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The effects of matrix module structure on shipyard panel line's throughput

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ABSTRACT

Over the last decades a really tough competitive environment has been observed in shipbuilding sector. Under these circumstances shipyards desire to reduce product cycle time in order to manufacture the product as soon as possible. For this reason it is required to make some alterations in shipyard production system in order to reduce cycle time. In this study a panel fabrication line used in a shipyard, has been considered. The workstations of the panel line have been modeled by using ARENA simulation software and the effects of matrix module assembly on panel line throughput, have been determined.

Key words: shipyard; ship production; panel line; matrix module assembly; simulation

INTRODUCTION

In recent years there is a hard competitive environment in many industry branches including shipyard industry. In order to increase their competitiveness shipyards have to consider the factors affecting competitiveness according to Rashwan and Naguib [1]. One of the factors is delivery time. To be able to keep the competitive power, the companies have to deliver the products to their customers on time and reduce the production cycle time. For this reason the companies have to investigate their production systems and improve their processes. In order to see the effects of the improvements on a real system, simulation tool is mostly used.

In this study simulation is used as an optimization tool. Simulation is used to understand character of real systems. There are many simulation applications in shipbuilding, as described in the literature. In a common study realized by Michigan University and Seoul National University, the whole processes of a shipyard are attempted to be modeled with simulation and the effects of some changes on the system are perceived [2]. In the study of Okumoto *et al*. [3], performed by modeling the scaffold placement with three-dimensional simulation CAD system, the effects of the changes on the system have been observed. Shin [4] has modelled the workstations of the sub-assembly line with the use of simulation and determined the effect of placing a welding robot on productivity. In the other study of Shin [5] an optimum shipbuilding layout has been found by using simulation. Alfeld *et al.* [6] has used a special software in simulating the shipyard processes to ensure that the planners take decisions easily. Alkaner [7] has simulated the processes of the profile cutting station and by making some changes in resources, the effects of these changes have been investigated. Doing some alterations on panel production station, Greenwood *et al.* [8] has investigated the effects of the changes on the production system**.** Lee *et al.* [9] has found the effects of the intelligent welding robot system on welding performance. Cha and Roh [10] have developed a simulation framework and applied it to block erection process. As can be concluded, there are many application fields of simulation in shipyard industry.

In this study the processes of the panel line of a shipyard located in Turkey have been considered. Firstly, the detailed process analysis of the panel line has been performed. In this way the whole work activities of the panel line and their durations have been found. In the second stage of the study the simulation model of the panel line has been elaborated by using ARENA 11.0 software. The required data achieved from the process analysis have been put in the simulation model. Then the model has been run for 10-day period and number of products manufactured by the panel line has been determined. In the third stage of the study an alteration in section spot welding station has been made. And, this alteration has been put in the simulation model and the model has been run again for 10- day period. Then the effect of this alteration on the system throughput has been determined.

As mentioned above, the alteration made in the panel line is interesting in the case of section spot welding station. In the section spot welding station of the panel line, minor and sub- assemblies are mounted on the flat panel assembly and their matrix structure is formed. In many shipyards in Turkey, minor and sub-assemblies are welded one by one on flat panel assembly in order to produce matrix structure. In this way it takes a longer time to manufacture the matrix structure and a bottleneck situation may occur on the panel line. Instead of the mounting of minor and sub-assemblies one by one, they should be mounted on flat panel assembly as a module. In other words, the matrix structure can be mounted as a module. It is believed that mounting the matrix structure as a module reduces the production cycle time and increases the throughput of the panel line.

METHODOLOGY

In this study, the steps presented in Fig 1 are followed, respectively. At the beginning the workstations forming the panel line are determined and defined (Step 1). Then the product to be manufactured in the panel line and its sub-compenents are defined (Step 2). After the process analysis of the workstations is performed, the panel line is modelled by using simulation (Model 1), (Step 4) and the model is run for a specified duration time (Step 5). In Step 6, work flow in the section spot welding is changed and module mounting is carried out instead of mounting the minor and sub-assemblies one by one on the flat panel assembly (Stage F). In Step 7, the panel line is modelled by using simulation again and consequently Model 2 is achieved. In Model 2, the workstations' work flows remain constant except for the section spot welding. In Step 8, Model 2 is run for the same time period as in the case of Model 1 and throughput quantity of the panel line is achieved. At the last step (Step 9), Model 1 and Model 2 are compared mutually in terms of throughput quantity.

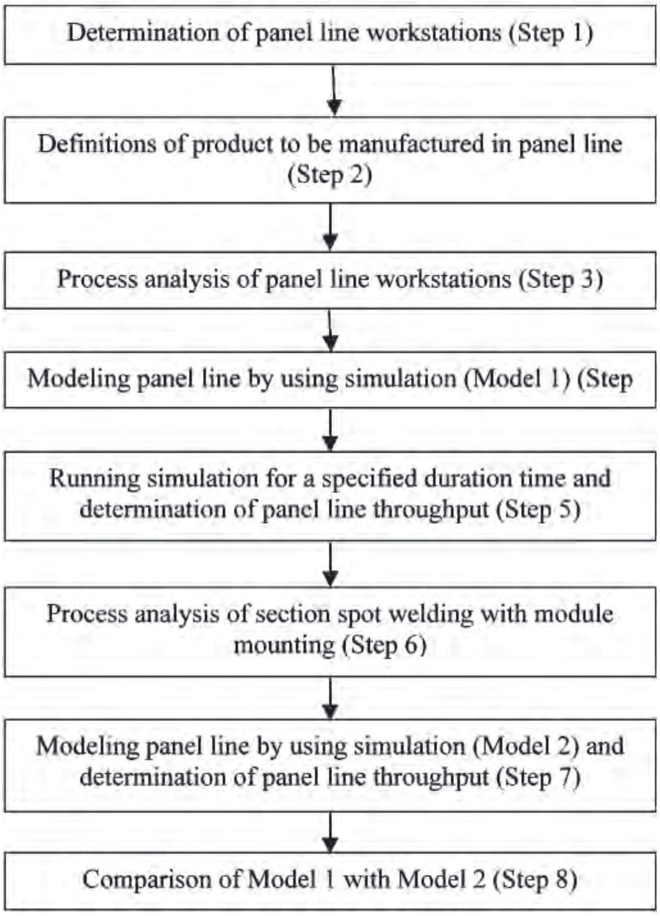

Fig. 1. *Methodology of the study*

Determination of panel line workstations (Step 1)

The panel line is a production cell where flat structures are fabricated. It consists of different types of workstations. There are 9 workstations on the panel line. Each workstation has a function in the production process. Tab. 1 shows the workstations located on the panel line.

Tab. 1. *Workstations on the panel line*

No. of workstation	Workstation name
I1	Edge cutting station
I2	Edge cleaning and sequencing
I3	Panel production
I4	Panel cutting
I5	Profile spot welding
I6	Profile tig welding
I7	Section spot welding
I8	Section tig welding
I9	Grinding

The edge cutting operations of the plates are performed in the edge cutting station (I1). The cutting operation is carried out by using plasma. The plates being cut are then sent to the edge cleaning and sequencing station (I2) where the edge cleaning operation of the cut surfaces is performed. Grinding machines are used in this operation. The sequencing operation is also carried out in this station in order to sequence the plates which enter the panel production machine. The plates are then sent to the panel production station from the edge cutting and sequencing station. In the panel production station (I3), the plates are mounted by using submerged arc welding. As an output of this station a panel is produced and then it goes to the panel cutting station where inside and outside cutting operations of the panel are performed. In the panel cutting station (I4), marking operation is also done. The cut and marked panel is sent to the profile spot welding station (I5). Here, the profiles are mounted on the flat panel and a flat panel assembly is produced as an output. a spot welding machine is used for this operation. The flat panel assembly is then sent to the profile tig welding station (I6) in order to complete the welding operations. After completion of the welding operation of the flat panel assembly it goes to the section spot welding station (I7) where minor assemblies and sub - assemblies are mounted on the flat panel assembly by using spot welding. As an output, a major sub-assembly is manufactured in this station. The major sub-assembly is sent to the section tig welding station (I8) from the section spot welding station in order to complete the welding operation. Finally, the major sub-assembly arrives at the grinding station, the last workstation of the panel line (I9). In this station the grinding operations of the welded places of the major sub-assembly are carried out. After completion of the grinding operations it leaves the panel line. Fig. 2 shows the material flow on the panel line.

Definitions of products to be manufactured in panel line (Step 2)

In the panel line interim products which have flat structure are produced. For a double bottom block, flat panel assembly and major sub-assembly are fabricated in the panel line. In this study, a major sub-assembly was considered as a product.

In ship production some codes, each representing a production stage of blocks, are used. Such coding system is very useful to seperate and check the production stages orderly. Tab. 2 shows the production stages and their definition.

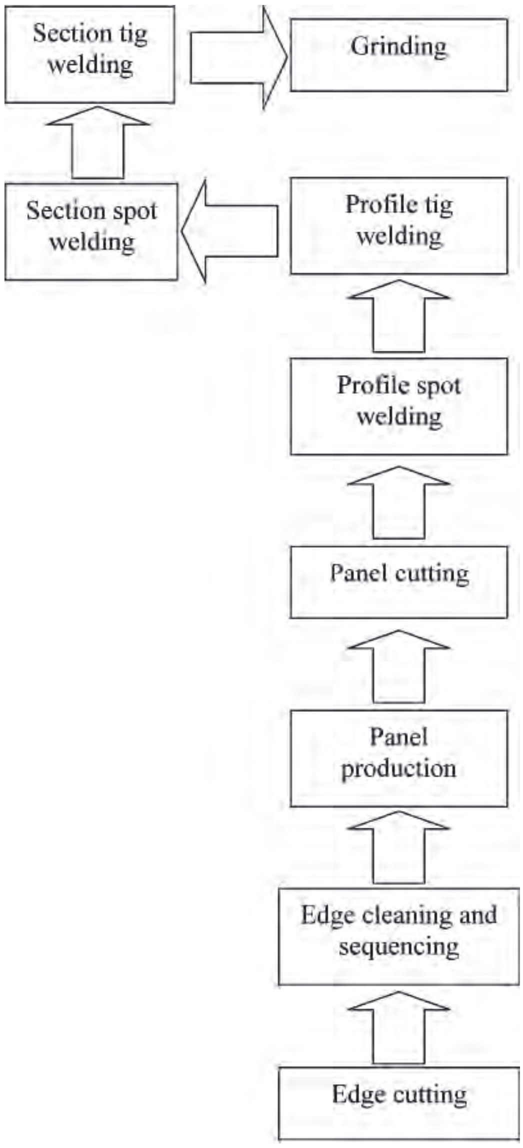

Fig. 2. Work flow through the panel line

Tab. 2. Production stages and definitions

Production Stage	Definitions of production stages	Structures representing production stage
A	Single section part	
B	Single plate part	
C	Minor assembly	
D	Sub assembly	
E	Flat plate assembly	
F	Flat panel assembly	
G	Major sub assembly	

The major sub-assembly (Stage G) is regarded as a throughput of the panel line in question and it includes structures of various types, such as single section parts (Stage A), single plate parts (Stage B), minor assemblies (Stage C), sub-assemblies (Stage D), flat plate assembly (Stage E), and flat panel assembly (Stage F), as defined in Tab. 2.

The single section parts and single plate parts which have specified dimensions are described as a and B production stages, respectively. a single profile is defined as a production stage and a single plate is defined as B production stage.

If one single section part and one single plate part are assembled together, the minor assembly (C) is manufactured. If two or more minor assemblies are fitted together the sub-assembly (D) is built.

The flat plates constitute flat panel structures. If two or more flat plates are fitted together they form the flat plate assembly (E). If single section parts (A) are fitted onto the panel, the panel with profiles, called the flat plane assembly (F), is formed.

Minor and sub-assemblies (C and D production stages) are fitted onto the flat panel assembly (F) to form finally the major sub-assembly (G).

As above mentioned, the major sub-assembly includes various types of production stages. Fig. 3 shows the product breakdown structure of the major sub-assembly considered in this study.

In the major sub-assembly production process some mounting operations take place. In the first stage a set of single section parts of 7 in number are welded together and the flat plate assembly is formed. In the second stage the flat plate assembly and a set of single section parts of 18 in number are welded together and the flat panel assembly is produced. In the third stage, the flat plate assembly, a set of minor assemblies of 14 in number and a set of sub- assemblies of 9 in number are mounted together to form the major sub-assembly being a throughput of the panel line.

Process analysis of panel line workstations (Step 3)

So far, the panel line and the structure of major sub-assembly as an output are briefly discussed. In this section a detailed process analysis of the panel line production system has been performed. During the process analysis each of work stations in the panel line has been considered in detail.

The main point of the process analysis is to determine the work activities. After determining work activities their operation times are calculated. Then, by considering the parallel and serial work activities, the completion times of work stations are determined. It is impossible to present here all the work activites in panel line. For this reason the process analyses of the profile spot welding (I5) and profile tig welding (I6) stations, are only exemplified in Tab. 3 and 4.

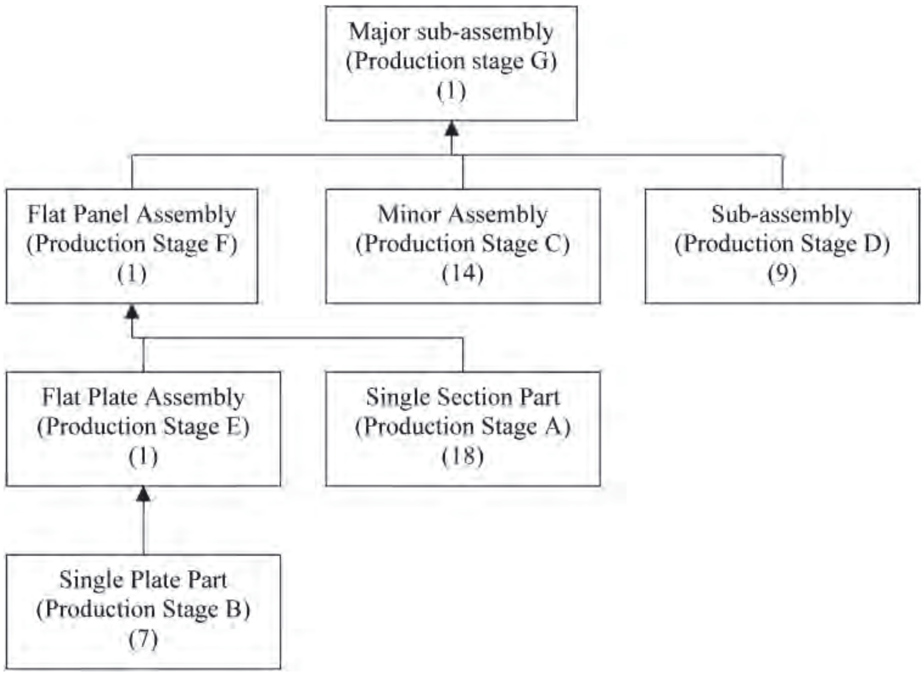

Fig. 3. *Product breakdown structure of major sub-assembly*

Tab. 3. *The process analysis of the profile spot welding station (I5)*

No. of activity	Activity description	Activity duration time [min]
1	The operator walks to the crane	0.146
2	The operator runs the crane	0.166
3	The crane goes to profile stock area	8.178
4	The operator assistants go to profile stock area	3.493
5	The crane comes down the profile	18.051
6	The crane holds the profile	15.2
7	The crane lifts the profile	18.037
8	The crane transports the profile from profile stock area to the porter system	8.473
9	The workers walk to the porter system	3.609
10	The crane puts down the profile onto the porter system	12.274
11	The crane leaves the profile operation area	4.428
12	The workers settle the profile on the porter system	3.8
13	The operator walks to the proter system	0.118
14	The workers walk to the profile welding area	0.404
15	The operator runs the porter system	0.166
16	The operator drives the porter system to the welding area	2.926
17	The operator walks to profile spot welding machine	0.042
18	The operator cleans the welding torch	1.5
19	The operator runs the profile spot welding machine	0.5
20	The profile spot welding machine goes to the porter system	44.755
21	The profile spot welding machine comes down the profiles	3.8
22	The profile spot welding machine transports the profile from the porter system to the flat plate assembly	46.486
23	The profile spot welding machine comes down the profile onto the flat plate assembly and alignment is performed	111.394
24	The profile spot welding is prepared for welding operation.	6.328
25	The process of spot welding	63.82
26	The conveyor system transports the flat plane assembly	1.9
	Total activity duration time	380

Tab. 4. *The process analysis of the profile tig welding station (I6)*

No. of activity	Activity description	Activity duration time [min]
1	The conveyor transports the flat panel assembly to the tig welding station	0.574
2	The operator removes the slag from the welding torch	38
3	The operator checks out the welding system and its connections	38
4	The operator drives the tig welding machine to the starting point of welding	11.577
5	The operator takes down the welding torches on the welding area	17.1
6	The process of tig welding	301.071
7	The operator takes up the welding torches	3.154
8	The conveyor transports the flat panel assembly to the buffer area	4.134
	Total activity duration time	413.61

Tab. 5. *Completion times of the workstations of the panel line (Model 1)*

No. of station	Station name	Number of work activities	Station completion time [min]
1	Edge cutting station	218	TRIA(111.5,144.9,200.8)
2	Edge cleaning and sequencing	167	TRIA(119.2,154.9,214.6)
3	Panel production	327	TRIA(368.2,478.6,491.5)
4	Panel cutting	15	TRIA(226.1,295.5,409.1)
5	Profile spot welding	298	TRIA(174.05,227.5,233.3)
6	Profile tig welding	110	TRIA(212.7,279.3,386.7)
7	Section spot welding	781	TRIA(501,656.3,911.8)
8	Section tig welding	160	TRIA(278,361.4,506)
9	Grinding	148	TRIA(85,111.3,154.7)

Tab. 3 illustrates the work activities of the profile spot welding station. As can be seen from Tab. 3, there are 298 work activities to be perform in the profile spot welding station and its total activity time amounts to 380 min; whereas the station completion time is only 227.5 min because some of the activities are parallel. That is why the total activity time and the station completion time are not same. Tab. 4 represents the work activities of the profile tig welding station. In this case 110 work activities are performed during the total activity time of 413.61 min; whereas the station completion time amounts to 279.3 min.

In the same way the process analysis of other workstations of the panel line are performed and the station completion times are achieved, as shown in Tab. 5.

It should be noted that the station completion times calculated from a comprehensive process analysis are regarded as optimistic ones. Because their distribution is assumed triangular, expected and pessimistic times are also needed to be assigned. In this study the optimistic and pessimistic times are assigned from gained experience.

Modeling panel line by using simulation (Model 1) (Step 4)

In this step the ARENA 11.0 software has been used for modeling the panel line. The required data have been achieved from the process analysis (Step 3); on this basis, apart from station completion times, transportation duration times are achived. The duration times are calculated by considering the production system and they are thought to have triangular distribution. Tab. 6 shows the duration times of transportation between workstations.

Tab. 6. *Duration times of transportation between workstations*

Between workstations	Transportation times [min]
Arrival to I1	TRIA(1.7,2.2,3)
I1→I2	TRIA(1.4,1.8,2.5)
I2→I3	TRIA(2.6,3.3,4.6)
I3→I4	TRIA(0.7,0.9,1.2)
I4→I5	TRIA(0.5,0.6,0.9)
I5→I6	TRIA(1.2,1.5,2.1)
I6→I7	TRIA(2.1,2.7,3.7)
I7→I8	TRIA(1.2,1.5,2.1)
I8→I9	TRIA(1.1,1.4,1.9)

In the simulation model in question, machine failures are also taken into considerations to reflect the real environment, as shown in Tab. 7. These values are not calculated but estimated. Failure times are thought to have exponential distribution.

Tab. 7. *Failure times of workstations*

Station name	Up time [min]	Down time [min]
Edge cutting station	EXPO(120)	EXPO(10)
Edge cleaning and sequencing	EXPO(140)	EXPO(4)
Panel production	EXPO(180)	EXPO(15)
Panel cutting	EXPO(160)	EXPO(20)
Profile spot welding	EXPO(130)	EXPO(12)
Profile tig welding	EXPO(155)	EXPO(18)
Section spot welding	EXPO(165)	EXPO(5)
Section tig welding	EXPO(200)	EXPO(25)
Grinding	EXPO(160)	EXPO(8)

In Figure 4, the simulation model of the panel line in question is presented.

Table 8 shows the module definitions of simulation model in Fig. 4.

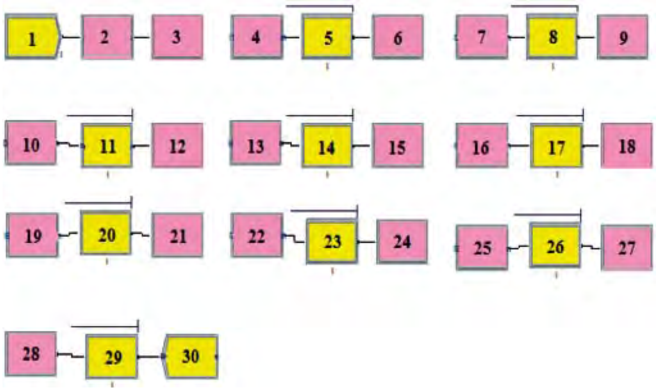

Fig. 4. *Simulation model of the panel line*

Tab. 8. *Module definitions*

Module no	Module name	Module no	Module name
1	Part Arrival	16	I5 Arrival Station
2	Arrival Station	17	Profile Spot Welding
3	Route to I1 Station	18	Route to I6 Station
4	I1 Arrival Station	19	I6 Arrival Station
5	Edge Cutting	20	Profile Tig Welding
6	Route to I2 Station	21	Route to I7 Station
7	I2 Arrival Station	22	I7 Arrival Station
8	Edge Cleaning	23	Section Spot Welding
9	Route to I3 Station	24	Route to I8 Station
10	I3 Arrival Station	25	I8 Arrival Station
11	Panel Production	26	Section Tig Welding
12	Route to I4 Station	27	Route to I9 Station
13	I4 Arrival Station	28	I9 Arrival Station
14	Panel Cutting	29	Grinding
15	Route to I5 Station	30	End of Panel Line

Tab. 9. *The process analysis of the section spot welding station (I7) (Model 2)*

No. of activity	Activity description	Activity duration time [min]
1	Transportation of matrix module structure to flat panel assembly	15
2	Alignment of matrix module structure on flat panel assembly	45
3	Horizontal spot welding and grinding operation after spot welding	50.285
4	Workers go to pick up single plate parts	0.2
5	Workers put down single plate parts	0.2
6	Workers do alignment of single plate parts	1.666
7	Horizontal spot welding of single plate parts	2.826
8	Vertical fixing of single plate parts	1.666
9	Vertical spot welding of single plate parts	2.922
10	Operating crane	0.083
11	Crane goes to single plate parts stock area	8.853
12	Crane comes down onto single plate part surface area.	12
13	Crane holds single plate parts	6
14	Crane lifts single plate parts	12
15	Crane transports single plate parts to flat panel assembly	8.83
16	Crane puts down the single plate parts for marking	12
17	Horizontal fixing of single plate parts	4
18	Crane leaves the surface area of single plate parts	6
19	Horizontal spot welding of single plate parts	7.958
20	Vertical fixing of single plate parts	4
21	Vertical spot welding of single plate parts	9.586
22	Operating grinding machine	1
23	Vertical and horizontal grinding after spot welding	14.492
24	Crane goes to pick up lifting lug	1.216
25	Crane comes down onto lifting lug's surface area	2
26	Crane holds lifting lug	1
27	Crane picks up lifting lug	2
28	Crane transports lifting lug to flat panel assembly	1.222
29	Crane puts down lifting lug on flat panel assembly	2
30	Fixing lifting lug on panel	4
31	Crane leaves lifting lug's surface area	0.332
32	Spot welding of lifting lugs	9.332
33	Crane departs from lifting lug	2
34	Cleaning	30
35	Transportation of major sub-assembly	2.528
	Total duration time	284

Running simulation for a specified duration time and determination of panel line throughput (Step 5)

The simulation model has been run for 10-day period under the assumption that the shipyard operates in two shifts. Each shift lasts 8 hours. Number of replication of the model is equal to 5. As a result of the running, the panel line has produced 11 major sub-assemblies.

Process analysis of section spot welding with application of module mounting (Step 6)

When the matrix module structure is assembled on flat panel assembly, the completion time of the section spot welding station will obviously change by nature of the things. To see the effect of the changing on throughput, the new completion time of the section spot welding station should be put in the simulation model shown in Fig. 4. In the current panel line system in question the completion time of the section spot welding station is determined as shown in Tab. 5. Tab. 9 presents the work flow of the matrix module structure. When the matrix module structure is assembled on the flat panel assembly the completion time of the section spot welding station reaches 284 min.

Modeling panel line by using simulation (Model 2) and determination of panel line throughput (Step 7)

In this step the simulation model shown in Fig. 4 is applied. All the completion duration times of the workstations remain constant except for the section spot welding station. By changing the completion time of the section spot welding station, Model 2 was obtained. The completion times of the work stations for Model 2 are shown in Tab. 10.

Tab. 10. *Completion times of the workstations on the panel line (Model 2)*

No. of station	Station name	Station completion time [min]
1	Edge cutting station	TRIA(111.5,144.9,200.8)
2	Edge cleaning and sequencing	TRIA(119.2,154.9,214.6)
3	Panel production	TRIA(368.2,478.6,491.5)
4	Panel cutting	TRIA(226.1,295.5,409.1)
5	Profile spot welding	TRIA(174.05,227.5,233.3)
6	Profile tig welding	TRIA(212.7,279.3,386.7)
7	Section spot welding	TRIA(284,367.4,516.9)
8	Section tig welding	TRIA(278,361.4,506)
9	Grinding	TRIA(85,111.3,154.7)

The transportation and failure times given in Tab. 6 and 7 are also valid for Model 2. When the simulation model is run for 10- day period under the assumption of two shifts, the panel line has produced 16 major sub-assemblies.

Comparison of Model 1 with Model 2 (Step 9)

Tab. 11 shows the comparison of Model 1 with Model 2. In both the models numbers of replication, replication lengths and working hours per day are the same, whereas the numbers of major sub-assemblies are different. This difference demonstrates the effect of the module mounting on the panel line throughput.

Tab. 11. *Comparison of the two applied models*

	Model 1	Model 2
Number of replication	5	5
Replication length [days]	10	10
Hour per day [hours]	16	16
Number of major sub- assemblies	11	16

CONCLUSION

- In this study the simulation model has been created by determining the processes performed on the panel line. The required data achieved from the process analysis have been put in the model. The simulation model has been run for 10-day period and as a result the panel line has produced 11 major sub-assemblies. In the next step, it was assumed that the matrix module structure is assembled on flat panel assembly. In this case, the completion time of section spot welding has changed from 501 min to 281 min. When the simulation model has been run in this case, the panel line has produced 16 major sub assemblies. This way the panel line produces 5 blocks more during 10 days, that means that its productivity increased by 45%.
- Therefore the application of assembling matrix module structure increases the panel line productivity by 45%. This is a good result in terms of shortening the ship production cycle.

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