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AN INNOVATIVE THEORY OF CONSTRAINTS BASED APPROACH FOR IMPROVEMENT OF SHIPYARD PROJECT MANAGEMENT

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ABSTRACT

There is a major manpower requirement for process production in shipyard industry under hard working conditions with hazardous material. Shipbuilding period comprises cutting and marking of the steel plates, steel fabrication, assembly of the sections, erection on slipway, launching of the vessel, sea trials and the delivery of the vessel to the Owner. Block fabrication is the main production process in shipyards. It includes many kinds of inputs and interconnected processes and each process has an effect on the next stages of a ship's life cycle. Thus, a good planning ought to be developed to make an efficient producing process. Besides, due to the growing environmental awareness, new and innovative methods must be implemented in ship manufacturing. In this study, work-flow and data have been obtained from production stations of a shipyard, which has duplicate production concept, and critical chain, project and feeding buffers have been calculated. The obtained data has been compared with the results of calculation and result has revealed that the new findings have contributed to gaining a more fruitful production process.

Keywords: *Theory of constraints, bottleneck analysis, project management, shipyard.*

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KISITLAR TEOREMİ YAKLAŞIMIYLA YENİLİKÇİ TERSANE PROJE YÖNETİMİ GELİŞTİRİLMESİ

ÖZET

Tersane endüstrisinde ağır koşullar altında zararlı malzemelerle gerçekleştirilen üretim süreçleri için büyük bir işgücüne ihtiyaç vardır. Gemi inşaa süreci, çelik levhaların kesimi ve işaretlenmesi, çelik üretimi, blokların birleştirilmesi, kızakta inşa, geminin suya indirilmesi, deneme seferleri ve geminin gemi sahibine teslimi alt süreçlerinden oluşur. Blok üretimi tersanelerdeki en temel üretim sürecidir ve çok sayıda girdi ile birbirine bağlı ve gemi yaşam döngüsünde kendisinden sonraki süreçleri etkileyen alt süreçlerden oluşur. Bu yüzden verimli bir üretim süreci için iyi bir üretim planlamasının yapılması gereklidir. Gelişmekte olan çevresel duyarlılık nedeniyle yenilikçi yöntemlerin kullanılması da ayrıca önemlidir. Bu çalışmada tekrarlayan üretim konseptine sahip bir tersaneden iş akışı ve çeşitli veriler temin edilmiş olup kritik zincir, proje ve besleme stokları hesaplanmıştır. Temin edilen değerler, hesaplamalar sonucunda elde edilen sonuçlarla karşılaştırılmış ve yeni sonuçların daha verimli bir üretim süreci oluşturulmasına katkıda bulunduğu tespit edilmiştir.

Anahtar Kelimeler: *Kısıtlar teoremi, darboğaz analizi, proje yönetimi, tersane.*

1. INTRODUCTION

Shipping has the major part of the world’s total trade network and ships are the most efficient vehicles in terms of carrying capacity/energy efficiency. Thus, they are used widely for various purposes such as trading, fishery, cruising and military.

Ships are built and repaired in shipyards. Due to the rapid and positive changes in economic rate, shipbuilding industry grew dramatically during the last decades. New ship constructing and ship repairing have many independent and interrelated processes. There are different methods, such as Life Cycle Assessment (LCA), six sigma method and lean manufacturing, offered and implemented for shipyards in order to re-organize the manufacturing processes and thus, increase the general efficiency. Despite LCA generally focuses on all manufacturing phases and considers all phases as one in a holistic perspective, six sigma method is a project-driven management approach to improve the organizations’ products, services and processes by continually reducing defects in the organization. Lean manufacturing is an approach that aims to increase the production speed and thus, decrease the production time to improve quality, cost and delivery performance at the same time (Bilgili and Çelebi, 2013; Bilgili et al., 2013). In a recent study, a new method was offered which automatically extracts the most frequent task flows from transport usage histories. A clustering technique was used to identify heterogeneous groups of process instances and derive a process model independently by group (Lee et al., 2013). In another study, it is indicated that the assembly and welding process of curved blocks are done mainly manually, which has been bottleneck of ship construction. The first recommended method to overcome the problem is advanced design method while the second one is using flexible process technology and equipment. Precision measurement technology can be used as third method (Zhao et al., 2017). Park et al., (1996) developed an algorithm for the spatial block scheduling problem in Korean shipyards. Cho et al., (1998) describes an integrated process planning and scheduling system for block assembly in shipbuilding. Ozkok and Helvacioglu (2013) implemented some improvements on the current production system and the building time of a double bottom block was shortened. According to the authors, the rate of the improvement of the cycle time is about 100 % in theory. Kafalı et al., (2018) focused on planning block manufacturing, updating the initial plan by considering new performance values and developing a production control system in order to prevent excessive stock increase.

1.1.Theory of Constraints

Theory of Constraints (TOC) is another method that is used in different industries and sectors. TOC is a management approach that mainly based on small number of constraints, which limit achieving the goals of a manageable system. TOC is used to identify and describe the constraints and reorganize the system in order to fix the weakest link in the chain. Studies on TOC can be classified in several subjects. There are many studies on capacity constraints such as source, political and logistic constraints that are presented by the theory. There are some studies on the main principles of the theory such as Haystack syndrome, Parkinson law and multiple assemblies.

TOC was introduced by Goldratt and Cox (1984), and the authors identified and brought a principal innovation to production systems. TOC is based on the concept, which is the basic purpose of an organization is to make money today and in the future. According to the authors, there are six variables, three of them are operational (throughput, inventory and operating expense), three of them financial (net profit, return on investment and cash flow). TOC identifies that the improving the bottleneck of the system is the key for improving the total system performance. Şimşit et al, (2014) investigated the historical background and basic concepts of TOC.

In general terms, project management is a source planning, organizing and management discipline that is developed in order to finish the project at the projected time. Goldratt brings a new perspective to the project management in his book named 'The Goal' in which he tells the story of a factory manager who interference to the period that begins with a late-delivery and results with an improvement of production duration (Eliyahu, 1984). The perspective of the TOC for the business systems defends the opinion that the basic goal of a company is 'earning money today and in the future'. According to Goldratt, the goal and the necessary conditions and tools must be separated. For instance, customer service, product quality, and employee satisfaction, social and environmental responsibilities are generally necessities or they sometimes represent the tools of the organization performance (Eliyahu, 1990). TOC is a cornerstone of operational management. The main aim of TOC is to find a constraining or bottleneck in a production or supply chain. After identifying the constraint, the system and workflow is reorganized around it. The authors hypothesized that diversion times can be dramatically reduced and that these reductions can be sustained by applying TOC to patient care workflow (Strear et al., 2010). TOC represents an application of general systems theory for optimizing production. It uses the most constrained of the "rm's activities to guide production and process improvement decisions. Firms adopting TOC indicate that it has aided in reducing lead time, cycle time, and inventory, while improving productivity and quality (Kee and Schmidt, 2000). TOC, or synchronous manufacturing, is a very useful and valuable system in modern operation management. TOC methods provide companies a large reduction of work-in-process and finished-goods inventories, significant improvement in scheduling performance and substitute earnings increase. TOC also serves as a valuable addition to or even as a substitute for such well-known manufacturing systems as materials requirements planning (MRP) and just-in-time (JIT). The theory basically identifies the constraints and makes decisions on working with these constraints to synchronize a production process. System constraints can be workers, machines, market demand, company policies and regulation affecting a company. A physical constraint is usually a bottleneck resource- that is, any resource whose capacity is less than or equal to the demand placed upon it (Radovilsky, 1998). In a recent study, the implementation of the TOC rules for job-shop systems to advance the state of research on constraint scheduling in investigated. A number of simulation scenarios for a case study in the automotive industry are discussed providing insights into the master production schedule (MPS), the drum–buffer–rope (DBR) scheduling method, the role of setup times in scheduling, the impact of free products (those that do not use constraint resources) on throughput, and the effect of priority rules in resource assignment to free products (Golmohammadi, 2015). Šukalová and Ceniga, 2015 discussed the possibility of applying TOC in the distribution systems for analyzing the system elements (inventories, planning of sale, the suppliers' reliability) and evaluating major shortcomings.

A recent study aims to bring evidence that TOC induces significant improvements considering TOC's bottleneck management strategy through the DBR methodology. By contrast with traditional management policies, TOC provides wide operational and financial advantages for each node in the supply chain without any undesirable collateral effect (Costas et al., 2015). Aguilar-Escobar et al, (2016) analyzed whether the TOC can be useful and applicable to the logistics of medical records in hospitals. They reached remarkable findings, which presents a significant increase in the level of service and employee productivity, as well as a reduction of cost and the number of patients' complaints. Wahlers and Cox, (1994) present an analysis on selection or proper competitive factors and modification to a firm's performance measurement system through the production process. They also investigate the effect of modifications implemented to the traditional manufacturing planning and control model to TOC. Steyn, (2002) explained why TOC is initially applied only to project scheduling and studied on a secondary TOC application to manage resources shared by a number of concurrent projects. He also developed a sample application on the statement 'Employees tend to finish the work in the duration that is determined for the work or more. If no duration is determined, then finishing the work is extended over a long period of time'. Critical chain responds to this statement with a formation of a project management in which the possibility of finishing the work is 50 % and it aims to remove this basic contrariness. Leach, (2000) schematized the 5 major points, which are defined as; determining the constraint, deciding how to use the constraint, re-organizing the other activities according to the new decision, removing the constraint and control for any other constraints. Rand, (2000) developed a schema in which he compares the critical chain with PERT and critical way applications in terms of activities. According to certain principles, adding the existing safeness area to an end of a work after each activity that is predicted by critical chain application is examined with the results. It is clearly understood that this system shortens the project duration. Jacob and McClelland, (2001) indicated that the programs are created with a completion probability that is approximately 85-90 % in project systems such as critical way. Another indication is that the critical chain project management and the range of reliability are used in the duration in which the completion probability is 50 %. The authors also propounded that TOC doesn't use safety margin and thus, the process shortens comparing the statistical variation calculation. Steyn, (2000) in a sample theoretical application, presents schematically how the feeding and project reserves are included in a project. Radovilsky, (1998) calculated the reserve duration amounts in his study on feeding and project reserves. The study was made with finite elements method and the optimal duration is calculated.

1.2. Application of Theory of Constraints

Project applications of TOC remain limited in theoretical academic studies in Turkey; however, European and American companies and some government departments use this theory effectively. Competitiveness force the firms to produce faster, response the proposals as soon as possible and organize flexible production lines. The firms that have rapid response to the demanded productions keep one step ahead in supply and demand equilibrium and they increase their capacity by using the time that they gain from production process. These improvements provide the firms a situation in which they can survive in a world that becomes more competitive day by day. TOC is a management system philosophy that is created based on these parameters and the starting point is accepting that the performance of a firm is determined by constraints and understanding that every system has several constraints.

TOC claims that the main goal of a firm is 'earn money today and in the future. According to Goldratt, necessary conditions and tools must be separated. For instance, customer service, product quality, employee satisfaction, social and environmental awareness are generally appointed as necessities or they sometimes represent the tools of organization performance (Eliyahu, 1990). Figure 1 symbolizes a project system.

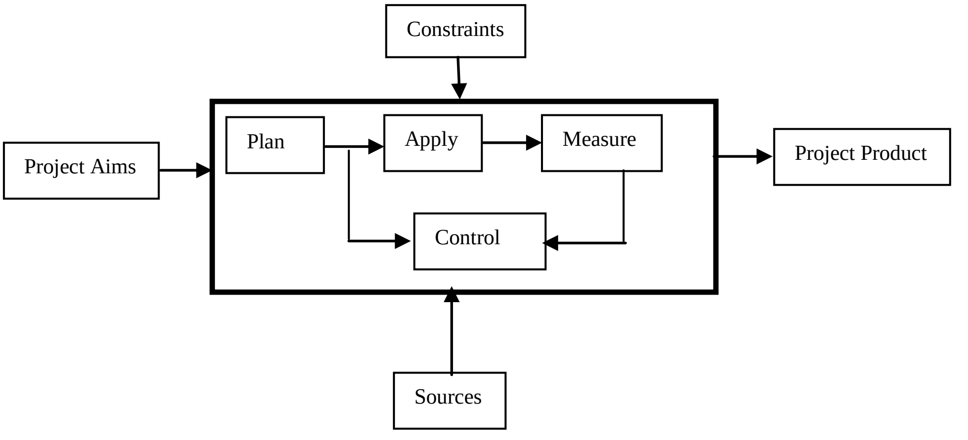

Figure 1: Project System Sample

1.3. Shipyard Processes

Great amount of manpower, complex work flows, variety of materials are the main points to describe shipbuilding industry as heavy industry. Production processes of the shipyards are divided into two main divisions: New building and ship repair industry. Production methods of these two divisions have similar characteristics. New ship construction and ship repairing have many industrial processes (Çelebi and Turan, 2011). Shipbuilding consists of cutting and marking of the steel plates, steel fabrication, assembly of the sections, erection on slipway, launching of the vessel, sea trials and the delivery of the vessel. In general, production type in the shipyards is block fabrication. In this production process, the vessel is composed of several blocks subject to the manufacturing and crane capacities of the shipyard. Each block is assembled in the workshops and after completion of the works and surveys; the blocks are erected on slipway. The vessel is launched after completion of all blocks' erection. The outfitting works of the vessel are completed in the sea and the vessels start their sea trials in order to test the efficiency and control whether they meet the requirements of the Owner and appropriate to the contract items. Consequently, the vessel is delivered to the Owner if the sea trial results can be accepted by the classification societies and the Owners (Turan and Çelebi, 2011).

In this study, the production flow of a shipyard, which has duplicate production process, is investigated in detail. The results of the new occurred conditions in case of applying TOC to a 1900 TEU

(Twenty-foot Equivalent Unit) container ship are assessed. In consideration of the shipyard data, the planned and real durations are investigated and calculated in detail. Following the investigations, the processes are enhanced, station duration, that occurred according to dates, are compared and the results are compared with TOC applications. The process improvement occurred due to the application of TOC in shipbuilding sector, in parallel with improvement, reduction of stock and costs, increase in practicability are the aims of this study. Figure 2 presents the flow chart of shipyard manufacturing and waste management plan. In Figure, processes on which Six Sigma and Lean Manufacturing can be implemented are presented such as Small Parts Production, Block Pre-Manufacturing, Block Outfitting, Block Manufacturing, Fabric/Harbor/Sea Trials and Tests. Error rates are tried to be reduced for each plate, pipe and profile production flow with the enhancement methods during Small Parts Production, Block Manufacturing and Block Outfitting processes. Waste management plan of the shipyard was formed with the former studies (Bilgili et al., 2013).

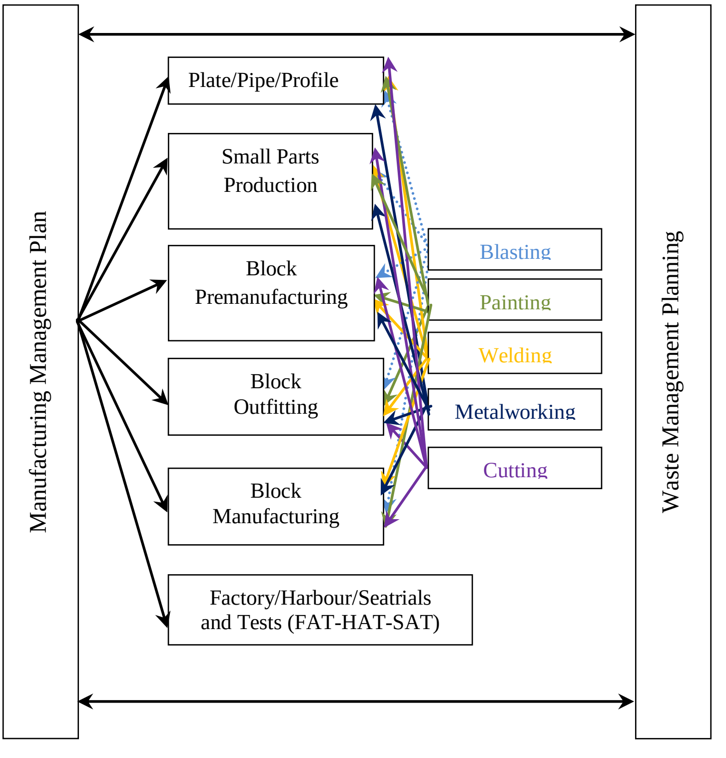

Figure 2: Flow Chart of the Shipyard Manufacturing Processes' Management Plan

2. SHIP MANUFACTURING PROCESSES FOR THE SHIPYARD A

This study was implemented in Shipyard A, which is located in Tuzla-Istanbul. Major improvements were developed in manufacturing plan of a 1900 TEU container ship. The length, breadth and draft of the ship are 180, 28 and 10 m, respectively. The 1900 TEU container ship is built based on block system. In order to compare the stations, there must be weight list per station. If the stations' weight lists are known, then it can be determined that which and how much equipment is needed. The weights of the blocks are determined by the design program. Due to the difficulties in production, the work load per tonnage in aft peak, fore peak and forecastle deck is much more than the work load in bulkheads and double bottom. This data is formed by using the information that is taken from production line. The calculated man-hour is 52,679. Man-hour calculation is the working capacity of the worker in an hour. The average number of workers is 80. Based on this data, it can be estimated that the duration between slipway block assembly and launching is 83 work-days. Calculating this data for all of the stations give the total situation of the ship. It can be known where and when the blocks stay and the total process is terminated with the correlation between previous and next data. Sheet steels are brought to the shipyard by sea or road and, by the help of warehouse personnel and riggers, they are placed to the stock field that is determined according to thickness and dimensions. Similarly, the profiles are placed to stock field according to their thickness and dimensions. After quality control, the sheet steels and the profiles are taken from the stock field by the special equipment. If the sheet steels are convenient for production, they are set to the conveyor, preheating and spray painting processes are made and after drying line the pieces are transmitted to the end of conveyor. The sheet steels that are painted with shop primer paint are sent to steel processing workshop. Figure 3 presents a flow chart of processes in shipyard.

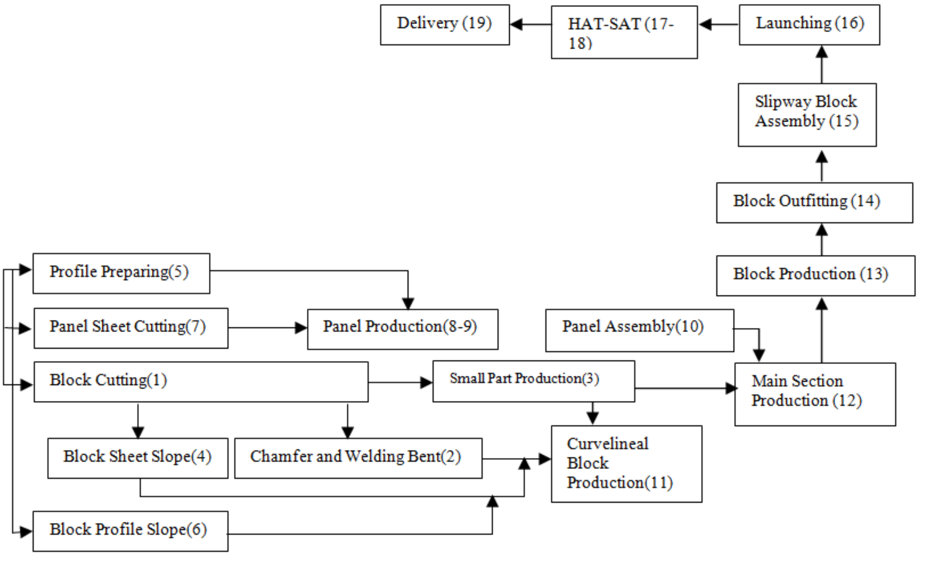

Figure 3: Flow Chart of Shipyard a Manufacturing Processes

2.1. Sheet Steel Curve Chamfer Profile Curve and Panel Cutting

After the cutting, the sheet steels are sent to press stock field as sanded in order to open a welding bent. During pressing process, wooden or chipboard molds are prepared pursuant to radii that are determined by CAD-CAM and these radii is used for bending process. All of these stages are applied to the profiles. There is also a cutting station for edge cutting of panels.

2.2. Small Group Pre-Production

A single plate and several elements are joined and the main object of this station is to make manual arc welding. In this station, turning the element and thus preventing overhead welding is possible. In this grade, the materials must be pre-painted, cut, curved, sanded and marked. The parallel production of starboard and port side materials makes the production faster. After finishing component production and sanding process, the material is sent to quality control and then, the next station.

2.3. Grouped Panel Production

Straight panel, curved panel or sub-groups and elements are joined in this grade. In this station, through joining the strengthened elements and joined panel sheet steel, front block production is done.

2.4. Block Production

The blocks are surrounded by board sheets that are prepared to production in the previous station. After this process, the blocks are turned down and sent to the paint shop.

2.5. Grade Painting

Considering the slipway montage queue, the blocks are sent to the paint halls. After finishing the welding, deburring and sanding processes, the block is sent to blasting and the surface is prepared for painting. After surface preparation, considering that the paint is flammable and can be deformed in high temperatures, the block is painted except the surrounding area or welded regions.

2.6. FAT-HAT-SAT and Delivery

In this station, the tests of circuit and related machine equipment and auxiliary equipment are made and these tests are called as harbor trial. In ship building sector, pre-delivery is defined as after finishing the feedbacks, which are determined between the customer and the shipyard via classification society, making the open sea trials that are realized several scenarios in generally two days period. The ship is delivered to the customer in this phase. Another ship's production flow follows the previous ship. After ending the production flow, it's possible to investigate the ship that is produced in this flow. The necessary data is completed with this investigation which shows how to calculate the raw and semi-finished materials.

3. RESULTS AND DISCUSSION

The determined and realized plan of the 1900 TEU container ship can be seen in Table 1. The determined plan is formed by project managers; the production durations based on the plan are taken from production monitoring programs. The 1900 TEU container ship is delivered after 217.66 days while the planned duration is 208.22 days. In

TOC, the flow plan is formed so that the stations follow each other's end point. Thus, while the work flow is being formed, the number of workers and capacities are determined considering the stations' weight. The planned dates are determined based on this information. Activities, which are applied until the first block is sent to slipway, are used as successive information for the work flow of TOC application. After sending all of the blocks to the slipway and slipway montage, activities are used as successive works.

Table 1: Real and Projected Results of Manufacturing Processes

JOB DEFINITION	REAL RESULTS	PROJECTED RESULTS
Block Cutting (1)	2 days	2 days
Chamfer and Welding Bent (2)	2 days	2 days
Pre-Production (3)	24 days	20 days
Block Sheet Slope (4)	4 days	4 days
Profile Preparing (5)	4 days	4 days
Block Profile Slope (6)	4 days	4 days
Panel Sheet Cutting (7)	3 days	3 days
Light Panel Production (8)	6 days	6 days
Panel Production (9)	6 days	6 days
Panel Assembly (10)	7 days	7 days
Curvilineal Block Production (11)	17 days	15 days
Main Section Production (12)	35 days	30 days
Block Production (13)	10 days	15 days
Block Painting (14)	5 days	5 days
Slipway Block Assembly (15)	80 days	80 days
Launching (16)	1 day	1 day
HAT (17)	40 days	38 days
SAT (18)	2 days	2 days
Delivery (19)	3 days	2 days
	217.67 d	**208.22 d**

Safety margin is determined considering that the completion possibility of the activities is 50 % and it is planned as projected in critical chain project plan that is based on the current project plan. The critical chain project plan is formed as 1-2-3-11-12-13-14-15-16-17-18-19with putting these tasks in order in project plan according to work queue. Critical chain gives the longest duration between the beginning and final days of a ship's production process. It is indicated that the source interference with capacity must be obstructed in the process. Labor force data is only used for the station that they are gathered from. The longest path is determined in the project in which source interference and 50 % completion problems are eliminated. The project and feeding stocks are placed by using the critical activities chain. The stock amounts are calculated by square-root method in manual project. Project stock is calculated by the following formula:

$$\sqrt{1^2 + 2^2 + 3^2 + 11^2 + 12^2 + 13^2 + 14^2 + 15^2 + 16^2 + 17^2 + 18^2 + 19^2} \quad (1)$$

As a result, project stock will be added to the end of the project as 50.5 days. Adding the project stock to the end of the project brings a need of the determination of feeding stocks' places. Feeding stocks are used in the points in which the sub-tasks take part in critical chain as primary activity. A one-day delay in the critical chain results a one-day delay in delivery, thus, the feeding stocks and amounts must be in consider during planning the project. There are 3 feeding stocks in this project. Sheet steel curve, profile curve and panel montage supply the critical chain as primary activities. The feeding stocks are placed in these zones based on the calculations of the criteria of processes. Although the scheduled duration of the project is 217.22 work-days, it is delivered in 159.5 days with the critical chain project plan which provides a 58 days improvement. The delivery date is 2.5 months earlier than projected which corresponds to a 26 % improvement. Thus, labor-force and sources are used 2.5 months less which corresponds to a 20 % improvement. Critical chain project plan needs some computer programs for the projects that have more than 50 sub-tasks. ProChain and Concerto can be suggested as sample programs. In this study, CC(m) Pulse program is used in order to compare with manual project plan. Safety margin works are coded to the program and some arrangements are applied in accordance with the demand of the program. In ship building work flow, a sub-task can be begun before a related sub-task is finished. Manual project plans and computer programs don't accept this flow and they need the data that involves tasks which begins after finishing the previous task. Therefore, all of the consecutive activities until the first block's slipway process are used as data. Project stock is calculated as 54.5 days via the program. Feeding stocks are placed in stations sheet steel curve, profile curve and panel montage. Unlike manual project, the delivery date improved 53 days. There are a few reasons why the program results 5 days delay comparing the manual critical chain plan. For instance, statistical effects of the weighted activities on critical chain occurred during calculations of the projects that have less than 50 sub-tasks, wider knowledge and better calculating skills of the project operator comparing the program and the experiences of the operator on application.

Shipbuilding is a labor intensive sector. There are many problems due to the lack of production management on ship production. Project management concerns the weaknesses of Turkish shipbuilding industry such as high costs, non-efficient production, lack of in organization and technology. It is well known that the ship building sector has weaknesses in project management and only a few shipyards have production flow. Shipyards are in need of changes in production flow, measurement of these changes' effects and increasing the capability of using these benefits. Providing the certain and measurable production planning system is the solution for Turkish shipyards. Figure 4 presents the compare of critical chain project management methods (PMM_1-PMM_2). The results are calculated for planned and realized production duration of 1900 TEU container ship.

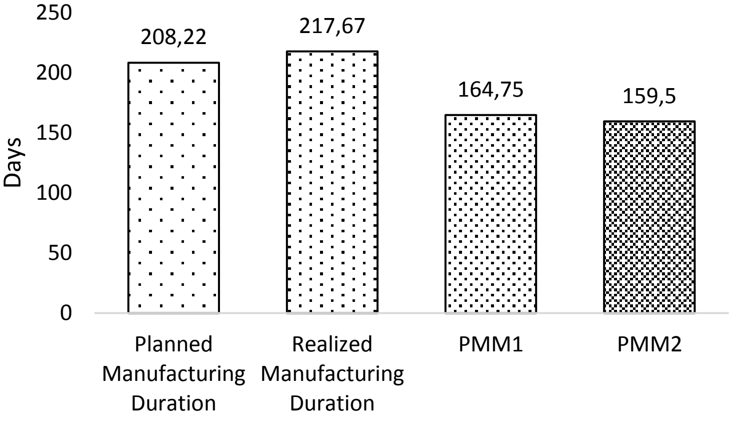

Figure 4: 1900 TEU Container Ship Production Duration

4. CONCLUSIONS AND RECOMMENDATIONS

The project was finished in 217.67 days and the improvements through the changes pursuant to the critical chain process can be seen in the graphic. TOC succeeded a 58 days saving with the design that considers the 50 % completion probability on realized durations and places the safety margin to the end of the project. The total improvement is about 26 %. Stock usage decreases in the same level and it is estimated that the operating expenses decrease about 20 % with the 2.5 months saving. This improvement has also effects on the next project and it can be begun 2.5 months before the planned date. An early delivery can have a positive effect on the company's prestige for the customers.

This study is mainly focused on time saving gained by implementation of TOC to a shipyard manufacturing process. Understanding the general benefits of TOC depends on the innovative studies, which use different perspectives. For instance, LCA and life cycle cost (LCC) are holistic methods to identify and determine the total useful and useless impacts of implementing various methods on manufacturing processes. Thus, in further studies, the total economic and environmental savings may be estimated in accordance with LCA and LCC. Theoretical studies on TOC can provide improvements close to the practical studies that are realized in abroad. These improvements also provide positive views for the companies. TOC must be used for especially in the shipyards which have serial production and work-flow and it should be studied by the authorities and operators.

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