An Overview of Applying Lean Principles to Shipbuilding

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1. ABSTRACT: This study attempts to find and define the concept of lean manufacturing as one of the engineering management strategies that can be used by Egyptian shipyards to help them compete in this global shipbuilding market. It has been noticed from previous cases in world-class shipyards that using tools such as just-in-time, one-piece flow, and takt-time as a suite of lean manufacturing techniques helped improve product cycle times and quality by eliminating waste in the manufacturing processes. These techniques have also become the basis for lean manufacturing in the world. So, to assist Egyptian shipyards in deciding how to respond to lean shipbuilding, this study provided a comprehensive overview of the potential applications of lean manufacturing principles as a roadmap for those looking to implement it. Also, the method of introducing lean manufacturing was explained in a way that suits the Egyptian culture, as Egyptian shipbuilders rely mainly on the professionality of the workers but not the use of robots, as is the case in European shipyards. that makes the Egyptian shipbuilders think to implement the principles of lean manufacturing which is known now as lean shipbuilding. in addition, proposed procedures deal with some engineering management procedures that mean shipbuilders will not have to invest more money to get. an example of applying lean manufacturing tools through a block assembly line at one European shipyard has been presented.

2. INTRODUCTION

The global shipbuilding market was approximately 132.52 billion USD in 2021, and it is anticipated to reach 175.98 billion USD by 2027, according to the Industry Analysis Report 2021–2027. Furthermore, the article states that Daewoo Shipbuilding & Marine Engineering obtained orders worth $5 billion USD in February 2022 to construct two LNG carriers and six container ships for a European shipper. Also, Six brand-new LNG-fueled vehicle carriers will have their fuel gas supply systems ordered from Mitsubishi Shipbuilding in December 2021. China State Shipbuilding Corporation announced a significant set of vessel newbuilding orders in December 2021 for the construction of eight vessels and eight contracts for marine equipment projects totaling 1.9 billion USD.

The 1990s saw the publication of the book The Machine That Changed the World: The Story of Lean Production, which is when the phrase "Lean Manufacturing" first appeared. (Womack J.P. et al.,1991) The movement of manufacturing concepts from worker-based production through mass production to lean production is continued in this book. Although it has its roots in the automotive sector and the Toyota Production System, other production lines are now using it. Lean Manufacturing aims to decrease waste, boost efficiency and production, add value, lower costs, and boost competitiveness. achieving consumer satisfaction is the goal of this.

Lean manufacturing, which was first introduced within the Toyota Production System, is becoming more and more popular among manufacturers and across all industries. And this is not done by adding new methods to the way products are made, but by changing the way of thinking about production processes. And while switching to lean shipbuilding can be challenging, the results prompt shipyards to try it. The fact that ships are custom build projects makes the use of lean manufacturing principles in the shipbuilding sector particularly challenging. Probably not all of Toyota's lean tool application techniques will apply to shipbuilding, but the philosophy and principles can be applied with some adjustments. It is possible to observe a lot of the same principles used in the Toyota production system at work in shipyards by looking at models of world-class shipbuilding. For instance, Japanese shipyards use largely standardized modular designs with a steady flow of basic and intermediate products. Materials are precisely sequenced and moved through the shipyard using the Just-In-Time principle. also, instead of being examined, quality is built in at the production workstation. Processes are timed using takt time and are highly standardized. steel plates are brought in as just-in-time Instead of being transported into the stockyard months in advance.

The research problem is that Egyptian shipyards have not yet entered the global market, preferring to supply the domestic commercial and military markets. Despite advancements in the field of standardization and standardized production directed by intermediate products generated by the Egyptian shipbuilding industry. Its overall integration level is still below the world-class level. Additionally, the majority of shipyards still employ the conventional intensive production management technique. The competitive advantage declines as labor expenses rise.

Egyptian shipyards must adapt their manufacturing processes and rely on lean manufacturing philosophies and practices as a result of steps taken to increase their competitiveness. The Toyota production system, the underlying lean concepts, and the best applications of the lean methodologies, according to the author, will serve as a platform for modernizing the production processes used in Egyptian shipyards. This paper provides a framework for using the lean shipbuilding process' ideas. that is with the assumption that the ship is built to be producible according to lean principles is necessary for the application of these principles. The lean shipbuilding model will be used to describe the lean manufacturing philosophy. Additionally, some outstanding shipbuilding examples will be provided.
Egyptian Shipyards should increase productivity and shorten the production cycle in order to survive and become more competitive (JEFFREY K. LIKER 2004). using Lean manufacturing as an engineering management strategy to eliminate waste is one of the objectives of this lean thinking, which can improve customer satisfaction and turn waste into value.

2. LEAN SHIPBUILDING OVERVIEW

2.1 Lean shipbuilding Philosophy

Because it utilizes less of everything than the mass production method, this system is known as the "lean manufacturing system." To build a new ship in half the time, lean manufacturing uses half the labor force in the facility, half the manufacturing area, half the tool investment, and half the engineering hours. Toyota's Production System is based on14 principles under four sections, all beginning with the letter P. (Sharma, S., & Gandhi, P. J.2017). (Philosophy) each organization must have a long-term philosophy. (Process) The right steps will produce the right outcomes. (People) By improving their work, they must bring value to the organization. (Problem-Solving) Regular problem-solving results in structured learning. Eliminating the Eight Waste Elements has become the core of lean shipbuilding.

2.2 Lean Manufacturing processes

lean manufacturing processes are:
i) Identify value. This can be done using value management, and simulation.
ii) Map the value stream to make the product defined as the value flow.
iii) If at all possible, develop a process flow to avoid or minimize batch and queue.
vi) Establishing a pull system by adjusting production to customers' needs.
v) Seek perfection and continuous improvement.
Lean manufacturing seeks to shorten lead times and eliminate all forms of waste from the production process (Phogat, S. 2013). Lean production is achieved through a variety of technologies, including JIT, Kanban, cellular manufacturing, total production maintenance, kaizen, and 5s (Liker. J, and T. Lamb,

2002). In order to attain uniform production directed by intermediate products, industrialized nations like the United States, Japan, South Korea, and others have taken the lead in applying the philosophy of lean manufacturing to the shipbuilding sector since the 1980s. Lean manufacturing is a different production system that was established by Henry Ford on the Ford Motor Company's moving assembly line. The majority of industrial companies that specialize in important industries like cars, aircraft, paint, computers, and furniture are moving in that direction (Womack, J. P., et al., 1991).

2.3 Definition of Waste in lean system

Numerous manufacturing processes present the possibility of waste issues impacting worker productivity, product quality, costs, and production time (Fitriadi et al, 2021). Waste in lean shipbuilding is anything that increases the time and expense required to build the ship but does not improve its value in the eyes of the customer. Value-added activities make the product a desirable item for the customer. Figure 1 shows simplified steps required to sub-assemble the ship hull steel plates. Only activities displayed in dark green add value. The light green dotted activities do not add value from the customer's point of view. Since the value-added time makes up a small portion of the overall time limit, it is evident from Figure.1 that the overall benefit of cutting cycle time value-added activities is only up to a small portion of the time total. The efficiency of value-added activities may be attacked, as may be anticipated from mass productive thinking. One may, for instance, shorten the cycle time required to cut steel.

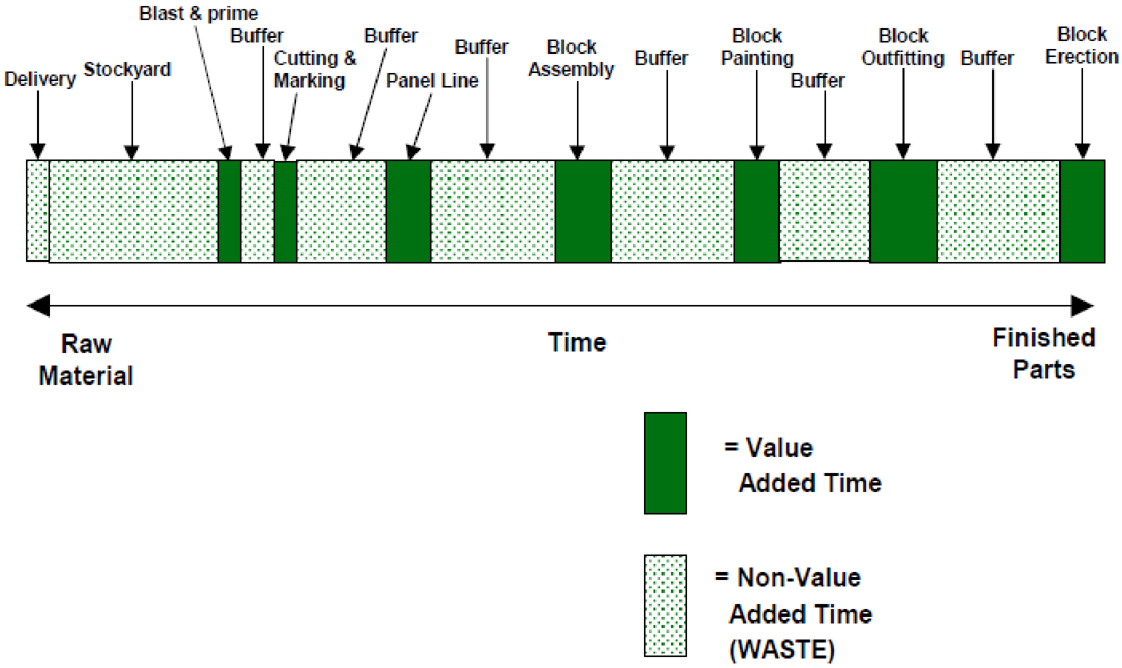

Figure 1 Elements of shipbuilding Lead-time (Liker,2002)

2.4 Lean Thinking

Lean thinking emphasizes the flow of added value and system effectiveness. The objective is to keep the product flowing and add value as much as possible, thus any portion that is in inventory is waste. (Poppendieck, 2002). The overall system and synchronized procedures are the main areas of concern to ensure that they are coordinated and produced at a steady rate. Lean shipbuilding is a manufacturing concept that, by removing waste, shortens the time between a customer's order and ship delivery. Figure 2 shows the results of the lean approach (Smith A, T. Y. 2015). Lean manufacturing decreases activities that are not just value-added, which has a bigger impact on lead time than reducing waste from value-adding activities, which will reduce waste as in the mass production strategy.

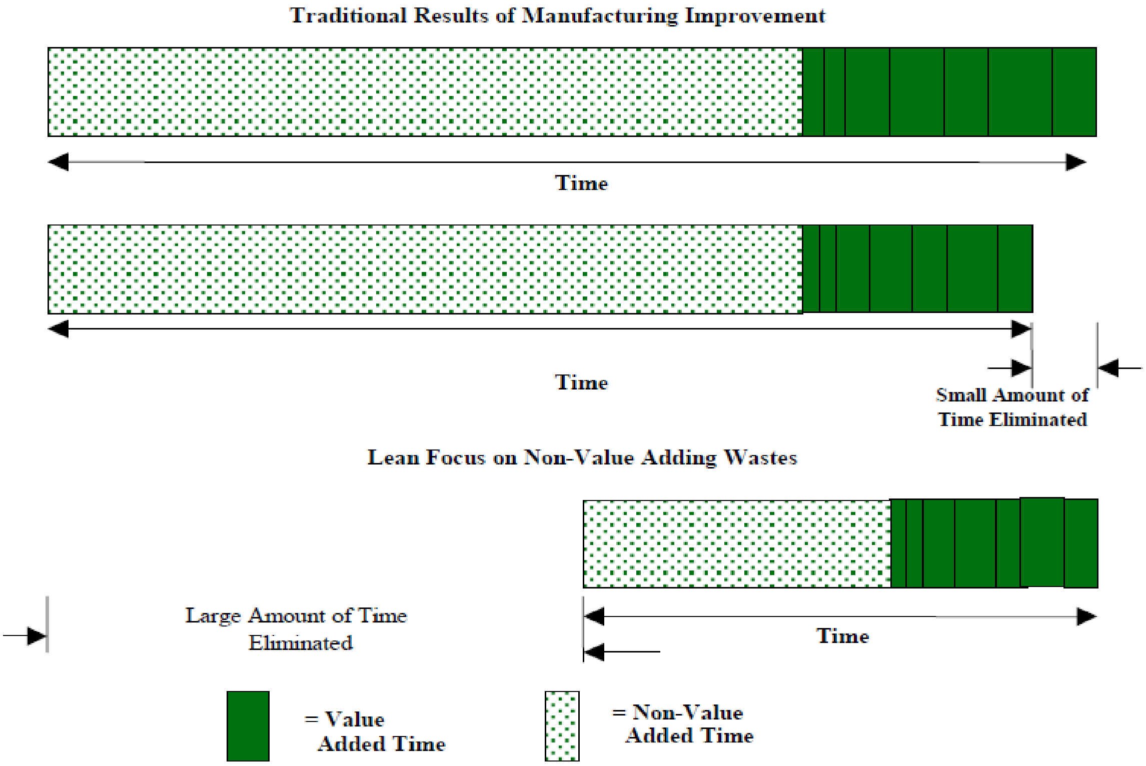

Figure 2 Traditional thinking vs Lean thinking (Liker, 2002)

2.5 The Eight Elements of waste (Liker. J, & T. Lamb, 2002)

i) Overproduction - the act of producing more than is required before it is required.

ii) Inventory - materials take up space, cost money, it is likely to be damaged.
iii)Waiting - waiting for materials, processes, or machines.
vi. Movement- any motion does not add value.
v. Transportation- transportation does not improve the value of the product.
vi. Defected product- unnecessary redundant operations to fix detects are waste.
vii. Over-processing- more work than the customers require.
viii. misallocated personnel- failure to allocate workers to work represents a kind of waste.

2.5.1 Overproduction in shipbuilding

In shipbuilding processes, the completion of the set of components naturally affects how quickly operations can begin. For instance, starting a block assembly requires the completion of all block components. But there is a possibility that a component was produced early waiting to produce other components to be processed in the next process. this condition is called shipbuilding overproduction. Overproduction refers to the production of components or work-in-process stocks too early, or too much (Ge and Kim, 2014; Harrison et al., 2014). Overproduction is the early termination of operations at a workstation in the shipbuilding industry, Reducing overproduction enhances production performance while also allowing the production line to get rid of surplus inventory (Longva, 2009). Overproduction has a detrimental impact on productivity and quality by causing an uneven material flow, which is the main source of waste (Harrison et al., 2014). Resources become more scarce for other uses because overproduction uses them up before they are needed. Furthermore, in this scenario, where the operational facilities are occupied by excess production, the overall cost of waste rises. Additionally, the utilization of resources for overproduction may result in an extension of the project's timeline. (Koskela, 2000), (Shahsavare, et. al 2021).

2.5.2 Waiting time in shipbuilding.

In shipbuilding operations, there is a high likelihood of waiting for work-in-process. For instance, a set of sections may be ready to form a block, but all the workstations may be occupied, or a sizable block may be waiting in line to begin the hull construction phase because there aren't enough workstations. The ineffective use of time in production processes is referred to as "waiting " as waste. (Harrison et al., 2014). When an activity is waiting to be processed because a workstation is not accessible, it is referred to as a wait in the shipbuilding industry. Waiting can drastically slow down production flow in the shipbuilding industry (Liker and Lamb, 2002). Waiting times do not allow for the best use of the scarce capital that some types of workers have access to in shipbuilding (Lee et al., 1996). Waiting for waste not only drives up overall shipbuilding costs but also lengthens project timelines (Koenig et al.,2002; Shahvari) , (Logendran, 2017).

2.6 Built-in quality

Built-in quality is superior to quality inspection and repair, and it is also less expensive. A set of statistical and problem-solving techniques that can assist in completing the task successfully are referred to as precision control, a phrase used in the shipbuilding industry. In the lean system, there is no buffer to use in the event of a quality issue due to the extremely low stock levels. Process B will abruptly cease if process A has issues, which is a problem made worse by a chain of processes. Figure 3 illustrates the issue of serial unreliability, which can lead to decreased system reliability overall. Four individually reasonably reliable processes (85% to 90% dependable) can cause this (62%). the concept of built-in quality is to allow only good parts to pass on to the next process. On occasion, a problem will arise, and if it is not swiftly fixed, it could shut down downstream activities. Therefore, the production line needs a mechanism to rapidly identify the issue and shut down the line in order to stop producing more defective parts.

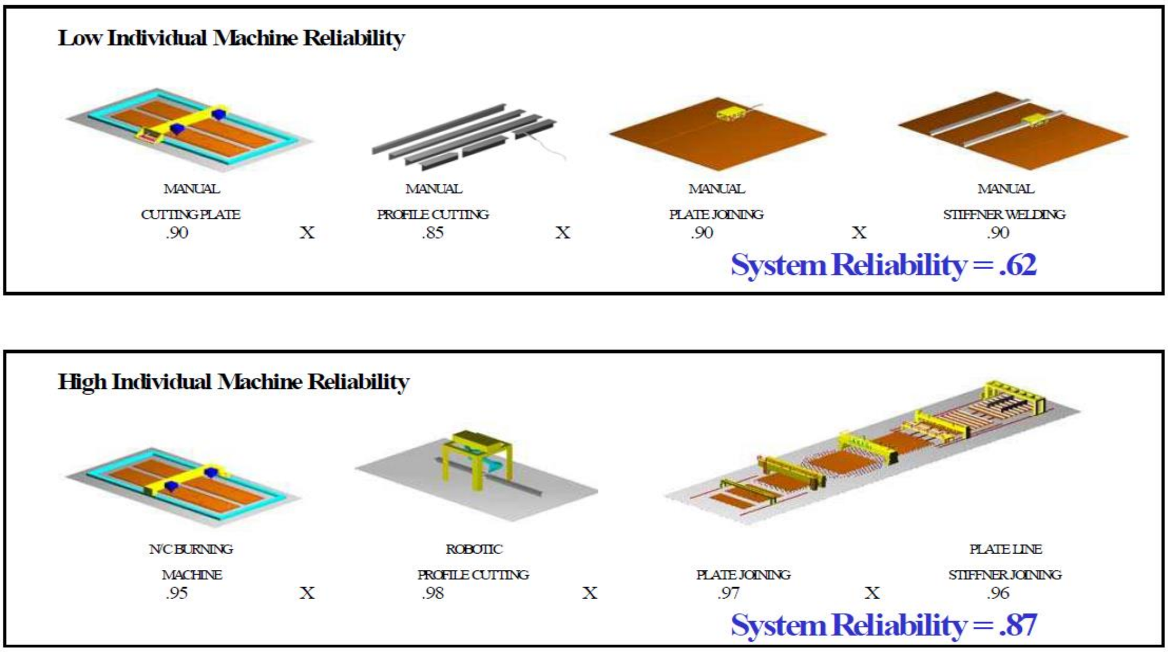

Figure 3 problem of serial unreliability (Liker, 2002)

2.7 Five S System

The stability of the workplace depends on its organization. Visual control can be exercised since it is easy to spot deviations from the standard when there are clear criteria for where objects belong. Lean 5S Manufacturing System is used to maintain cleanliness and order in the workplace:

Sorting- involves classifying goods, keeping only what is necessary, and getting rid of the rest.

Sort the items in the yard first, putting a red flag on everything that is rarely or never utilized and separating what is needed every day to accomplish value-added work from what is not. then bring them outside to the main holding area where it is assessed further. The other stuff is thrown away, while the usable items are organized at the store.

Straighten - assign a place for everything and everything in its place.

once items are narrowed down to those in regular use, they can be arranged close to where they are used and labeled so that it is easier to identify ideally. All materials must be well organized and use efficient storage procedures, use floor coatings, delineation work areas and locations, and shade boards.

Sweep - a type of inspection that reveals unusual circumstances and early failure.

The workspace must be completely cleaned after the clutter has been cleared away and the workspace has been organized, and keeping its cleanliness must become a regular habit.

Standardize (creating rules)

After accomplishing the first three S, it is vital to standardize the best practices to improve the operations' sustainability and achieve control over the first three S.

Sustain - maintaining the new quality through the upkeep of a steady workplace.

The process of constant improvement is continued in this cycle. Employees can easily pull things back since rigid procedures are difficult to change, making staying with the changes that have been made the hardest thing to do. For this reason, it's crucial to understand and improve the changing processes.

2.8 Best Practices of Lean Shipbuilding

The application of Lean principles in shipbuilding is not well documented in the literature. This is not to say, however, that there aren't plenty of instances from the shipbuilding sector where lean principles have been successfully applied.

i- Lean Shipbuilding in Japan (Phogat, S. 2013) By successfully implementing lean concepts and achieving improved production, product quality, and the exploitation of human resources, Japanese shipyards are now considered "role models" in the industry. Japanese shipyards are therefore regarded as being the best examples of lean thinking in shipbuilding. To the extent that it was practical, Japanese shipyards used JIT and a one-piece flow. Numerous circumstances now incorporate both lean manufacturing and Total Quality Management. (Koenig, p.c. et al. 2002).

ii- Lean shipbuilding in Norway (Bertelsen, Sven 2007) The shipbuilding industry in Norway is renowned for producing highly customized goods with a high level of outsourcing and little standardization. The combination of lean manufacturing and lean construction has been embraced by Norway Shipyard as a result of this specialization as a completely new idea of lean shipbuilding. The production and warehouse sectors also employ 5S. To enhance procedures, they use Value Stream Mapping.

iii-Lean shipbuilding in the U.S. (Liker. J, and T. Lamb, 2000) Lean Shipbuilding is a project that the National Shipbuilding Research Program has launched to increase efficiency and cut costs. Despite advancements in facilities and procedures, the U.S. Shipyard's performance is still subpar when compared to Japan and Korea, but there are huge gains to be made by fully implementing lean manufacturing principles.

iv-A shipyard in Mississippi (Liker, J.K. 2006) Lean was actively applied in the year 2000, and the outcomes were reported as a lead time reduction of 54%, a rework reduction of 80%, and a Productivity improvement of 29%, as well as the establishment of a Standardized work procedure for label plates.

v-Puget Sound Naval Shipyard By implementing one-piece flow in operations, improvements were made that resulted in a 60 percent decrease in non-value-added time, a 95 percent decrease in wait time, a 73 percent decrease in total lead time, a 70 percent decrease in paperwork travel distance, a 67 percent decrease in process steps, and an 80 percent decrease in workstations.

3. ROADMAP TO LEAN SHIPBUILDING

3.1 Build flexible, motivated, and capable Teamwork.

More reliance on humans, not less, is the result of lean manufacturing. A combination of committed management, suitable training, a culture that encourages the ongoing improvement of normative behavior, and the involvement of all employees are required to achieve this. An organizational structure based on work teams is necessary for maximizing employee engagement. Determining the workload involves operators who have been jointly taught, as well as job rotation and employees with the flexibility and ability to switch between operations.

3.2 Use the Just-in-Time technique.

By obtaining the correct amount of raw materials and creating the right amount of goods at the right time and location, the just-in-time manufacturing principle helps to reduce waste (Phogat S 2013 b)**.** The ideal for an on-demand production system is a one-piece flow (Kolich,et al.2012). Although this method is primarily used for mass production, elite shipyards, particularly Japanese yards, have adapted it. Therefore, a one-piece flow, as depicted at the bottom of Figure 4, is the best solution from the perspective of lean manufacturing. In this situation, you can work with one plate and one stiffener at a time, cutting only the material you need to pass it on, finish the cutting, pass it on, put the subassembly

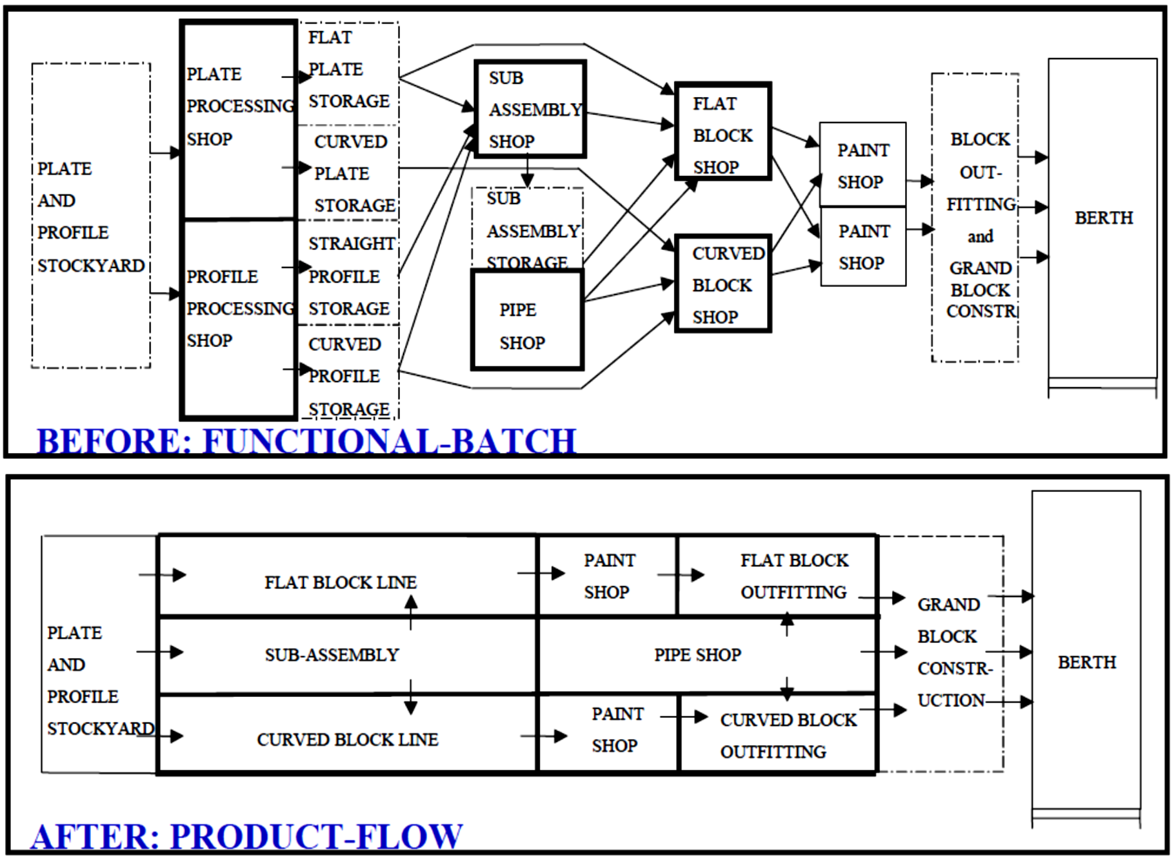

Figure 4 just-in-time in shipbuilding (Liker,2002) together, pass it on, and assemble the block. A larger perspective of the shipbuilding process is shown in Figure 4.

Egyptian shipyards have often been arranged according to their functions. For instance, all structures, whether curved or flat, are created in a separate workshop, and both straight and curved profiles are created in different workshops. large quantities of Panels and profiles are made, which are subsequently put into storage. After that, they are moved to the sub-assembly for sorting. Every component must go through the same paint shop, which frequently turns into a bottleneck. Figure 4's bottom half depicts a configuration that is common in lean shipyards. The yard in this instance is arranged by "product line." A production line does not refer to individual vessels but rather to collections of related components; in this scenario, flat blocks go through one set of operations while curved blocks go through a different set. For instance, all flat panels are cut in process lanes using straight profiles before being transported in tiny lots to the flat block line for assembly. The two separate paint shops are seen in Figure 4; one is for flat blocks and the other is for curved blocks. Then, flat blocks and curved blocks are prepared in different locations before being combined into a huge block assembly.

3.3 Use the Takt time technique.

One of the major advantages of continuous-flow manufacturing is the ability to give clients shorter lead times and enhance the usage of the shipyard, which results in increased revenue. depending on the size and complexity of the ship, Takt time might vary significantly from ship to ship. Similarly, each portion of a ship, which is made up of numerous distinctive components, may have a varied Takt time. It makes more sense to think of the ship as a collection of smaller pieces when considering Takt's period. Think about the following process:

i) How frequently does the ship need to leave the dry dock to meet the delivery timetable, starting with this one? Every six months, all components must be constructed just in time for a ship to emerge from a dry dock.
ii) Next, determine when each component must be finished to satisfy this delivery deadline. as a ship is made up of several different building blocks that must all be constructed simultaneously and more quickly than the ship. As a result, the ship's delivery schedule and the period of time it will be in drydock can be used to establish the block Takt time.

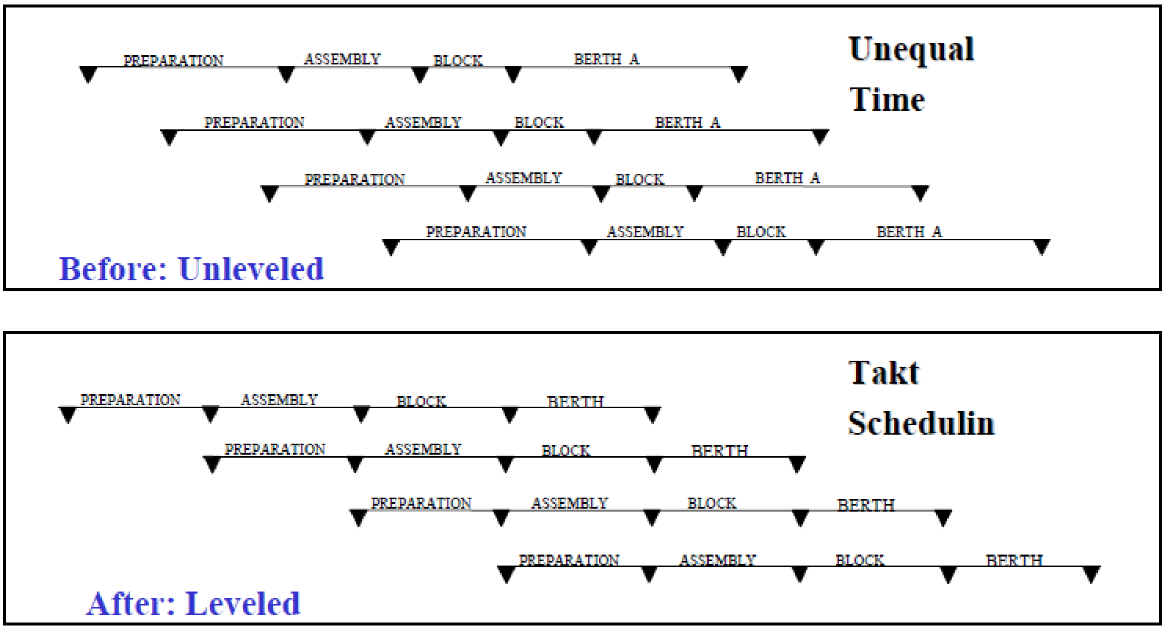

Figure 5 work leveling using Takt time (Liker, 2002)

The block's separate parts are all divided into groups that arrive in time to be assembled before being cut, shaped, and welded. The processing time asymmetry in scheduling is shown in Figure 5's upper portion, where none of the primary products are ready until they are required in later processes. As a result, there will be bottlenecks. The workflow when synchronized using Takt time planning, enables the creation of flows that make the best use of available resources, as shown in Figure 5's lower portion.

3.4 Use the Group Technology technique.

A processing philosophy known as "Group Technology" is founded on the idea that goods should be handled similarly if they are similar. A manufacturing system should be broken down into smaller systems as part of group technology. It decreases set-up time, delivery time, paperwork, tooling, rework, scrap material, and manufacturing lead time. It also decreases labor and work-in-process costs. (Shahin, A., & Janatyan, N. ,2010)**.** The conceptual model for Group Technology is divided into four parts:
i) processes: product categories, a coding system, categorization, design conformity, group production, group technology management, and the automated factory system.
ii) Intermediate factors include identifying the part family, standardizing the process plan, group scheduling, group tooling setup, reducing the amount of inventory that must be purchased, and using CNC machines. The work-in-process inventory, material handling, utilization of jig and fixtures set-up time, needed space, and quality are the secondary intermediate factors.
iii) Wastes in production include inventory, mobility, complexity, waiting, needless processes, and defects.
iv) goals: The major objective is to cut expenses and eliminate waste to increase productivity.

3.5 Use a simulation model.

Different scenarios for resource planning, scheduling, and investment planning can be tested and evaluated using a simulation model. The expense of finding the best solutions and the risk associated with making poor decisions in the real world can both be significantly lowered by using a virtual shipbuilding environment. (Krause, M., et.al, 2004).

Simulations procedures are:
i) Setting goals as simulations can be used for multiple goals, increasing productivity, assisting in new investments, reducing inventory, material flow analysis, manpower sizing,and continuous improvement of production.
ii) Collect the appropriate data.
iii) Build the model and establish the logic and procedures to represent the real system.
iv)Validate the form to check that the model is already working as a real system.
v) Run the simulation and collect the results, if you must, change some parameters and seehow the model behaves, otherwise, you will fall then back to step (iii).
vi) Analyze the results to aid decision-making.
vii) extract Final documentation with a detailed description of what needs to be done.

3.6 Applying Lean Manufacturing at European Shipyard (Kolich, et al.2012)

Traditional panel lines and built-up panel lines, which are still in use in many European shipyards, shall be transformed to apply lean manufacturing effectively. Combining lean concepts yields time savings and a reduction in man/hour, which immediately results in the shipyard saving a sizable sum of money. (Kolich, 2011) The classic block assembly lines seen in the majority of European shipyards are depicted in Table 1 below as being in operation.

Work station	description	Takt time (hours)	Coefficient	Takt time x coefficient = Man/hours
1	Forming a panel by joining and welding steel plates	4	4 seams x 2 workers x 4 panels = 32	128
2	The panel is turned over, and the other side is butt-welded.	4	4 panels x 2 workers = 8	32
3	Making longitudinal stiffener markings on the plate blanket	4	4 panels x 2 workers = 8	32
4	longitudinals fitting and welding.	4	4 panels x 2 workers = 8	32
5	Transportation to the built-up panel line and quality assurance.	4	4 panels x 1 workers = 4	16
6	using heat to turn and level	8	2 built-up panels x 2 workers =4	32
7	Transverse labeling, laying, and tack welding	8	2 built-up panels x 12 workers = 24	192
8	Welding of transverses.	8	2 built-up panels x 12 workers = 24	192
9	preliminary outfitting and grinding.	8	2 built-up panels x 10 workers = 20	160
10	final assembly of three-dimensional blocks before being erected on the slipway	16	11 workers	176
Total man/hours for complete block assembly				1000

Table 1 Activities of the block assembly workstations (Kolich, et al.2012)

According to the European model, the shipyard has to use lean manufacturing techniques, by applying engineering management procedures and using more new machines and robots, so, it was recommended for the shipyard under study to install the following machines in the block assembly line:

i) At lean workstation 2, install a High-grade fitting machine to do fitting up to four longitudinals simultaneously,
ii) At workstation 3, install four automatic welding machines on the girder to weld longitudinals on both sides simultaneously,
iii) At workstation 4, install three machines of one side automatic Flux-Copper Backing,
iv) at lean workstation 5, install Push-type insert equipment to push transverses,
v) at lean workstation 6, install four portable welding robots which are suspended from two girders.
The activities of the lean block assembly workstations are displayed in Table.2 below.

Work station	description	Takt time (hours)	Coefficient	Takt time x coefficient = Man/hours
1	unit plate trimming along the edges	1	5-unit plates x 4 panels x 2 workers = 40	40
2	The panel is turned over, and the other side is butt-welded.	1	5-unit plates x 4 panels x 2 workers = 40	40
3	Making longitudinal stiffener markings on the plate blanket	1	5-unit plates x 4 panels x 2 workers = 40	40
4	longitudinals fitting and welding.	1	4 one-sided seams x 4 panels x 2 workers = 32	32
5	Transportation to the built-up panel line and quality control	4	2 built-up panels x 20 workers = 40	160
6	using heat to turn and level	4	2 built-up panels x 5 workers = 10	40
7	Transverse labeling, laying, and tack welding	4	12 workers	48
Total man/hours for complete block assembly				400

Table 2 Activities of the lean block assembly workstations (Kolich, et al.2012)

4. CONCLUSIONS

The shipyard will best organize the processes if lean manufacturing is appropriately adopted. The space required by the shipyard production will be reduced, along with delivery time and consumed man/hours. Lean manufacturing and lean thinking are the keys to staying competitive in the global shipbuilding business. By using lean shipbuilding, the shipyard Block assembly line's production efficiency can be significantly increased. The best solution now available to increase production efficiency and assist shipyards, particularly small and medium-sized shipyards, is lean manufacturing. When opposed to automation, lean production is distinguished by its low cost, low investment, and significant advantages and reliance on professional workers, which is why this paper expects lean shipbuilding to be an excellent application when applied at Egyptian shipyards. In this study, a lean shipbuilding system that integrates lean manufacturing tools including just-in-time, takt time, and continuous flow operation was presented. Egyptian shipyard has the resources needed to implement lean manufacturing and fix the flaws in the conventional approach, which only focuses on plan scheduling and production process monitoring. By utilizing the lean shipbuilding methodology described in this paper, production balance may be significantly improved while staff and time waste can be significantly decreased. The current methods of shipbuilding are significantly altered by lean production, which represents the direction in which the shipbuilding industry will develop going forward. Future work will examine how lean can be implemented in the block assembly line and activity analysis in the lean shipbuilding system. also, to improve the production efficiency of shipbuilding enterprises and the market competitiveness of small and medium-sized shipyards, future work will focus on optimizing using discrete event simulation.

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