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Analysis and balancing of assembly line in a machine molding factory

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ABSTRACT

In industrialization, to be able to make cheap and fast production, assembly lines are one of the most basic elements in serial production systems. It is important to balance the assembly line to continue production smoothly. By assembly line balancing is created, each work step is grouped, stations are created and each station time is brought close to the station cycle times. In this study, a refrigerator top panel pressing line is analysed. The study's aim is balancing the line for increase production rate. Firstly, the line is observed and some studies are planned. A time study is done to analyse the current situation of the line. Time study data are calculated by using Excel. Ranked Positional Weight Method is used as an intuitive method for single model U type assembly line balancing problem and mathematical modelling method is applied. The methods are used to balance the line using time study data. The solution of mathematical modelling is obtained by using Lingo. Results are compared and they are observed that results have almost the same. In conclusion, an assembly line balancing problem is mentioned in this study. Various programs related to the applied methods were used, and the data obtained as a result of current and final calculations were compared. First and last calculations and results are verified with each other. It was seen that the data obtained as a result of the study provided improvement.

1. Introduction

Technological advances and the global trade in recent years, strict price and quality competition, concentrated on production methods entail a number of new functions. Today, with the impact of rapidly increasing world population level, life is getting much more complex with the requirement to produce a large number of products. Therefore, in the middle of the 20th century "assembly line balancing" idea was posed that the amount of the claim as soon as possible, as a result of the effort to produce the desired quality and cheap. Companies must make the best use of their assembly lines in today's competitive environment. The importance of assembly line balancing also occurs here. Assembly line workstations are systems that combine a material handling system. The purpose of the system is to assemble the components of a product and obtain the finished product [1]. When the line of the product to be assembled is designed, the problem of balancing the time differences arises between the operations of the product. Assigning work elements to stations for this purpose is called 'assembly line balancing problem'. During the creation of the product need to be done jobs, should be assigned to the assembly stations to minimize assembly line balancing times. The installation of a work element should be done by looking at the priority relationship at the predetermined station [2].

Various classifications can be made as single, multiple or mixed models depending on the number of models produced on the assembly line. Assembly line balancing problems can be classified into two groups according to the status of duty times; stochastic and deterministic assembly lines. When an assembly line is fully automated, all the tasks will have a fixed operation time. When tasks are performed manually at the workstations, variability (or stochasticity) emerges [3]. There can be two main goals while balancing an assembly line. The goals are

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minimisation of the number of workstations for given cycle time and minimisation of the cycle time for a given number of workstations [4].

As already mentioned above, types of assembly line balancing are based on a set of limiting assumptions. Some of those assumptions; the processing sequence of tasks is subject to precedence restrictions, no assignment restrictions of tasks besides precedence constraints, all stations are equally equipped for machines and workers [5].

The manufacturing / installation line balancing problem is classified in different types according to the shape of the line. Assembly lines can be designed in different forms such as straight, circular, random, different angle, U-typed, zigzag according to their physical location. Conventional assembly lines are designed straight. Later, the U-typed line was preferred more in new production lines. Assembly lines are placed in u shaped lines in u shaped assembly line balancing problem. The entrance and the exit of the line are on the same parallel position in a U-type line design [6]. In recent years, the just-in-time production philosophy has been spread, U-type assembly lines usage rate has been increased [5].

The assembly line balancing method should be inspected in two groups in terms of solution method; analytical methods and heuristic methods. Analytical methods are known as optimization methods. The methods comprise of objective function and constraints. Heuristic methods give an approximate solution to the problems. There are some heuristic methods in literature such as the Ranked Positional Weight Method (Helgeson-Birnie), Precedence relationship diagram (Hoffman), COMSOAL technique (Arcus), Two-phase balancing technique (Moddie-Young), Probabilistic line balancing (Elsayed-Bouch), Grupping technique (Tonge) [7].

Assembly line balancing is mostly used the production systems. The first article about assembly line balancing was written by Salveson. In this study 0-1 integer programming model was improved to solve the problem [8]. Alagas et al studied a new constraint programming model for mixed-model assembly line balancing problems. The model minimizes the cycle time for a given number of stations [9]. Nicosio et. al. studied the problem of assigning operations to an ordered sequence of non-identical workstations, which also took precedence relationships and cycle time restrictions into consideration. The study aimed to minimise the cost of workstations. They used a dynamic programming algorithm and introduced several rules to reduce the number of states in the dynamic program [10]. Helgeson and Birnie developed a heuristic method that is called the 'Ranked Positional Weight (RPW) Method' in 1961. This method provides to assign work elements to the station in an optimal way. It takes into account the precedence relationships as well as the processing time of all tasks. The RPW value of each operation is determined and assigned operations to workstations in this method [11]. In the literature, besides the RPW method, heuristic algorithms such as tabu search are also used in line balancing problems [12]. However, when looking at the studies done, one of the most commonly used heuristic line balancing methods in the industry is the RPW approach [13]. Bongomin et al used the RPW method at balancing a trouser assembly line to increase the line efficiency as well as minimize the number of workstations. According to scenario 1, after calculating the existing assembly line the results show that the line efficiency is 35.66%, the last situation gave an improvement of line efficiency which is 80.56% by using the RPW method. The balance delay reduces from 64.34 to 19.44 and workstation number decreases from 61 to 27 in the study [14]. Ikhsan used the RPW method to develop and balance the assembly line. The number of actual workstations is 9 and it decreases to 8 in the last situation. Idle time reduce from 10441 to 3286. While Line efficiency and balance delay are 66.08%, 33.92% respectively in the initial situation, they become 86.09%, 13.91% after the RPW calculations [15]. The studies show that minimization of workstations contributes to an increase in line efficiency. In addition to the RPW method, we tackled the problem with mathematical modelling and supported the result with two approaches in the study. While dealing with the problem in the study, in addition to the RPW, which is one of the solution methods in the literature, the solution was supported by an analytical method by using a mathematical modelling method. Since there are not many studies in which these two methods are used together, it will offer a different perspective for researchers.

In this study, the role and usage method of assembly lines in the production system is mentioned. The problem of assembly line balancing is addressed frequently encountered in production lines in factories. A problem is defined related to the factory's order in a line where is the pressing process of refrigerator top panel in the molding factory. The problem arises from idle time, bottleneck between the stations and unbalanced line flow. As a result of these problems, the order is not satisfied on time and firms wait for their orders for a long time. This study was deemed necessary to eliminate these problems arising on the lines and to meet customer orders on time. It is aimed to solve the problem by using two techniques that are the "RPW" and "mathematical modelling" while balancing the assembly line. In the last part, the results have been evaluated and mentioned the effect on real life.

2. Material and Method

The assembly line balancing problem was handled with analytical and heuristic methods in this study. Heuristic methods like the RPW method present close solutions to the problems. Balancing the assembly line two techniques were used which are the "RPW method" and "mathematical modelling". The modelled problem was solved by the time study's data. In the study, the RPW method approach was supported by a mathematical modelling approach, and solutions were compared.

2.1 Time Study Calculations

Time study is a method for recording times and rates of working for specific job elements to build standards. The time study aims to establish a time for a qualified worker to perform specified work under stated conditions and at a defined rate of working [16]. There are 34 work elements in the stations. The works' times were observed by using a stopwatch for 20 observations. Observation time, normal time, average observed and normal time, standard time, and standard deviation calculated for each element. All of these calculations are shown in time study forms in appendix (Table A.1).

The observation number was calculated at a 95 percent confidence level with acceptable error 0.05 (k). While analyzing the sample size of observation, t distribution table is used [14]. The observation number is calculated by this formula. s is standard deviation; t is distribution value; k is an acceptable fraction for error; $\bar{x}$ is the mean of the sample observations.

$$n^{\iota} = \frac{S * t}{k * x} \tag{1}$$

The required observation numbers' notations and formula are shown below.
N=sufficient number of observations
n'=number of observation taken
x_i= time measured in i.th observation.
40 (hours) = 8(shift)*5(day)

$$N = \left[\frac{40\sqrt{n'\sum x_i^2 - (\sum x_i)^2}}{\sum x_i}\right]^2 \tag{2}$$

If the required observation number is higher than the observed number, the observation number should be tested once more time. The observation time values calculation is shown in a table in Appendix (Table A.1).

2.1.1 Performance Rating Calculations

The procedure is for determining the value for a factor which will adjust the measured time for an observed task performance to a task time that one would expect of a trained operator performing the task, utilizing the approved method and performing at a normal pace under specified workplace conditions [17]. Performance rating shows, level of workers' motivation. The most convenient method to designate performance rating is the Westinghouse System. According to Westinghouse System Method, there are four factors in evaluating the performance of the operator. These are skill, effort, conditions, and consistency [16, 17]. The system factors' ratings are shown in the performance rating in Table 1.

If the method is applied for the first work element;
Rating Factor = 1 ∓ Westinghouse Rating,
According to these data performance rating is;
100+100*(0.02-0.04+0.00-0.1) = 88.
The performance rating values are calculated with this formula for each operator.

2.1.2 Calculation of the Normal Time

Normal time is calculated by this formula:

$$\textit{Normal Time=Observed time*}\frac{\textit{Performance rating}}{100} \tag{3}$$

If the first work element's normal time is calculated by this formula;
1st element's normal time is calculated as 1.5*(88/100) =1.32 second.

2.1.3 Calculations of the Allowances

There are various allowances to build standard time. These are personal, fatigue, delay allowances. Calculations of the allowances are shown below.

Personal Allowances Calculations:

$$\textit{Normal Time=Observed time*}\frac{\textit{Performance rating}}{100} \tag{4}$$

A daily work hour is a total of 420 minutes in the factory. Calculation of Personal Allowances are given in Table 2.

Table 1. Performance ratings for the first element [16].

Effort	E1	Fair	- 0.04
Conditions	C	Good	+0.02
Consistency	D	Average	0.00
Skill	E2	E2	-0.1
Total Rating Factor			-0.12

Table 2. Calculations of personal allowances

Personal Allowances	**Times in a day**
Taking a drink	7 minutes
Going to bathroom	8 minutes
Talking to other workers	7 minutes
Total Personal Allowances	22 minutes
Personal allowances percentage [(22 minutes/420 minutes)*100]	5.23%

Fatigue Allowances Calculations:

$$\text{Fatigue Allowances Percentage} = \frac{\text{Fatigue allowances time}}{\text{Daily work minute}} * 100 \quad (5)$$

Calculation of Fatigue Allowances are given in Table 3.

Delay Allowances Calculations:

Delay Allowances Calculations = (Delay Allowances Time/ Daily Work Minute)*100
Total allowances=Personal allowances+ Fatigue Allowances+ Delay Allowances.
Calculation of Fatigue Allowances are given in Table 4.

2.1.4 Calculations of the Standard Times

While the standard time is calculated; assigned to a particular employee is a qualified job, tools and equipment, raw materials, the work environment, and the level of performance are needed to be defined. Standard Time is calculated using the following formula.
Standard Time=Normal Time*(1+Allowances)
For example for the first element performance rating is below;
Standard Time = 1.52*(1+0.16)=1.766≅1.77 seconds.

Other work elements' standard time is calculated in the same way as the first work element. The total standard times are calculated as 100. 22 seconds.

For obtaining and saving data time study and the stopwatch methods are used. In the time study form model name work element name and number, operator name machine, machine number, performance ratings are written. For every work element in the assembly line, 20 observations were made and written on to the time study form (Table A.2). A time Study form was prepared for work element 1. The time study form of every task is shown in Appendix (Table A.1).

Table 3. Calculations of fatigue allowances

Fatigue Allowances	Times in a day
Work breaks (tea or coffee breaks)	30 minutes
Total Fatigue Allowances	30 minutes
Fatigue Allowances percentage [(30 minutes/420 minutes)*100]	7.14%

Table 4. Calculations of delay allowances

Delay Allowances	Times in a day
Machine injury	5 minutes
Machine maintenance and breakdown	6 minutes
Waiting for materials	3 minutes
Controlling and cleaning work place	2 minutes
Total Delay Allowances	16 minutes
Delay Allowances (16 minutes/420 minutes)*100	3.80%
Total allowances=5.23%+7.14%+3.80% (Personal+Fatigue+Delay Allowances)	16.17%

2.2 Application of Assembly Line Balancing

The work study processes are applied for line balancing. The standard times are calculated by using the work study method. According to observations which are done in the factory determined operator's number, machine numbers, and work hours in the assembly line in this factory. The factory works from 8:45 to 16:45. There is an assembly line that has 34 operations, 6 machines, and 7 operators in the production area. These machines are 2 excentric and 4 hydraulic presses. Sixth and seventh operations are done in the same machine because the machine has two processes sides.

The factory wants to increase the production rate. An assembly line balancing study was done in the factory to meet demand. Firstly, some calculations were made, such as calculating cycle times, drawing the priority relationship diagram, and applying the sequential positional weight method. Then, the mathematical modelling method was used and compared the two methods' results.

2.2.1 Ranked Positional Weight Method

The RPW method takes account of the standard times value of the element and its position in the precedence diagram. Then the elements are assigned to the workstation in the general order of their RPW values. Precedence Relationship Diagram and standard time of work elements are calculated and shown in appendix (Table A.3). The precedence matrix of the top panel is shown in appendix (Figure A.1).

2.2.2 Calculation of Cycle Time

The company starts to work from 8:45 am to 16:45. A shift period takes 8 hours. There are a one-hour lunch break and 2 coffee/tea breaks. Every coffee or tea break takes 15 minutes. According to these data, available working time and cycle time are calculated. "C" states cycle time, "N" is production rate, and "T" is daily work hours (Available working time).

$$C = \frac{T}{N} \quad (6)$$

N=1150;
Available working time= (8 hours*60 minutes)-(30 minutes +15 minutes +15 minutes) = 480minutes-60 minutes = 420 minutes = 25200 seconds.
C = 25200/1150 = 21.90 seconds. After calculation of cycle time, workstation number has been calculated.
$\text{Workstation number} = WS = (\text{Total Production Time})/(\text{Cycle Time})$
$WS = 100.22/21.90 = 4.57 \cong 5$ *workstations*

Calculations of "RPW" and "distribution of the tasks" are shown in Table 5.

Table 5. Calculation of RPW and distribution of tasks

Station No	Tasks	Cumulative Station Time	Weight Distribution	Ranked Positional Weight
1st station	1	1.76	1.76	100.22
	2	3.64	5.40	98.34
	3	0.95	6.35	94.70
	4	0.79	7.14	93.75
	5	2.38	9.52	92.96
	6	3.42	12.94	90.58
	7	3.98	16.92	87.16
	8	1.04	17.96	83.18
	9	3.34	21.30	82.14
2nd station	10	3.66	3.66	78.80
	11	2.28	5.94	75.14
	12	2.18	8.12	72.86
	13	0.68	8.80	70.68
	14	9.31	18.11	70.00
	15	1.99	20.10	60.69
3rd station	16	2.23	2.23	58.70
	17	3.17	5.40	56.47
	18	1.59	6.99	53.30
	19	0.57	7.56	51.71
	20	4.13	11.69	51.14
	21	2.03	13.72	47.01
	22	5.13	18.85	44.98
	23	1.78	20.63	39.85
4th station	24	5.04	5.04	38.07
	25	4.07	9.11	33.03
	26	2.30	11.41	28.96
	27	2.05	13.46	26.66
	28	2.17	15.63	24.61
	29	3.59	19.22	22.44
5th station	30	4.43	4.43	18.85
	31	1.61	6.04	14.42
	32	5.12	11.16	12.81
	33	3.03	14.19	7.69
	34	4.66	18.85	4.66

The calculation of idle time is as follows. "C" states cycle time, "D" is the difference between task and cycle time, "T" is workstation time (task time), "K" is station number, and "d_k" is the delay time of k^{th} station.

$$d_k = C - Tk \quad (7)$$

$$D = k_c - \sum ti \quad (8)$$

Total Idle Time= $\sum$ D = (21.9-21.30) + (21.9-20.10) + (21.9-20.63) + (21.9-19.22) + (21.9-18.85)

$\sum$ D =9.40 seconds.

Proportion of idle time for each cycle = 9.40/(21.90*5) = 0.085 = 8.5%.

2.2.3 Calculation of Balance Efficiency and Balance Delay

There are some notations for the calculations of balance efficiency and delay as follows. D is balance delay; t is time of the work elements; E is efficiency; C is cycle time; K is number of work station.

Balance Efficiency;

$$E = [(\sum ti)/(K * C)]*100 \quad (9)$$

Balance Delay;

$$D = [(K * C - \sum ti)/(K * C)]*100 \quad (10)$$

Before the line balancing:

Balance Efficiency; $E = [100{,}2/(7 * 21{,}90)]$**100=0,65*

Balance Delay; $D = [(7 * 21.90 - 100.22)/(7 * 21.90)]$ **100=0.3462*

After the line balancing:

New Balance Efficiency; $E = [100.22/(5 * 21.90)]$**100=0.915*

New Balance Delay; $D = [(5 * 21.90 - 100.22)/(5 * 21.90)]$*100=0.0847

2.3 Mathematical Modelling Method

The assembly line balancing is an optimization problem. The proposed mathematical model is solved with the Lingo program providing solution near to optimal solutions. "Task" defines work elements, "Station" defines station number, and "Predecessor" defines the precedence relationship between works. While writing the constraints, have been taken into account the criteria below. The mathematical model is formulated for our problem.

- The sum of task times for the set of tasks assigned to each workstation does not exceed the cycle time (Equation 11) [18].
- Each task must be assigned to only one workstation (Equation 12) [18].
- The stations must be arranged according to a precedence relationship. If task v is to be assigned to station b, then it is immediate predecessor u must be assigned to some station between 1and b (Equation 13) [18]. These constraints are among the strict constraints in the model.

In this model, the station number is assigned to a big number "M (100.000)" (Equation 14). The set of P identifies the assembly order constraints.

There are some notations in the model:

P = {(u,v): task u must precede task v}.

K: Number of workstation

N: Number of tasks

R: Required number of workstation.

C: Cycle time

The notations considered in the mathematical model are clarified as follows:

Indices

i, u, v: tasks

k, b, j: stations

t: Time of the work elements

t_i: Completion time of the task "i"

Decision Variables

$$x_{ik} = \begin{cases} 1; \text{ if task i is assigned to station k} \\ 0; \text{ otherwise;} \end{cases}$$

Constraints

$$\sum_{i=1}^{N} t_i X_{ik} \leq C \qquad k = 1, \ldots, K \tag{11}$$

$$\sum_{k=1}^{K} X_{ik} = 1 \qquad i = 1, \ldots, N \tag{12}$$

$$X_{vb} \leq \sum_{j=1}^{b} X_{uj} \quad b = 1, \ldots, K \; and \; (u,v) \epsilon \, P \tag{13}$$

$$\sum_{i=1}^{N} X_{ij} \leq MR_j \qquad \forall_j \tag{14}$$

$$x_{ik} \, \epsilon \, \{0,1\} \qquad \forall_i; \; \forall_k \tag{15}$$

The optimization problem is formulated using binary variables as decision variables. Equation (15) denotes the constraint showing that the decision variable consists of 0-1 integer variables. The domain of the variables is defined in this way.

Objective Function

$$Min \sum_{j=1}^{K} R_j \tag{16}$$

3. Results and Discussion

Some data were obtained as a result of the calculations. The mathematical model and RPW method's results were calculated and comprised by using the data. According to the RPW method's results, when the initial situation and the last situation are compared it is clear that while the workstation number decreases, the line efficiency increases. Total idle time had been calculated 53.08 seconds in the actual situation. After balancing, the total idle time had decreased to 9.40 seconds. Balance efficiency was improved from 65% to 91.52%, and balance delay was decreased from 34.62% to 8.47%. It shows that, when the workstation numbers drop from 7 to 5, time losses decrease significantly. The values of the initial and the last situation of parameters are shown in Table 6 comparatively.

The objective of the mathematical model is to minimize the number of stations. The model is applied for two cycle time "22" and "35". Additionally, to see the effect of the increase in cycle time on the number of stations, the model was also solved with a high cycle time such as 35. The distribution of tasks to each station is shown in the two situations clearly. The mathematical model is calculated for the cycle time 22 and then for cycle time 35.

Table 6. Comparison of the parameters before and after balancing

Parameters	**Initial Situation**	**Last Situation**
Number of workstations	7	5
Total idle time (sec.)	53.08	9.40
Balance delay (%)	34.62%	8.47%
Balance efficiency (%)	65%	91.52%

Table 7. Results of mathematical model on lingo

Global optimal solution for "cycle time 22"	**Global optimal solution for "cycle time 35"**
Objective value: 5.000000	Objective value: 4.000000
Objective bound: 5.000000	Objective bound: 4.000000
Infeasibilities: 0.000000	Infeasibilities: 0.000000
Extended solver steps: 129	Extended solver steps: 267
Total solver iterations: 15883	Total solver iterations: 41316

According to lingo solutions, the objective function value is 5 for the cycle time 22. If the cycle time is increased to 35, the station number is to be 4. It means that, if the cycle time is increased, the station number is decreased. These calculations' results of lingo solutions are shown in Table 7. However, "cycle time 22" and "5 stations" are more optimal to balance both cycle times and the number of stations.

Similarly, with the RPW method solution, the station number is decreased from 7 to 5 stations in the mathematical model with cycle time 22. With the decrease in the number of stations, line efficiency increased and delays decreased. In this way, the mathematical modelling solution is near and parallel to the RPW method solution.

4. Conclusion

In this project, an assembly line was analysed. At the end of the literature review and researches, some methods were determined to solve the assembly line balancing problem. The RPW method and the mathematical modelling methods were used. These methods were compared and it was found that the results similar to each other. As a result of the studies, after line balancing, balance efficiency was improved from 65% to 91.52%. Balance delay decreased from 34.62% to 8.47% according to the current situation of the line. At the same time, idle times were decreased. In the mathematical modelling solution, the station number decreased from 7 to 5 stations similar to the RPW method solution. The mathematical modelling method was applied with two different cycle times to see the difference between changes in station numbers. While station number decreases, idle times decrease. The order will be satisfied as requested. It has been found that the proposed solution provides a significant improvement in assembly line efficiency. It is thought that this study will provide a different perspective for researchers dealing with assembly line balancing problem. In future studies, in addition to minimizing the number of stations, new constraints will be added to the model and effective and efficient use of stations will be provided. Moreover, in future studies, in addition to mathematical models and RPW solutions, artificial intelligence algorithms will be used to achieve more optimal results faster in the solution space.

Declaration

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The authors also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

Author Contributions

E. Can developed the methodology, collected data, and formed the inputs of the mathematical model. She worked in the time study process, applied heuristic algorithms and analyzed the data. A. Öner structured the mathematical model and contributed to other processes.

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Appendix

Table A.1. General time study form

Station	work element no	work element	t value	Standart deviation	Mean	k	n'	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Station 1	Bur Cutting Process												OBSERVED TIMES														
	1	Taking panel from table with magnet	2,09	0,372	1,728	0,05	81,1	1,5	1,800	1,320	1,260	1,980	1,500	2,040	1,560	1,620	2,340	1,320	2,400	1,200	1,380	2,340	1,920	1,500	1,980	1,860	1,740
	2	Putting panel into the press	2,09	0,240	2,831	0,05	12,5	2,82	2,75	2,33	2,56	2,89	2,71	3,01	2,91	2,36	2,87	3,12	3,24	2,58	2,93	3,06	3,09	2,99	2,73	2,79	2,87
	3	Standing on press button	2,09	0,211	0,745	0,05	140	0,66	0,72	0,61	0,92	0,47	0,95	0,81	0,65	0,77	0,68	0,85	0,42	0,47	1,32	1,03	0,57	0,68	0,82	0,68	0,81
	4	Working the press	2,09	0,007	0,572	0,05	0,3	0,57	0,57	0,57	0,58	0,58	0,57	0,57	0,58	0,57	0,57	0,57	0,58	0,56	0,56	0,57	0,59	0,56	0,57	0,57	0,57
	5	Taking the panel from press stall and putting to the table	2,09	0,327	1,954	0,05	48,8	1,32	1,76	1,48	1,52	1,99	1,73	2,06	2,14	1,96	2,45	2,66	2,14	1,85	1,67	1,96	2,15	2,26	1,82	1,97	2,19
Station-2	Border Bending Prosses												OBSERVED TIMES														
	work element no	work element	t value	Standart deviation	Mean	k	n'	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1	Taking panel from table with magnet	2,09	0,542	2,949	0,05	59	2,100	2,800	2,63	2,87	2,61	3,21	3,61	2,99	3,01	3,67	2,89	3,27	3,54	4,01	2,21	2,38	3,64	2,54	2,71	2,29
	2	Putting panel into the press	2,09	0,407	3,265	0,05	27,2	4,08	2,94	3,71	2,96	3,19	3,65	2,94	3,17	2,89	2,86	3,76	3,49	2,98	2,81	4,03	2,91	3,25	2,88	3,25	3,54
	3	Standing on press button	2,09	0,082	0,721	0,05	22,4	0,66	0,68	0,71	0,69	0,77	0,65	0,81	0,91	0,67	0,68	0,74	0,61	0,73	0,68	0,66	0,66	0,73	0,81	0,67	0,90
	4	Working the press	2,09	4,200	3,027	0,05	3363	2,088	2,088	2,088	20,87	2,089	2,08	2,084	2,084	2,089	2,09	2,091	2,092	2,087	2,088	2,09	2,09	2,088	2,089	2,09	2,088
	5	Taking the panel from press stall and putting to the table	2,09	0,658	2,865	0,05	92,1	2,28	2,54	3,12	3,89	2,75	1,53	1,87	3,65	3,54	3,42	3,22	2,96	2,74	2,51	4,04	2,25	2,31	2,87	3,17	2,63
Station-3	Bending Proces												OBSERVED TIMES														
	work element no	work element	t value	Standart d	Mean	k		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1	Taking panel from table	2,09	0,583	2,2355	0,05	119	1,44	1,61	1,29	1,84	2,11	2,15	2,64	1,58	1,67	2,66	3,16	2,73	2,41	2,77	2,95	3,05	2,67	1,85	1,69	2,44
	2	Putting panel into the press	2,09	0,854	2,086	0,05	293	1,26	1,02	0,54	1,56	1,83	1,33	1,47	2,16	2,83	2,67	1,98	1,65	2,74	3,26	2,87	3,14	2,81	3,65	1,53	1,42
	3	Standing on press button	2,09	0,145	0,5313	0,05	130	0,36	0,456	0,65	0,49	0,89	0,52	0,58	0,39	0,46	0,71	0,58	0,46	0,81	0,51	0,37	0,6	0,43	0,55	0,39	0,42
	4	Working the press	2,09	0,023	8,0156	0,05	0,01	8,02	8,01	8,03	8,04	7,99	8,02	8	8,05	7,98	8,04	8,05	7,99	7,98	8,01	8,03	8,04	7,99	8	8,01	8,031
	5	Taking the panel from press stall and putting to the table	2,09	1,172	1,9495	0,05	632	0,48	1,32	0,98	0,84	2,65	4,27	3,82	3,64	2,17	0,88	0,79	2,11	2,6	1,27	3,52	2,49	0,99	0,78	1,18	2,21
Station-4	Flange Bending Process												OBSERVED TIMES														
	work element no	work element	t value	Standart d	Mean	k	n'	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1	Taking panel from table	2,09	1,087	1,8315	0,05	615	0,9	0,36	0,48	0,51	0,98	1,29	2,33	0,89	3,55	0,99	1,58	1,91	2,11	3,21	3,36	1,59	1,69	2,28	4,01	2,61
	2	Putting panel into the press	2,09	0,993	2,374	0,05	306	1,57	1,12	3,24	0,98	0,87	2,31	2,87	3,64	1,69	0,91	2,64	2,87	3,67	1,85	2,53	2,67	4,13	2,59	1,82	3,51
	3	Standing on press button	2,09	0,482	1,5599	0,05	167	0,42	0,87	1,11	1,16	1,09	1,65	1,998	1,45	1,59	2,1	1,66	0,99	1,84	1,92	2,22	2,09	1,88	1,79	1,92	1,45
	4	Working the press	2,09	0,002	0,4929	0,05	0,02	0,492	0,491	0,492	0,495	0,496	0,493	0,492	0,496	0,492	0,492	0,491	0,493	0,492	0,492	0,493	0,491	0,496	0,495	0,49	0,492
	5	Taking the panel from press stall and putting to the table	2,09	0,861	2,74	0,05	173	1,25	3,42	1,66	2,28	2,64	2,98	4,12	3,66	1,24	1,68	1,94	2,59	2,97	2,61	3,16	4,1	2,98	2,71	3,14	3,67
Station-5	Flange Ironing Process												OBSERVED TIMES														
	work element no	work element	t value	Standart deviation	Mean	k	n'	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1	Taking panel from trolley	2,09	0,890	2,06	0,05	326	0,96	1,26	1,24	1,3	0,98	0,94	0,87	2,22	2,51	3,65	3,1	1,45	1,96	3,46	3,11	2,57	2,25	2,27	2,61	2,49
	2	Putting panel into the press	2,09	0,588	3,9115	0,05	39,5	3,11	2,99	3,27	3,21	5,23	3,46	4,02	3,91	4,87	4,42	3,39	4,56	3,99	4,1	3,99	4	3,97	3,51	4,27	3,96
	3	Standing on press button	2,09	0,176	1,521	0,05	23,3	1,32	1,69	1,54	1,67	1,66	1,98	1,59	1,36	1,34	1,64	1,49	1,48	1,44	1,61	1,67	1,59	1,32	1,29	1,41	1,33
	4	Working the press	2,09	0,010	4,3435	0,05	0,01	4,34	4,35	4,35	4,34	4,34	4,35	4,34	4,36	4,33	4,36	4,35	4,35	4,35	4,34	4,32	4,34	4,33	4,35	4,34	4,34
	5	Taking the panel from press stall and putting to the table	2,09	0,800	3,0215	0,05	122	2,98	3,21	3,45	1,26	1,29	2,85	2,67	3,64	3,94	3,46	2,61	1,91	2,47	3,69	3,27	2,88	3,91	3,46	3,81	3,67
Station-6	Border Bending Process												OBSERVED TIMES														
	work element no	work element	t value	Standart d	Mean	k	n'	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1	Taking panel from table	2,09	0,652	1,627	0,05	280	0,72	1,12	1,26	0,98	0,94	0,71	1,26	1,98	1,87	2,65	2,12	0,81	2,71	1,46	2,19	2,61	1,75	1,56	1,63	2,21
	2	Putting panel into the press	2,09	0,554	2,5235	0,05	84,3	2,41	3,26	1,92	2,95	3,12	1,97	1,83	2,55	3,12	1,93	2,77	2,54	2,69	2,81	3,45	1,69	1,82	3,14	2,51	1,99
	3	Standing on press button	2,09	0,350	2,08	0,05	49,4	2,11	2,25	1,85	1,96	2,53	2,45	2,15	2,14	2,31	2,67	2,21	2,26	1,64	1,59	1,67	1,26	2,45	1,98	2,11	2,01
	4	Working the press	2,09	0,118	2,9185	0,05	2,87	2,94	2,98	3,02	2,96	2,64	2,65	2,67	2,99	3,02	3,03	2,94	2,98	2,96	2,94	2,94	2,94	2,95	2,93	2,95	2,94
	5	Taking the panel from press and dragging to the table	2,09	0,580	4,8975	0,05	24,5	5,1	4,87	4,56	4,99	5,26	5,31	5,6	3,49	5,16	5,45	4,99	4,58	4,76	5,26	3,91	5,16	5,34	4,66	3,89	5,61
Station-7	Hole Punching Proces												OBSERVED TIMES														
	work element no	work element	t value	Standart d	Mean	k	n'	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1	Taking panel from trolley	2,09	0,650	1,365	0,05	396	0,66	0,92	0,64	0,87	1,22	1,69	0,82	1,65	1,98	1,54	0,36	0,88	0,73	1,59	1,99	2,06	2,58	2,41	0,85	1,86
	2	Putting panel into the vertical press	2,09	1,075	5,6585	0,05	63,1	6,3	5,61	5,33	7,2	5,12	4,65	6,31	4,99	5,03	7,1	4,61	5,73	6,21	4,92	4,85	8,21	7	4,1	4,77	5,13
	3	Fixing the panel manuel(pressing pro	2,09	0,062	2,4865	0,05	1,09	2,46	2,65	2,49	2,67	2,49	2,48	2,45	2,47	2,46	2,49	2,43	2,46	2,44	2,49	2,48	2,46	2,49	2,46	2,46	2,45
	4	Taking the panel from press stall and putting to the table	2,09	0,786	3,718	0,05	78	2,72	3,45	3,65	4,98	4,52	3,67	2,98	2,46	2,77	4,26	4,15	3,65	3,33	5,01	2,97	3,66	4,51	2,82	4,12	4,68

Table A.2. Time study form

TIME STUDY FORM				
Location: Machine Molding Factory				
Work Element No:1				
Work Element Name: Bur Cutting Process				
Analyst Name: Esra Can				
Observation No	**Observed time**	**Performance rating**	**Normal time**	**Allowances**
1	1.50	88	1.32	16.17
2	1.80	88	1.58	16.17
3	1.32	88	1.16	16.17
4	1.26	88	1.11	16.17
5	1.98	88	1.74	16.17
6	1.50	88	1.32	16.17
7	2.04	88	1.80	16.17
8	1.56	88	1.37	16.17
9	1.62	88	1.43	16.17
10	2.34	88	2.06	16.17
11	1.32	88	1.16	16.17
12	2.40	88	2.11	16.17
13	1.20	88	1.06	16.17
14	1.38	88	1.21	16.17
15	2.34	88	2.06	16.17
16	1.92	88	1.69	16.17
17	1.50	88	1.32	16.17
18	1.98	88	1.74	16.17
19	1.86	88	1.64	16.17
20	1.74	88	1.53	16.17
Average Observation Time				1.73 seconds
Average Normal Time				1.52 seconds
Standard Time				1.76 seconds
Total Allowances Percentage				16.17%
Standard Deviation				0.372

Table A.3. Precedence relationship diagram

Work Element	Standard Time	Precedence Relations
1	1.76	_
2	3.64	1
3	0.95	2
4	0.79	3
5	2.38	4
6	3.42	5
7	3.98	6
8	1.04	7
9	3.34	8
10	3.66	9
11	2.28	10
12	2.18	11
13	0.68	12
14	9.31	13
15	1.99	14
16	2.23	15
17	3.17	16
18	1.59	17
19	0.57	18
20	4.13	19
21	2.03	20
22	5.13	21
23	1.78	22
24	5.04	23
25	4.07	24
26	2.30	25
27	2.05	26
28	2.17	27
29	3.59	28
30	4.43	29
31	1.61	30
32	5.12	31
33	3.03	32
34	4.66	33

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2			1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3				1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4					1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5						1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6							1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7								1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8									1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9										1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10											1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11												1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12													1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13														1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14															1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15																1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16																	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17																		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18																			1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19																				1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20																					1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21																						1	0	0	0	0	0	0	0	0	0	0	0	0	0
22																							1	0	0	0	0	0	0	0	0	0	0	0	0
23																								1	0	0	0	0	0	0	0	0	0	0	0
24																									1	0	0	0	0	0	0	0	0	0	0
25																										1	0	0	0	0	0	0	0	0	0
26																											1	0	0	0	0	0	0	0	0
27																												1	0	0	0	0	0	0	0
28																													1	0	0	0	0	0	0
29																														1	0	0	0	0	0
30																															1	0	0	0	0
31																																1	0	0	0
32																																	1	0	0
33																																		1	0
34																																			1
35																																			

Figure A.1. The precedence matrix of top panel