is to enhance lean flow of materials and information. During the production of subsea protection construction module, according to the product family breakdown, four
production areas are identified: automatic assembled large panels (AALP), automatic assembled panels (AAP), automatic assembled micro panels (AAMP) and manually assembled micro panels (MAMP). In order to shorten the production time and reduce man-hours, it is important to create a VSM of the actual production state, and then find possible interim products that can be produced on the same production areas. The idea is to define where improvements can be made as well as consolidating them into new and improved processes.

4.1 Current value state map
All necessary data related to the selected production process of the subsea protection construction module have been collected. Fig. 3 shows a legend of VSM symbols; fig. 4 displays the current state value stream map of conventional hull block assembly line; fig. 5 shows the current state value stream map [7, 8] for the subsea protection construction. During the production of ship hull block, according to the product family’s breakdown, three production areas are identified: automatic assembled large panels (AALP), automatic assembled micro panels (AAMP) and robotically assembled micro panels (RAMP).

![Figure 3: Legend of VSM symbols [7, 8].](image-url)
Figure 4: Ship hull block current state value stream map.
Figure 5: Subsea construction current state value stream map.
The VSM is read from the left to the right. The customer is in the top right; the processed steel plates and profiles are on the top left. In the current state process the flow of information is drawn back from customer to the production engineering and control and then to the processed material storage corrosive protected plates and profiles, welded on the panel line and prepared for the next production step.

Regarding monthly production planning, semi-opened hull welding line is prepared (ordered) by steel supplier on a three month basis.

In pre-assembly production process, material was removed from the interim storage (IS1) (fig. 5) after welding on the panel line to the automatic micro panel assembly line, manually micro panel assembly line, or in the case of the hull block assembly, to the robotically micro panel assembly line (fig. 4). The takt time, the changeover time (C/T) and the number of operators are listed under each workstation. For the automatic micro-panel assembly line, the takt time for hull block is listed as 90 min with 4 operators (fig. 4), while for the subsea construction takt time is listed 240 min with 4 operators (fig. 5). For hull block there is robotic micro-panel assembly line listed as 120 min time with 6 operators (fig. 4), while manually micro-panel assembly line for subsea construction is listed as 420 min with 6 operators (fig. 5) in two shifts. For hull block pre-assembly line is listed in 2700 min (45 hours) with 20 operators on the line (fig. 4), while on the subsea construction pre-assembly line is listed in 4500 min (75 hours) with 20 operators (Fig. 5). Semi-open block is transported to the next step of production process where is stored in the interim storage (IS2) (fig. 5).

In this workshop, the assembly line is organized for the 50 random pieces for subsea construction. The same process was used for the hull block pre-assembly with workshop cranes. The assembly process for hull block is listed as 3600 min (60 hours) with 10 operators (fig. 4), while subsea construction is listed as 4950 min (85.5 hours) with 20 operators (fig. 5).

After assembly, both hull block or subsea construction are equipped with outfitting components and corrosive protected and stored in the interim storage (IS3) (fig. 5), where they are prepared for the erection process (Fig. 4) or loading on the transportation barge (fig. 5).

Calculation of the duration time is done by adding timeline segments of all production process activities. Calculation is done by 'conventional process method' in eq. (1) [7, 9]. 'Man hours are calculated by multiplying processing time of each process with the number of operators' [7], see eq. (2).

\[ DT_{\text{Total}} = DT_1 + DT_2 + DT_3 + DT_4 + DT_5 + DT_6 + DT_7 \]  

(1)

\[ \text{Man-hours}_{\text{Total}} = DT_1 \times O_1 + DT_2 \times O_2 + \ldots + DT_7 \times O_7 \]  

(2)

'\( DT_{\text{Total}} \) is total processing time, \( DT_{1,2,3,7} \) are processing times of the different processes, and \( O_{1,2,3,7} \) are the number of operators' [7].
Production lead time for hull block assembly is 11.58 hours, while processing time is 108.50 hours. Production lead time for subsea protection construction shows 11.70 hours, while processing time is 168.50 hours. Comparison of the production times shows differences between these two processes. Both values increase in case of the production of subsea protection construction. For subsea production construction process there was not only for this project an organized manual micro panel welding line, also welders where removed from other workshops. In pre-assembly workshop was organized production line for 50 pieces of Venice subsea protection construction, there were positioned specially turning devices, steel preparation tools and NDT (non-destructive testing devices), while production process of the hull blocks uses all free workshop areas without any specific changes in shipyard downstream process.

### 4.2 Future improved value stream map

It is important to improve the current production process and reduce non value-added activities like setup time, movement of material in between the work processes and additional storage and processing of material. It is very important to have close monitoring of processes to reduce process variability (defects of the plates and profiles during welding, pre-heating, transportation). Efficient planned maintenance of all machines (regarding increased availability) and time reduction in all non-value-added activities are also very important in value stream mapping implementation. The future value stream map of the subsea construction is shown in fig. 6. It is necessary to improve flow and eliminate excessive transportation, interim storages time and unnecessary waiting, defects, ineffective motion. Improvements are made starting from the ordering of standardized processed steel material by kanban supermarket pull input. Because of the variable interim products in the shipyard production process, it is necessary to use standardized dimensions wherever possible. Steel suppliers will not deliver steel in one shipment, instead it will be created a kanban supermarket and steel will be delivered according to pull inputs from the production process. A prerequisite for this is standardization of steel dimensions in the design stage with Design for Production principles.
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Figure 6: Subsea construction future value stream map
In the production process, there are some improvements like parallel processes for automatic and manual welding line. Interim storages are avoided as much as possible; transportation routes shorten when the process is organized in the same transportation line of workshop. Kanban post, withdrawal kanban and production pull signal to production engineering and control and to the production stations means strongly improvement and efficiency of the production process. The OXOX represents 'load leveling' of process flow which is very important in undisturbed downstream processes flow [7, 9]. Production lead time showed improvements from 11.70 hours to 4.75 hours, improvements in production time changed from 168.50 hours to 93.0 hours (fig. 6). Comparing the results of the current state and future state for the subsea construction leads to results in terms of improvement in subsea construction production. There was no excessive production and fulfilling of interim storages in the future state, as was the case in the current state of Venice construction production. The continuous flow no longer requires interim storage between processes. The process flow in the line without unnecessary over production.

5 CONCLUSION

In the presented value stream mapping methodology a case study for the production of heavy lift hull block and subsea protection construction module for the Venetian harbor is shown. This VSM process, which incorporates the use of lean symbols and terminology, can be applied to any production process. Main concern of the value stream mapping is the inspection of defects and problem spots in similar construction production. From the future state map it can be determined that processing time but also production lead time are reduced in comparison to current state. It is achieved by applying the lean production tools and the implementation of continuous flow optimization. This new organizational change in process leads to increased net profit and acceleration of production and delivery. The presented future state needs to follow improved planning and documentation; the topics of the changes need to be better organized, more skilled workers organized as part of the standard shipyard downstream process in due time for achieving a more effective production process. Also unnecessary material transportation must be avoided and transport routes cut, as observed during the preparation of the current state map for subsea construction. For future research the authors would recommend a more detailed analysis of the assembly and steel preparation processes, in order to demonstrate where the actual improvements can be made.
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Hochschule Ostwestfalen-Lippe
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The proceedings of the fifth International Conference on Production Engineering and Management, held between October 1 and 2, 2015 at the University of Trieste (Italy), collects the works carried out by professors, lecturers, researchers, graduates and students of the University of Trieste (Italy), the Ostwestfalen-Lippe University of Applied Sciences, Lemgo (Germany) as well as experts from other European universities and from industry. The main aim of the fifth edition of the conference has been to cover a broad range of topics and to bridge the gap between theory and practice in the field of production engineering and management by offering an occasion where academia and industry could discuss practical and pressing questions. The conference therefore covers not only production technologies and management in a narrower sense, but also new aspects of additive manufacturing, of lean management, of innovation and product lifecycle, of supply chains, of quality improvement, and addresses sustainable and revolutionary developments in modern industry.

Elio Padoano is an assistant professor of Operations Management at the University of Trieste; he also teaches evaluation methodologies in master and doctoral courses. He has coordinated research projects regarding evaluation methods for capital projects, sustainable production and business process reengineering.

Franz-Josef Villmer is a professor for Engineering and Design at the Ostwestfalen-Lippe University of Applied Sciences; he teaches product development, project management, rapid development and innovation management. From 2011 to 2013 he served as president of the Academic Council of the International Master Program Production Engineering and Management.

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