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A Continuous Process Improvement Application in Shipbuilding

Professional paper

There is hard competitive environment in production industry and shipyards have a lot of competitors. Under these circumstances, the process improvement operations are very significant in shipbuilding industry. In recent years, shipyards have been attempting to improve their processes by investigating their current production system so that they can keep their competitive power in global extent. Shipyards seek to decrease the cycle time of the interim products in order to increase the annual production capacity and the market share of the shipyard. In order to do this, shipyards have to analyze their own production system and perform some improvements on the current production system. In this study, the process improvement model is presented. The process improvement model consists of the continuous improvement method, OPT (Optimized Production Technology), and simulation. The phases in the model were implemented for a double bottom block of a container ship. As a result, by doing some improvements on the current production system, the cycle time of the double bottom block was shortened. The rate of the improvement of the cycle time is about 100% in theory. The results of the study are discussed in the final section.

Key words: *continuous improvement, OPT, shipbuilding, shipyard, ship production, simulation*

Primjena metode kontinuiranoga poboljšanja procesa u brodogradnji

Stručni rad

U proizvodnim industrijama na svjetskom tržištu vlada jaka konkurentnost, pa brodogradilišta imaju veliki broj suparnika. Radi toga aktivnosti poboljšanja procesa postaju vrlo važne u brodograđevnoj industriji. Proteklih godina brodogradilišta su nastojala poboljšati proces istražujući trenutačno stanje svoga proizvodnog procesa kako bi zadržala konkurentnost na tržištu. Brodogradilišta žele smanjiti vrijeme izrade međuproizvoda radi povećanja godišnjega kapaciteta proizvodnje. Pri tome, moraju analizirati vlastiti proizvodni proces i unaprijediti ga. U ovom radu prikazan je model unapređenja proizvodnoga procesa koji se sastoji od metode kontinuiranog unapređenja procesa OPT i simulacije. Faze rada u modelu primijenjene su na analizi proizvodnje bloka dvodna kontejnerskog broda. Predložena poboljšanja proizvodnoga procesa ukazuju na mogućnosti znatnoga skraćenja vremena izrade. U završnom su poglavlju rada prokomentirani rezultati istraživanja.

Ključne riječi: *kontinuirano unapređenje, OPT, brodogradnja, brodogradilište, proizvodni proces, simulacija*

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1 Introduction

Shipbuilding is a global industry competing in the world extent [1] and shipyards have many competitors in this environment. In recent years, shipyards have been attempting to improve their production processes in order to gain advantages against their competitors by manufacturing a ship in less time. In order to improve the production processes and reduce the cycle time, shipyards have to examine the work activities comprehensively.

The processes of a system should be improved continuously after being designed [2]. Therefore, the process improvement has to be performed by shipyards continuously.

The applications of process improvement play an important role for the companies in order to keep the competitive power. Comparing the cycle times of the interim products of the shipyards located far eastern with the other shipyards in the world, it can be clearly seen that the cycle times of the interim products are pretty short in the far eastern shipyards. *Geoje Samsung Shipyard* is capable to manufacture 40 ships per year in South Korea and it is also known as one of the most efficient shipyards in the world [3]. As compared with other shipyards, it has a great competitive advantage against its competitors. So, the shipyards have to investigate their production processes and do some improvements by using improvement methods in order to keep the competitive power.

One of the most time consuming production processes in shipbuilding is the block production. In the presented study, a double bottom block of a container ship was considered and the improvement model was applied for the double bottom block. The process improvement model is based on the combination of three methods, i.e. continuous improvement method, OPT (Optimized Production Technology), and simulation.

The OPT or bottleneck theory was introduced in 1979 and it is thought that it may be used as a tool in production planning and scheduling [4]. OPT is used to maximize the usage of the critical resources and the throughput of the system and it is also used to reduce work-in-process (WIP) and the cycle time [5]. The main rule of the bottleneck theory is "balance the flow, not the capacity" [6]. According to this rule, in order to increase the throughput of the production system, the improvements should be applied on the stations leading to bottleneck, not on the non-bottleneck stations. The gains obtained from the bottleneck stations direcly affect the system throughput. The bottleneck theory or OPT is applied to the entire system performance rather than the performance of each work stations. So, the product quantity manufacured in a given period is an important factor. The bottleneck theory does not care about the idle waitings in the work stations. The main point is the product quantity manufactured in the system.

Simulation has a great importance for the production companies. In the competition environment, the changes on the production system and the effects of these changes are very significant in terms of the company performance. Simulation has been applied in many industries as it provides a great advantage for the planner. In shipbuilding industry, it has a great deal of application fields such as layout, production processes and so on.

ARENA simulation software uses Seize-Delay-Release model. This is a standard discrete-event-simulation approach and many other simulation tools use the same or similar model. Each entity simply goes through Seize-Delay-Release logic and simulation tool manages the entity queueing and allocation of resource capacity to the entities. In addition, most simulation software automatically records queue, resource and entity-related statistics as the model runs.

2 State of the art

The processes in the painting shops of *Sedef Shipyard* and *Schalekamp Shipyard* were compared and, as a result of this comparison, some improvement suggestions were reported [7]. *Senesco Shipyard* obtained the increase of 50% in efficiency with a team work by getting workers, suppliers, management and technology factor together [8]. In another improvement operation carried out in a shipyard, the format of the design drawings coming from the design department was changed. As a result of the improvement operation in the shipyard, the cutting process was carried out in shorter time and in more effective way [9]. The process improvement operation in a shipyard was applied to the scaffold area and material stock area [10] and was applied to the layout of the work stations [11,12]. As a result of continuous improvement application in *Todd Pacific Shipyard*, the moving distances of the forklifts were shortened in the rate of 50% and the oil wastes occuring during the operations of the forklifts were also reduced. Moreover, the enegy usage reached a lower level. In *Bender Shipbuilding and Repair Company*, the quality control team consisting of 13 persons focused on reducing the rate of overwelding and they tried to reduce the welding size. As a result, less welding emissions were achieved. *Bath Iron Works Company* applied a process improvement operation on its processes. In the current case, it is seen that the completion times of the same process differed from each other. So, this deviation in the process time was reduced and the completion time of the process was tried to be standardized [13]. In the study that has been still going on by *Michigan University* and *Seoul University*, it is aimed to simulate all the activities in the shipyard and to see the effects of the changes on the production system [14]. In the other study, the stations forming the sub assembly line were modelled by using simulation and after the system was simulated, a robot was settled in the production line and the rate of productivity was determined [15]. In [16] the aim was to settle the work stations of the shipyard in the optimum way. That is a layout application of simulation. In [17] a profile cutting station is considered. The product is the profiles of a double bottom block. In the study, the processes of the profile cutting station were determined. Then, these processes were modelled in a simulation program and the effects of changing the resources were investigated. In [18] the panel production station is considered as a bottleneck station. Processes were determined and modelled in a simulation program. Then, by doing some changes on the processes, the completion time of the panel cutting station was tried to be optimized.

In this study, a simulation program [19] was used for modelling the work flows between the work stations since the modules of the simulation program are very appropriate for modelling the shipyard's production activities.

3 Description of double bottom block

A double bottom block is manufactured by coming together some production stages. In the first phase of the double bottom block production, single section parts (A) and single plate parts (B) are fabricated. These parts are cut from standard-dimensioned plates and profiles in the shipyard and they have specific dimensions after cutting process. Then, they are mounted together and minor assembly is constructed (C). Two or more minor assemblies constitute sub assembly structure (D). Flat plates are welded with SAW (Submerged Arc Welding) method and flat plate assembly (E) is fabricated. When the profiles are welded on the top of the flat plate assembly, the flat plane assembly (F) is fabricated. Minor and sub assemblies are welded on the flat plane assembly (F) and major sub assembly (G) is manufactured. Curved panel assembly (H) is manufactured on pin jigs. In block assembly area, sub unit assembly (J) and curved panel assembly are mounted and welded, finally a double bottom block (K) is produced.

There is also some outfitting equipment in the double bottom block such as manholes, bottom plugs, zincs, vertical ladder, and doubling plates.

4 Workstations in double bottom production

Ship production is a hard task since it contains thousands of work activities. These work activities are carried out in the work stations which have different functions. Table 1 shows the work stations and the work activities related to double bottom block production.

Table 1 **The work stations in the production process of the double bottom block**
Tablica 1 **Radne operacije u proizvodnji bloka dvodna**

Station no	Station name	Activity
I1	Edge cutting	Edge cutting operation of ship hull plates
I2	Edge cleaning and sequencing	Edge cleaning operation of ship hull plates
I3	Panel production	The hull plates are welded and the panel structure is produced
I4	Panel cutting	Counter cutting of the plates
I5	Stiffener mounting	Profiles are assembled on the panel by tack welding
I6	Stiffener welding	Profiles are welded on the panel by tig welding
I7	Web mounting	Minor and sub assemblies are joined on the flat panel assembly by tack welding
I8	Web welding	Minor and sub assemblies are welded on the flat panel assembly by tig welding
I9	Grinding	Grinding operations of the flat panel and major sub assemblies
I10	Profile piece part preparation shop	Standard-dimensioned profiles are cut and specific dimensioned profiles are fabricated
I11	Profile bending	Bending operations of the profiles
I12	Plate piece part preparation shop	Single plate assemblies are manufactured
I13	Pre-fabrication	Minor and sub assemblies are produced
I14	Jig	Curved panel assemblies are produced
I15	Plate bending (Press)	Bending operations of the flat plates
I16	Block assembly	Block structure is formed by assembling the related parts.

The material flows occur between the work stations given in Table 1. After the material is processed in a work station, it is transported to the other work station to be processed. For instance, the material processed in the edge cutting station is transported to the edge cleaning and sequencing station. From the edge cleaning and sequencing station (I2), it goes to the panel production station (I3) to be processed. So, there is a flow relation between the work stations. This flow relation is given in Table 2.

Table 2 **Flow relations between the work stations**
Tablica 2 **Veze između radnih operacija**

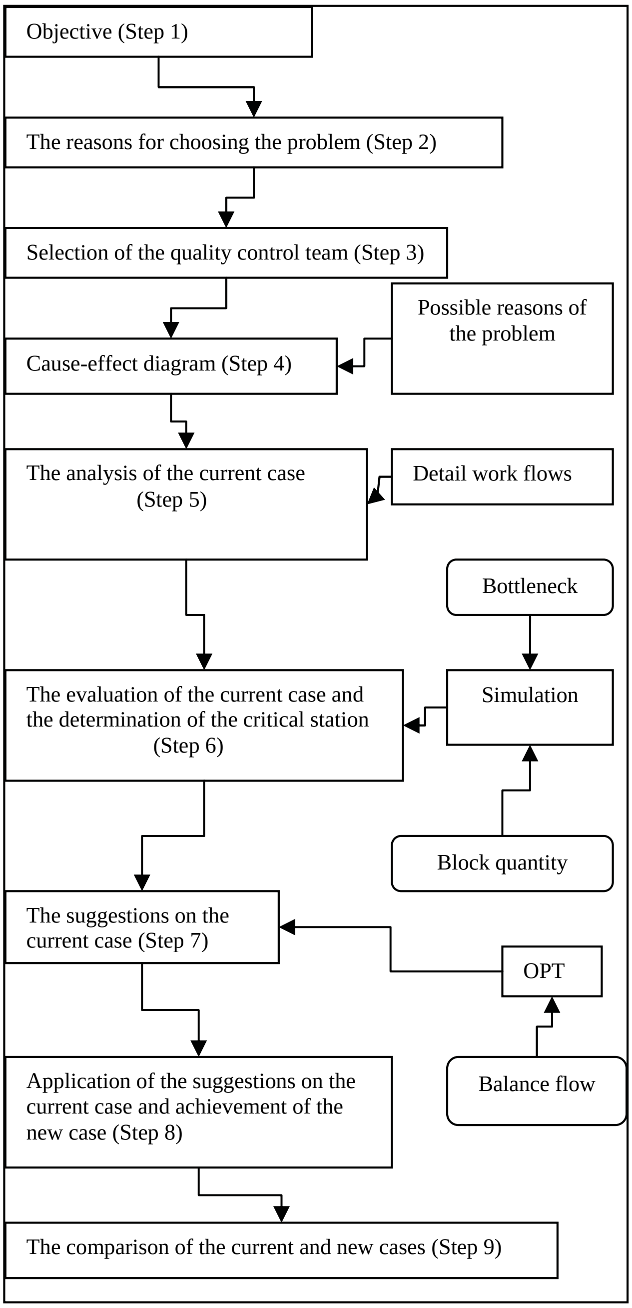
From	To
I1	I2
I2	I3
I3	I4
I4	I5
I5	I6
I6	I7
I7	I8
I8	I9
I9	I16
I10	I5, I11,I13, I16
I11	I14
I12	I7, I13, I14, I15, I16
I13	I7, I14
I14	I16
I15	I14, I16

5 Process improvement model

The process improvement model is presented in this study with the aim of reducing the cycle time of interim products. This model is based on the continuous improvement, optimized production technology (OPT), and simulation methods. The existing and the improved processes were modelled in the simulation program and the results were compared. The performances of the current and the new production systems were evaluated according to the quantity of the block (throughput) manufactured in a given period.

Determining the problem is the first phase of the continuous process improvement model [20] shown in Figure 1. In the second phase, the team, that will find the problem, is chosen. The team comes together to do brainstorming which helps in finding the reasons for the problem and the cause-effect diagram is created. The cause-effect diagram is one of the problem solution methods; however, it gives only starting estimations to the team. To be able to find the real reason, the detailed process analysis has to be performed by the team. The team examines all of the work stations involved in the production activities for the considered product. After the comprehensive current process analysis, the work activities and their durations are obvious. Using the data obtained from the process analysis, the completion times of the work stations are calculated and the simulation model is created for the current production case. The simulation model is run along a given time and some data such as the throughput and queue times are obtained. At this point, the team thinks about how to increase the throughput. In order to increase the throughput, some improvements have to be done on the current system. The improvements can be done for any station but the main point here is that whether the performed improvements are going to increase the throughput or not. The improvements have to be done on the bottleneck stations in order to increase the throughput according to OPT rules. The bottleneck stations are found by queue times, which are obtained from simulation results. After the bottleneck station is found, the improvements are carried out on the bottleneck station. The changes done are noted on the current production case and the new work activities are achieved. The new case is modelled in simulation and the simulation modelled is run along the same time period and the new data for the new case are obtained. The procedures mentioned in the previous current case are applied to a new case. The process improvement continues in this way until the satisfactory throughput results are reached.

Figure 1 **Process improvement model**
Slika 1 **Model unapređenja procesa**



6 Case study

A continuos process improvement application was performed here by using the improvement model shown in Figure 1. A double bottom block of a container ship was chosen as the product since almost all of the work stations are involved in its production activities. The double bottom block considered in this study has the weight of 73 tons, the height of 5 metres, the length of 8 metres, and the width of 16 metres (as described in Section 3). The study is based on the processes of a shipyard located in Turkey and the shipyard has 16 units of workstations for ship hull production as defined in Section 4. The shipyard also has a capacity of 40,000 tonnes of steel per year.

6.1 Determination of the problem - objective (Step 1)

In this study, the problem is “reducing the cycle time of a double bottom block”.

6.2 The reasons for choosing the problem (Step 2)

The reasons why this problem was choosen are given below:

a. To deliver the ship in shorter time,
b. To unload the block assembly area as soon as possible,
c. To increase the quantity of the ship manufactured per year,
d. To increase the competitive power.

6.3 Selection of the quality control team (Step 3)

The problem mentioned in Step 1 will be solved by the authors of this study and the working team in the shipyard.

6.4 Cause-effect diagram (Step 4)

The cause-effect diagram contains the main reasons leading to the problem mentioned in Step 1. The main reasons were thought to be resulting from block assembly (I16), press (I15), jig (I14), nest cutting (I12), profile cutting (I10) stations and the panel line stations.

Block assembly station (I16) is the last work station in the production system for this study. According to Table 2, Grinding Station (I9), Profile piece part preparation (I10), Plate piece part preparation (I12), Jig Station (I14) and Press Station (I15) send the parts to Block Assembly Station (I16). So, the reason why the cycle time of DB is long may be originated from these stations, as can be seen from Figure 2. There might be some problems with respect to equipment, manpower or processes. Before doing the analysis of the current case, such kind of estimations and speculations are done by the team. These estimations give some ideas to the team at the beginning of the work. The main reason leading to the bottleneck can be found by doing the detailed current case analysis.

6.5 The analysis of the current case (Step 5)

In this phase, the team performed the comprehensive work flow analysis for each work station. Work activities and durations of work stations of the current production system were identified and then the completion times of the work stations were determined. Table 3 shows the completion times of each work station.

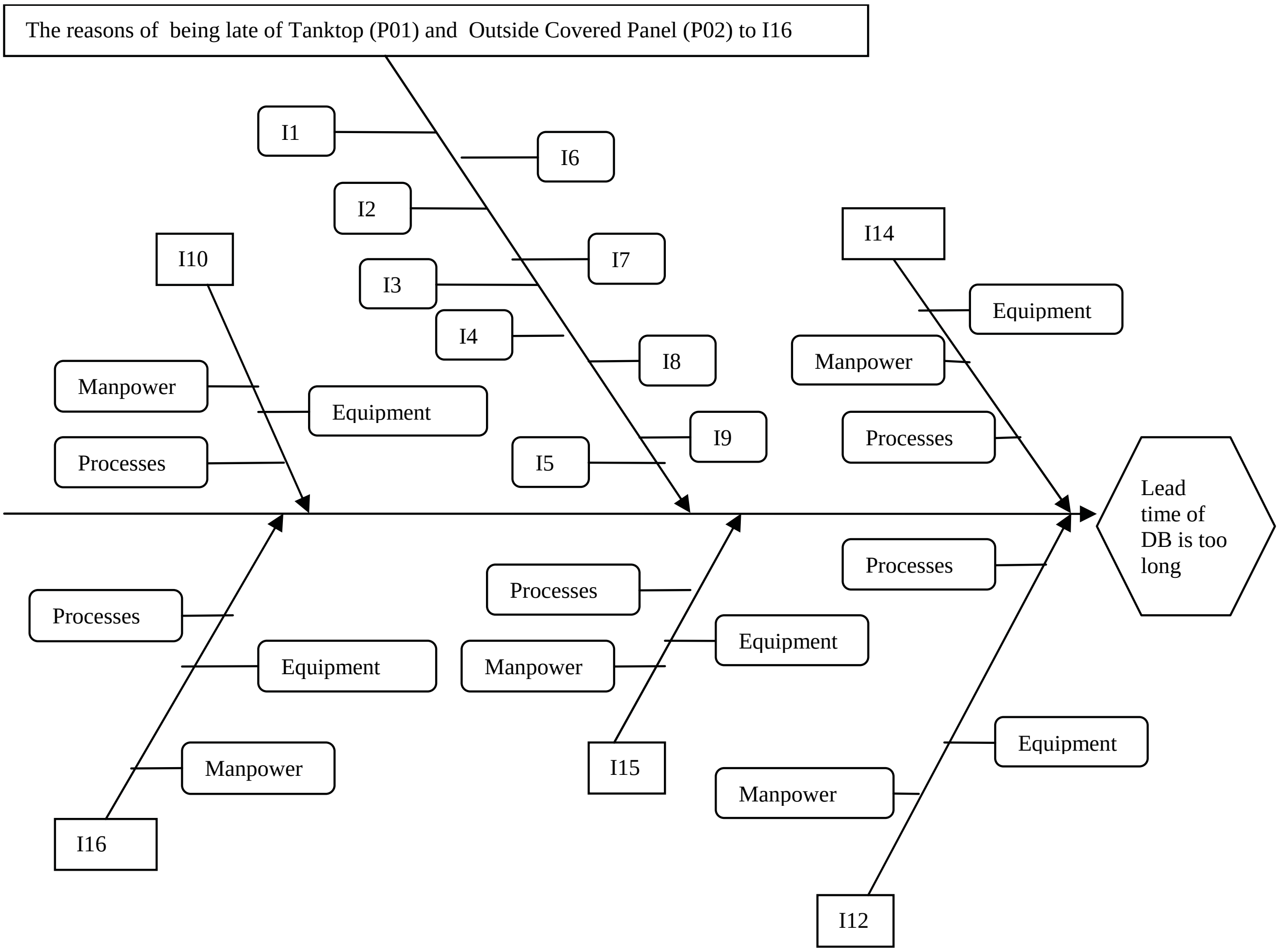


Figure 2 **Cause-effect diagram**
Slika 2 **Uzročno-posljedični dijagram**

Table 3 **Station completion times for the current case**
Tablica 3 **Vrijeme trajanja pojedine operacije - postojeće stanje**

Station name	Completion time (min.)
Edge cutting	190
Edge cleaning and sequencing	203
Panel production	622
Panel cutting	356
Profile spot welding	372
Profile tig welding	414
Section spot welding	501
Section tig welding	660
Grinding	99
Profile cutting	410
Profile bending	350
Nest cutting	653
Pre-fabrication1	448
Pre-fabrication 2	632
Jig	1,522
Plate bending (Press)	1,317
Block assembly	2,196

6.6 The evaluation of the current case and the determination of the critical station (Step 6)

In this phase, the current production system was modelled by using the simulation program as shown in Figure 3 and the modules of the model were expounded in Table 4. The simulation model was run along 720 hours and some data were obtained from the model. The first data are about the system throughput. The current production system has the quantity of eighteen double bottom blocks as throughput at the end of 720 hours. Therefore, the cycle time of the double bottom block is around 2400 minutes. The data that we wanted to examine are the queues of the production system. According to Table 5, there is a queue in front of the block assembly station. So, improvement activities have to be focused on the block assembly station (I16) for the system throughput enhancement.

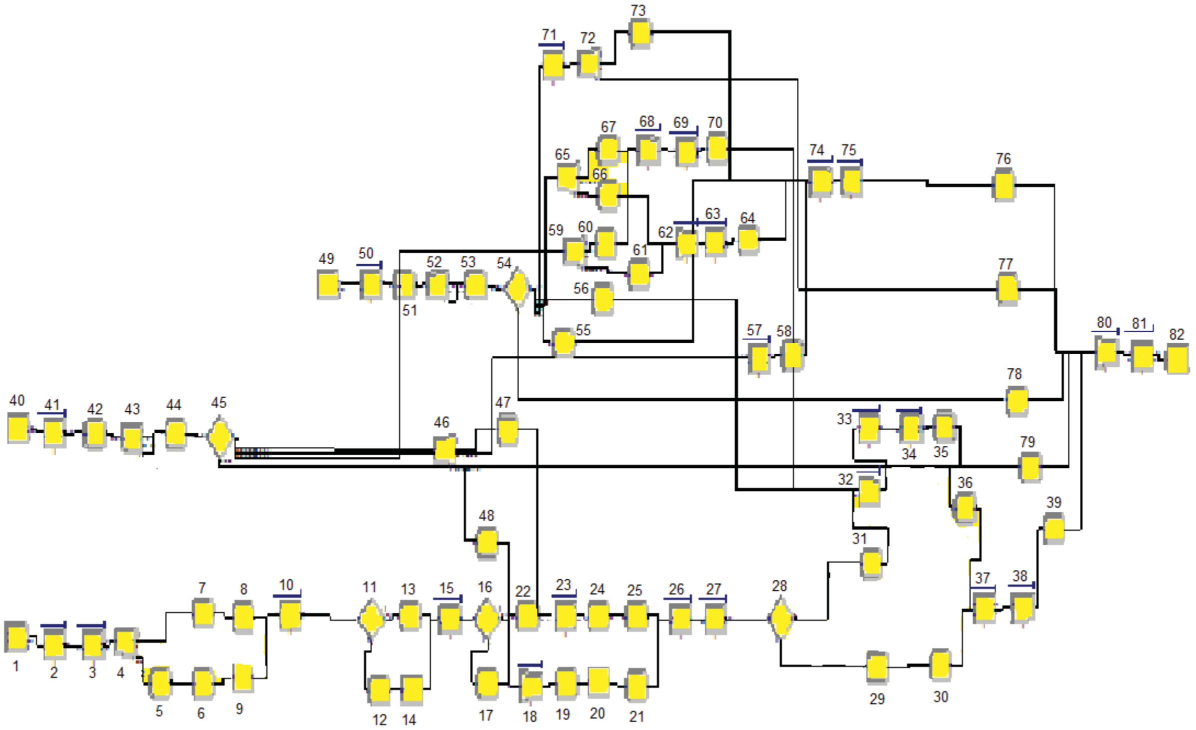


Figure 3 **Simulation model of the current case**
Slika 3 **Simulacijski model postojećeg stanja**

Table 4 **Definition of module numbers**
Tablica 4 **Definicija modula simulacijskog modela**

Module no	Module name	Module no	Module name	Module no	Module name
1	Create1	29	Assign 13	57	Process of profile bending (I11 station)
2	Process of plate edge cutting (I1 station)	30	Assign 14	58	Assign 27
3	Process of plate edge cleaning	31	Assign 15	59	Seperate 5
4	Seperate 1	32	Batch 3	60	Assign 28
5	Assign 1	33	Process of section spot welding (I7 station)	61	Assign 29
6	Assign 2	34	Process of section tig welding (I8 station)	62	Batch 5
7	Assign 3	35	Assign 16	63	Process of prefabrication 1
8	Assign 4	36	Assign 17	64	Assign 30
9	Delay 1	37	Process of grinding (I9 station)	65	Seperate 6
10	Process of panel production (I3 station)	38	Batch 4	66	Assign 31
11	Decide 1	39	Assign 18	67	Assign 32
12	Assign 5	40	Create 2	68	Batch 6
13	Assign 6	41	Process of profile cutting (I10 station)	69	Process of prefabrication 2
14	Delay 2	42	Assign 19	70	Assign 33

Module no	Module name	Module no	Module name	Module no	Module name
15	Process of panel cutting (I4 station)	43	Seperate 2	71	Process of plate bending (I15 station)
16	Decide 2	44	Assign 20	72	Seperate 7
17	Assign 7	45	Decide 4	73	Assign 34
18	Batch 1	46	Seperate 3	74	Batch 7
19	Assign 8	47	Assign 21	75	Process of jig (I14 station)
20	Delay 3	48	Assign 22	76	Assign 35
21	Assign 9	49	Create 3	77	Assign 36
22	Assign 10	50	Process of nest cutting (I12 station)	78	Assign 37
23	Batch 2	51	Assign 23	79	Assign 38
24	Assign 11	52	Seperate 4	80	Batch 8
25	Assign 12	53	Assign 24	81	Process of block assembling (I16 station)
26	Process of profile spot welding (I5 station)	54	Decide 5	82	Dispose
27	Process of profile tig welding (I6 station)	55	Assign 25		
28	Decide 3	56	Assign 26		

Table 5 **Queue times for the current case**
Tablica 5 **Vrijeme čekanja na pojedinoj operaciji - postojeće stanje**

Station name	Waiting time (hr)
Edge cutting	6.78
Edge cleaning and sequencing	22.86
Panel production	140.51
Panel cutting	0.00
Profile spot welding	0.17
Profile tig welding	0.15
Section spot welding	0.00
Section tig welding	7.88
Grinding	0.05
Profile cutting	18.45
Profile bending	0.00
Nest cutting	122.56
Pre-fabrication1	56.67
Pre-fabrication2	24.45
Jig	286.13
Plate bending (Press)	177.07
Block assembly	314.1

6.7 The suggestions on the current case (Step 7)

In the previous step, it is mentioned that the critical station which leads to bottleneck is the block assembly station (I16). So, the improvements have to be based on this station. This is because, according to the bottleneck theory, the improvements on the system must be performed on the bottleneck stations. Here, the first rule of the bottleneck theory was employed. This rule is "balance flow, not capacity". The improvements on the current case are shown in Table 6.

Table 6 **The suggestions on the current case**
Tablica 6 **Smjernice poboljšanja**

No. of suggestions	Workstation	Description of suggestions
1	Panel cutting	The welding operations of the manholes on tanktop panel were carried out. These welding operations are one side welding. In this way, the one side welding operations of the manholes will be finished
2	Panel cutting	The one side welding operations of the bottom plugs (two pieces) on hull panel.
3	Panel cutting	The welding operations of the zincs (six pieces) on the hull panel were carried out and finished.
5	Pre-fabrication	The assemblies of vertical ladders (three pieces) were carried out on the sections
6	Pre-fabrication	The assemblies of the zincs (thirty-two pieces) were carried out.
7	Pre-fabrication	Assemblies of pipe systems (twenty-six) on the module.
8	Pre-fabrication	Manufacturing the module in prefabrication station (I13) in order to assemble the piping systems
9	Jig	Assembly of pipe systems (nine) on the box blocks in jig station
10	Block assembly	Assembly of one vertical ladder when the block is upside down

No. of suggestions	Workstation	Description of suggestions
11	Block assembly	Completing of the welding operations of two bottom plugs when the block is upside down
12	Block assembly	Completing of the welding operations of four manholes when the block is in flat position
13	Block assembly	Assembly of twenty doubling plates when the block is in flat-position
14	Block assembly	Assembly of two bilge wells when the block is in flat position
15	Block assembly	Assembly of four zincs when the block is in flat position
16	Block assembly	Carrying out the outfitting and steel operations in parallel way in the block assembly station
17	Block assembly	In the block assembly station (I16), in the steel operations, there are fourteen tig welding and spot welding workers in the current case. In the new case, there are sixteen tig welding and spot welding workers for steel operations. The tig welding and spot welding operations are carried out by the same workers. Also, two spot welding and tig welding machines that are idling are added to the station

6.8 Application of the suggestions on the current case and achievement of the new case (Step 8)

In Step 7, some improving suggestions were done on the basis of block assembly station which leads to bottleneck on the current production system. Panel cutting, section spot welding, pre-fabrication, jig and block assembly stations were influenced by the suggestions on the current case. In Step 5, the comprehensive work flow analysis had been performed. Based on these work flows, the suggestions here were transmitted to the work flows and the new work flows were achieved, which we call the new case 1. While the completion times of panel cutting, section spot welding, pre-fabrication, jig and block assembly stations were changing, the others remained constant. Table 7 shows the completion times of each work stations for new case 1.

Table 7 **Station completion times for the new case 1**
Tablica 7 **Vrijeme trajanja operacija - poboljšani slučaj 1**

Station name	Completion time (min.)
Edge cutting	190
Edge cleaning and sequencing	203
Panel production	622
Panel cutting	460
Profile spot welding	372
Profile tig welding	414
Section spot welding	284
Section tig welding	660
Grinding	99
Profile cutting	410
Profile bending	350
Nest cutting	653
Pre-fabrication1	621
Pre-fabrication2	632
Jig	1,634
Plate bending (Press)	1,317
Block assembly	1,073

After that, 6 new cases and 25 steps were analysed and a comparison with the current case is given in the next section.

6.9 Comparison of the current case and the new cases and the determination of the best case (Step 9)

So far, starting from the current production case, a continuous improvement process was applied by using the improvement mo-

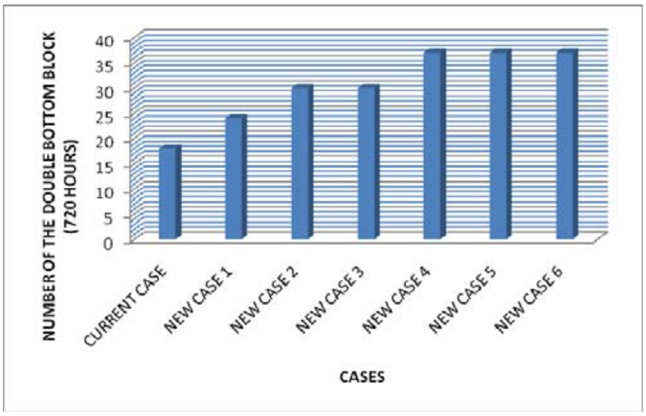
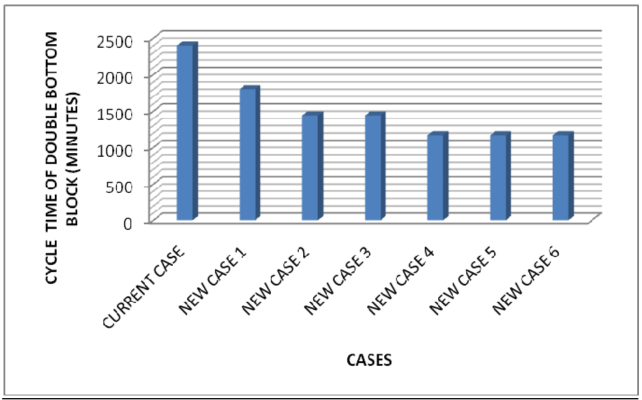


Figure 4 **The number of the double bottom block in the production time of 720 hours**
Slika 4 **Broj izrađenih blokova dvodna u proizvodnom vremenu od 720 sati**

Figure 5 **The cycle times of the double bottom block in the production time of 720 hours**
Slika 5 **Vrijeme izrade jednog bloka dvodna za različite slučajeve**



del. In this improvement process, six types of production cases were obtained. Figure 4 shows the number of the double bottom block for each case. According to Figure 4, the new case 4, 5 and 6 present the highest throughput. Figure 5 shows the cycle times of the double bottom block. In the new cases 4, 5 and 6, the cycle time of the double bottom block is shorter than in the others. So, each of the new cases 4, 5 and 6 is appropriate for the shipyard since the best output is obtained.

7 Conclusions

Shipyards, which need to deal with the hard competition environment, have to increase the system throughput in a given period. By doing this, they yield some advantages against their competitors. In order to increase the system throughput, the shipyards need to examine the production processes comprehensively and improve some work activities and they have to fulfill the improvement works continuously.

Considering the situation mentioned above, a continuous improvement model was presented in this study. The phases of the model were applied step by step for a shipyard with the aim to reach the highest throughput. For this purpose, six types of production cases were obtained, starting from the current production case of the shipyard. During application, the system throughput was increased by approximately 100% by doing some improvements cumulatively. In other words, the cycle time of the double bottom block was decreased. It is believed that it causes a great competitive advantage for shipyards against their competitiors.

The system throughput might be increased by doing some improvements on the sixth production case. But, in the study, the improvement process was terminated since the throughput enhancement was deemed sufficient.

It should be noted that the effects of the suggestions were found by simulation in theory. It is strongly recommended that the shipyards implement the suggestions in practice and use the continuous improvement model presented in this study for the workshop activities. Moreover, the shipyards can utilize the improvement model presented in this study for their production process improvement. In this way, they can improve the work activities continuously and can yield productivity enhancement.

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