International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:14, No:12, 2020

Time Compression in Engineer-to-Order Industry: A Case Study of a Norwegian Shipbuilding Industry

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***Abstract*—**This paper aims to explore the possibility of time compression in Engineer to Order production networks. A case study research method is used in a Norwegian shipbuilding project by implementing a value stream mapping lean tool with total cycle time as a unit of analysis. The analysis resulted in demonstrating the time deviations for the planned tasks in one of the processes in the shipbuilding project. So, authors developed a future state map by removing time wastes from value stream process.

***Keywords*—**Engineer to order, total cycle time, value stream mapping, shipbuilding.

I. Introduction

ENGINEER to Order (ETO) production is associated with large, complex project environments in sectors such as construction and capital goods [6]. ETO supply chain is regarded as a supply chain where the "decoupling point" is located at the design stage, so the customer order comes in at the design phase of a product. Nowadays, the shipbuilding market is too competitive in delivering ships with advanced technology, high quality and on time to customers. The problem is that shipbuilding industry needs to reduce the cycle time in order to increase the volume or throughput at the shipyard

During the 1980s and 1990s, many activities at the shipyard were outsourced. This generated many competitive suppliers in the industry [5]. Today as much as nearly 85% of the value of the ship is sourced value. Therefore, quite a large number of suppliers are providing different products, material, services and solutions to these shipbuilding companies. These companies also require the suppliers to remain competitive. As many shipyards outsource many of their activities to these suppliers in different scales, there is a growing necessity to compress the ships' delivery time along with integrating the suppliers into the shipbuilding companies in order to compress the total cycle time at the shipyard.

In this paper, the focus is on compressing Total Cycle Time (TCT) in the production networks of a Norwegian Shipbuilder, referred to as Norship by using the Value Stream Mapping (VSM) tool that integrates the value stream of a surf treatment supplier, referred to as Surftreat into that of Norship Shipyard. The integrated value stream shows the Value added (VA), and the Non-Value-Added (NVA) activities in the current value stream and serves as a base for developing a future value stream where the NVA activities would be reduced or removed gradually.

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II. Literature Review

The literature review starts with the concept of the TCT. Later on, the TCT is connected with the concept of ETO to explore whether Time Compression (TC) is possible in ETO. Then, lean construction is discussed followed by an analysis on VSM.

A. Total Cycle time (TCT)

TCT is defined as "the elapsed time between customer enquiry and customer needs being met is shown to be a fundamental driver in achieving enhanced business performance" [12]. Especially in the agile supply chain, TC has become an important key enabler. The approach of TC has become so powerful that it is now known as a paradigm.

Reference [16] also argued that in a construction supply chain, the TCT compression paradigm can be simply expressed as "the principle of reducing the time taken to execute a business process from perception of customer need to the satisfying of the need" [16]. Thus, it is assumed that this paradigm has a very important relevance to construction in the shipbuilding industry. An increase in productivity, an improvement in quality, a reduction in cycle time and an expedition of innovative products to market have been the primary objectives of TC [8].

B. Engineer-to-Order (ETO) Production

A widely used phenomenon in the field of industrial engineering is ETO. ETO manufacturers produce customer-specific products that require unique engineering or design work, or significant customization activities. Primarily, ETO production is associated with large, complex project environments in sectors such as construction and capital goods [7].

C. Lean Construction (LC)

Reference [4] defines LC as "the continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream and pursuing perfection in the execution of a constructed project." According to [15] waste in this context is understood as the actions and/or the use of resources or features that are not necessary to deliver a product or service to the customer. Wasteful practices consume resources but do not add value to the final deliverable. Reference [9] argues that "a coherent philosophy for lean construction has not yet been developed." However, [3] defines lean as "a fundamental business philosophy – one that is most effective when shared throughout the value stream".

D. LC Principles

There is ample evidence that the efficiency of flow processes in production activities can be considerably and rapidly improved through those principles [10]. The principles are believed to be crucial to LC. However, most of them also apply to lean manufacturing [11]. Reference [11] added that in general, the principles are applicable to both the total flow process and its sub-processes. In addition, the principles implicitly define flow process problems, such as complexity, in either transparency or segmented control. The principles are: 1. Meeting the requirements of the customer, 2. Reducing NVA activities, 3. Reducing cycle time, 4. Reducing variability, 5. Increasing flexibility, 6. Increasing transparency.

E. Value Stream Mapping (VSM)

Reference [14] explained that a value stream consists of all activities (both VA and NVA required) to bring a product or a group of products from the raw material stage to the customer. Reference [14] stated that VSM's ultimate goal is identifying wastes in value stream and eliminating them by the implementation of a future-state value stream that can be applicable in a short time period. Reference [14] stated that four steps are involved in VSM in order to design and introduce a lean value stream:

- Step One: Selecting a product family by focusing on one product family from the customer end of the value stream.
- Step Two: Drawing a current state map that serves as the basis for developing the future state map by using measurements such as cycle time, setup time and lead time in order to examine the production floor and to analyze the complete path a product takes [13].
- Step Three: Developing a future state map which demonstrates the output of the proposed changes based on the gaps identified in the current state map [17]. Drawing a future state map is done by answering a set of questions on issues related to efficiency and on technical implementation related to the use of lean tools [1].
- Step Four: Conducting a work plan to implement the future state map based on the differences between the current and future state maps [2].

III. Research Design

Research design in this study would be categorized as an empirical study. The empirical study uses primarily qualitative analysis although quantitative data from the companies planning and reporting systems also are used. The study and thus the findings discussed, analyzed and reported in this paper focus on the dyad relationship in the supply chain between a supplier of surface treatment, Surftreat, and a major Norwegian shipbuilder, Norship. The scope of the investigations and observations in this case study was narrowed down from focusing on analyzing all the production networks in Norship shipyard to being focused on the production network of the surface treatment.

A. Data collection

The primary data collection in this case study has been done through participants' observations, interviews with some Norship and Surftreat managements. To collect the secondary data for this study, several sources were used to obtain information i.e. websites of Norship Shipyard, Surftreat supplier and other maritime-related entities. These were information on internal presentations of the company, job descriptions, performance reports and visual images from selected pages in different information systems.

IV. Findings and Discussion

Empirical findings show that there are significant wastes due to the nature of the buyer and supplier relationship, buyers' feeble project planning, and a mismatch between planning and execution. All these findings show that the TCT of Norship's production networks is unnecessary high and there are opportunities to compress the TCT by integrating the key supplier's value stream into that of the shipyard.

A. TC in Norship's ETO Production Networks

Based on the empirical findings, it was clear that there were many deviations on Norship project's plan across the whole production networks of the shipyard.

Generally, Norship Shipyard needs to compress the TCT of the overall project phases in order to remain competitive and to increase the throughput of production. Therefore, the scope of the analysis was narrowed down to focus on the outfitting phase as it is the main value-added phase. The example of one supplier, Surftreat, should function as a model example to generalize from and to other supplier tasks and processes.

VSM was used in this study to integrate Surftreat's value stream into that of Norship. The integrated value stream would contribute significantly to remove the NVA activities and to reduce the TCT of Norship's project.

B. VSM Application

Step One: Selecting a Product Family

The focus was on one product family as the target for improvement. Based on a discussion with Norship, a decision was made to work on the tank in the outfitting phase of Norship's project. Moreover, the tank was selected because tanks were the most expensive work of Surftreat.

Step Two: Drawing a Current State Map

There were time deviations regarding executing the project tasks by Surftreat. The VSM tool was used in order to visualize the elements of a specific production process from door to door where Surftreat conducted its tasks on the tank to remove the NVA activities of the process.

Since the ship had been delivered to the final customer the current state map has been drawn based on the flow and sequence of the production process from Norship operating system (Synergi). This contained the necessary elements of the map, such as processing activities and NVA activities from the customer's point of view. Moreover, the time duration for each task in the current value stream was assumed by the project leading coordinator who was responsible for allocating time slots for each task in the project plan.

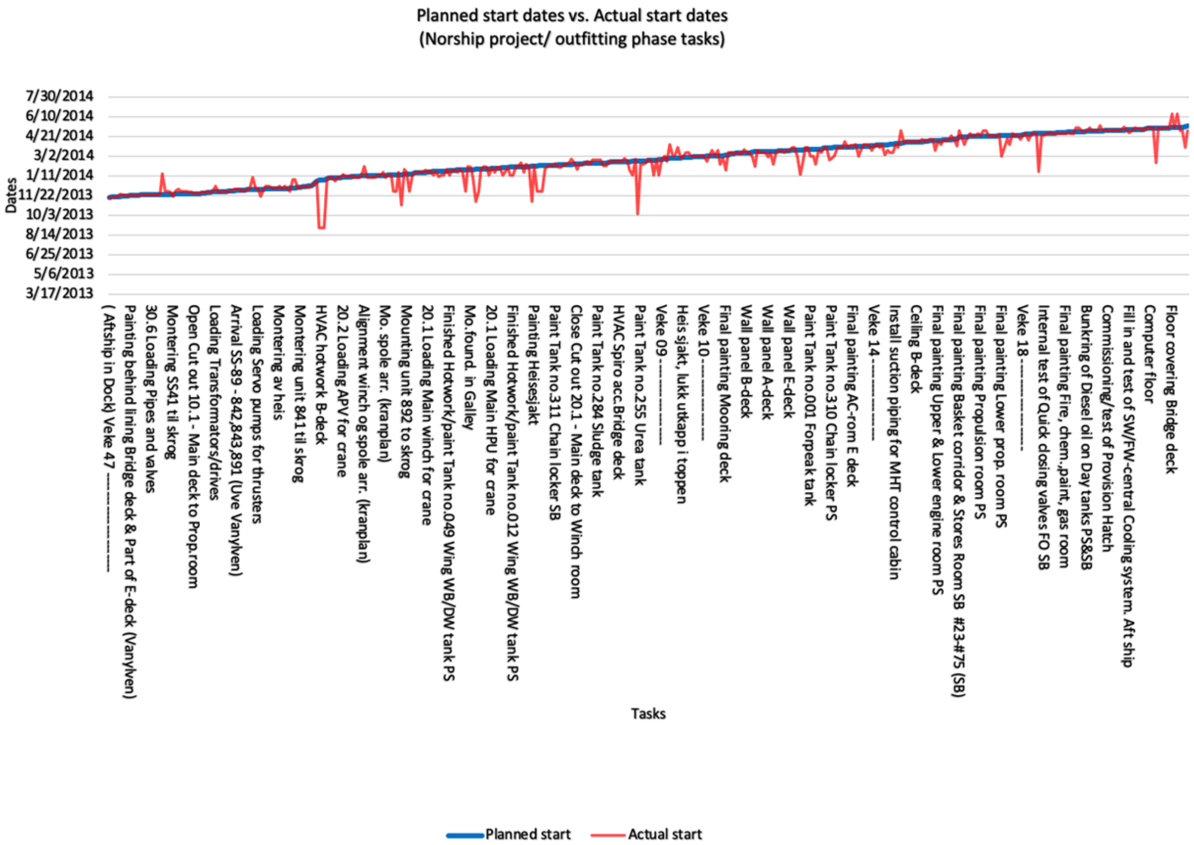

Fig. 1 Planned start dates versus actual start dates for outfitting phase tasks [18]

- *Current State Map Analysis*

The analysis of the current state map for Surftreat value stream focuses on the appraisal of the VA and NVA activities. Fig. 2 displays the Surftreat value stream for its tank tasks.

The elements of the supplier's value stream in the flow of information and raw materials into products consist of inspection, processing time, waiting time and reworks or/and repairs. Tasks in the current state map were linked together through arrows indicating the information and material flow alongside triangles representing the time a tank has to wait until it is processed by the following task. Regarding the duration, a specific number of man hours for each task in the current state was allocated at the bottom of each task based on the project coordinator's assumptions.

The lead time for tank tasks was displayed in arrows at the top of each task. Consequently, the total NVA times or waste were calculated by subtracting the total processing time from the total lead time for the tank production process. Processing times in the current state map were considered to be the VA time and specified based on assumptions of the project coordinator who was responsible for allocating time slots for each task in the project plan.

It was problematic to obtain the exact VA time from the processing time for each task. Therefore, as an approximation, the VA time was considered as the processing time. Moreover, the unit of time for each task is a man-hour and the unit of time for the current state map is a week, with each week representing 100 working hours.

- *Current State Map Analysis Results*

In the process of mapping the current state of the surf treatment processes of the tanks, the total duration average was around six to eight weeks to flow through the production process. According to the project plan, this process should have taken three weeks on an average. So, there was a time deviation from the plan. This deviation took place as a result of conducting several NVA activities such as inspection, waiting time, reworks and repairs. Moreover, as mentioned by a respondent from Surftreat, the tank tasks were considered to be the most complex works it performed.

Surftreat's VA activities in the current state map represented the processing time (44.5-36% of the total time in the production process) where value was added. Beside this there are all NVA activities—such as reworks or repairs (22-18.5%) conducted by Surftreat, required inspections (16-12.5%) conducted by Norship's production control and waiting time (17.5-33%) where no inspection, processing or reworks occurs. In other words, this means that only 47-36 hours of 100 hours per week add value to the tank as a final product, while the remaining 53-64 hours were NVA time.

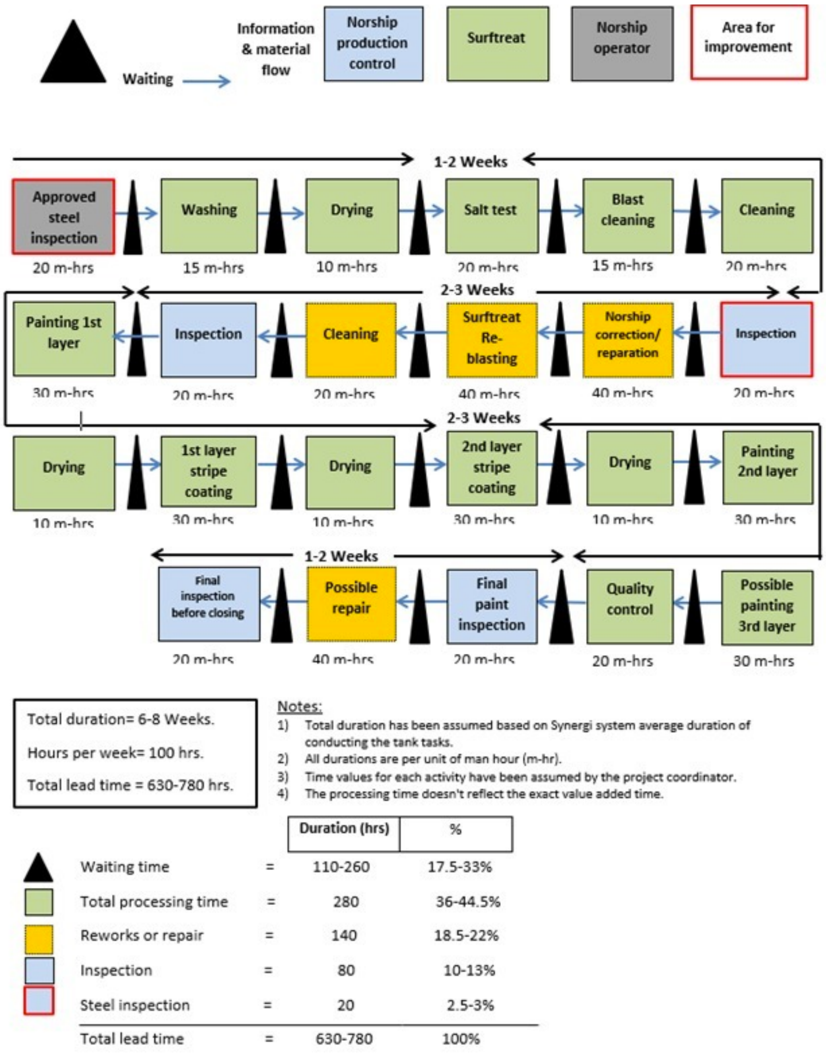

Fig. 2 Surftreat current state map for tank production process [18]

- *Causes of Non NVA Activities (Obstacles or Bottlenecks)*

NVA activities or waste refer to the total efforts of Surftreat that do not add value to the tanks as a final product from the perspective of the customer. There are several reasons for this:

1. *Inspection:* Norship conducted a crucial steel inspection to ensure that the quality of the steel met the quality standards. Therefore, NVA time was consumed for this activity. In case the steel did not meet quality norms, additional NVA time was consumed to repair and reform the defects.
2. *Repairs or reworks:* Surftreat primarily, alongside Norship, conducts rework or repairs. According to a respondent from Norship, those activities occurred due to defects in the quality of steel and inter-dependencies between the suppliers in conducting their tasks that caused delays and, in certain circumstances, damaged the work. In addition, details on reality and the requirements of work tasks by the planning department were missing.
3. *Waiting time:* Waiting time refers to the idle time in which no inspection, processing or reworks occurs. Delays in delivering the necessary material and information contributed significantly to the waiting time. Meanwhile, from the guided tour of the dock yard and several interviews with the participants of the production process, it had been observed that multitasking affected the waiting time in the production process. That is the interdependencies between the different suppliers.

Thus, a dilemma for Surftreat began as it needed more time to complete the second task and then come back to the first. This was another cause of the waiting time. It was believed that there would be scope for compressing the TCT and integrating the value stream of Surftreat into Norship's value stream by removing and mitigating the NVA activities such as inspections, waiting times, repairs and reworks from the current state map.

Later, a future state map was developed based on the current state map where the NVA activities were removed from the value stream. This future state map lets the value flow; the customer pulls the value instead of pushing and offers suggestions on how to implement this future state map.

Step Three: Developing Future State Map

An analysis of the current state map of the tank production process found that waiting time alongside rework and repairs were consuming more time than other activities. On the project plan, an average lead time of three weeks was required for Surftreat to finish its tank tasks while, the average actual lead time to finish their tasks on tank was eight weeks. It means that in the project's actual lead time, the waiting time consumed around one to two-and-half weeks, reworks or repairs consumed almost one-and-half weeks and inspection consumed one week. In total, five weeks were consumed for NVA activities from the customer's point of view. Therefore, a future state map in Fig. 3 was developed where NVA activities had been mitigated and removed from the current state map.

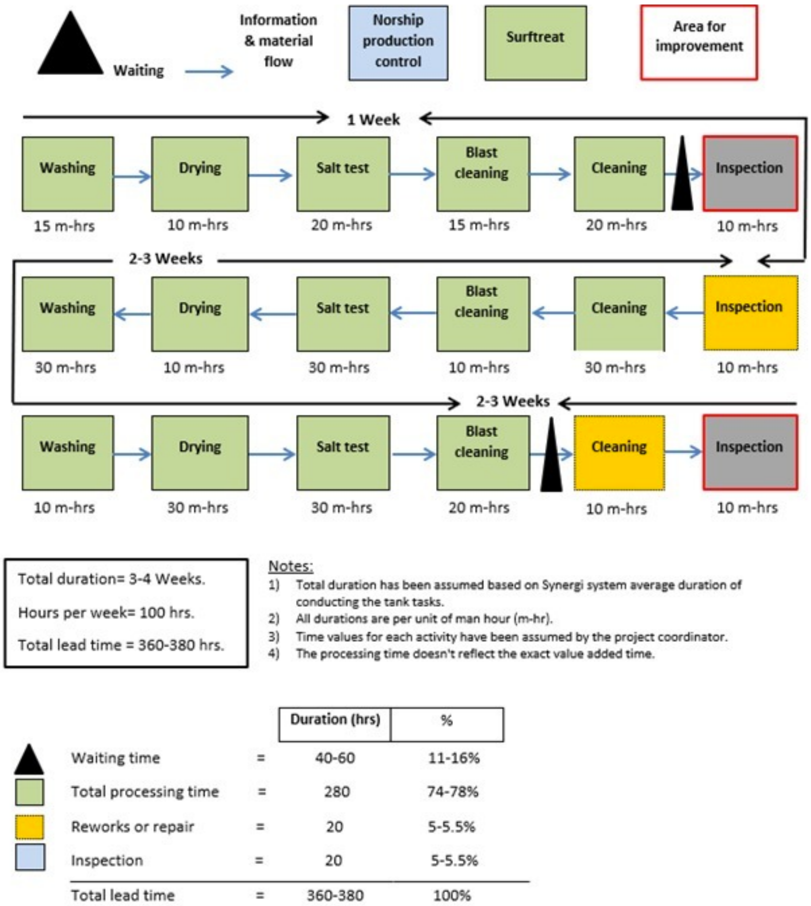

Fig. 3 Surftreat future state map for tank production process [18]

- *Future State Map Analysis*

Future state map for the tank production process was developed through the following three steps. 1) Elimination of the steel inspection activity from the current state map by shifting that activity backwards to take place in the source of the steel production, specifically in Poland. The actual lead time (630–780-man hours) for the tank tasks would be reduced by 2.5-3% (20-man hours), and the likelihood of finding defects in the steel quality will decrease and influence the time consumed for repairs and rework. 2) To improve the project plans for the tank tasks by taking into consideration the inter-dependencies between the suppliers while they conduct their tasks. This will significantly reduce the time consumed to conduct repairs or rework by 15-19% (120-man hours) from the actual lead time (630–780-man hours).

Repairs or rework can also be avoided by greater involvement of the project planners with the inner dock site. Reduction of the waiting time in the tank tasks by understanding clearly the realities and the requirements of the project plan tasks, integrating the information flow regarding the project plan tasks between Surftreat and Norship by using the same operating system (Synergi) and prioritizing the plan tasks to avoid multitasking influences on the waiting time. Thus, it will help in mitigating and reducing the waiting time by 17.5–33% (70–200-man hours) from the total lead time (630–780-man hours).

- *Future State Map Analysis Results*

The project's actual lead time in the developed future state map fell to 360–380 man hours from 630–780 man hours, the waiting time decreased to 40-60 man hours from 110-260 man hours, the time on rework or repairs fell to 20 man hours from 140 man hours and that on inspections (including steel inspection) dropped to 20 man hours from 100 man hours.

Step Four: Implementing Future State Map

Implementing the developed future state map alongside obtaining the actual results requires a long-time scale to be processed and executed. Such a time scale was not available and has been considered to be one of the case study limitations.

V. Managerial Implications

The responsibility for bringing about improvements in the value stream mainly belongs to Norship management. It has to understand its role in visualizing the whole flow, improve the future lean flow and take the lead to implement the program. Implementing the developed future lean flow has to be a part of everyday activities in Norship.

VI. Limitations and Suggestion for Further Research

The scope of the analysis in this project was limited to only one production network, i.e. the production network of the tanks in the shipyard. Apart from the scope limitation, there were time limitations in: Calculating activities' exact cycle times and VA time in the value stream because the authors were not able to be present when the activities took place at the shipyard. The implementation of the future state map was never a part of the research project but further research on the application of the implementation of the ideas presented in this study and especially the investigation of the integration of suppliers and the implementation of the developed future state map are recommended.

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