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PROCESS ANALYSIS AND OPTIMAL FACILITY LAYOUT PLANNING IN MANUFACTURING SYSTEMS

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Abstract: In this article, it is emphasized that the process analysis for companies is carried out by using the DISCO process mining program and the results are interpreted and developed. In the light of machine and worker occupancy information obtained as a result of process analysis, imbalances, if any, are detected. These imbalances are resolved by arranging job assignments. Another information that we obtain is the time elapsed until the processing of any workpiece on a machine is finished. This time consists of the time elapsed between the machines and the waiting time in the queue of the machine to be processed. The waiting time in the queue of the machine will be improved by adjusting the workload balance of the machines and the transportation times will be improved by creating the best plant layout suitable for the process. As a result, the facility layout of the factory was made considering the functional grouping. In the study, a layout is designed in accordance with the workflow of the products. With this newly designed plan, it has been determined that the products can be produced by covering 50% less transport distance. In addition, the workload imbalances of the machines and workers were corrected by changes in job assignments. This has reduced the cycle time of a product by eliminating bottlenecks at the factory.

Keywords: Process analysis, facility layout planning, process mining, optimization of facility layout, operations research.

MSC: 90C11.

1. INTRODUCTION

Organizations need various processes in order to carry out their activities and each department has its own processes. For an enterprise in the manufacturing sector the process of the production department, for instance, starts with the delivery of raw materials and continues until the final product is formed. Particularly the manufacturing process which includes transporting raw materials and semi-products across machines till they are in the form of final, is vital for efficiency purposes.

Process analysis can provide information about the transport time between machines and the workload density of the machines and workers. In light of this information, the bottlenecks that cause problems in production, workload imbalances between machines and between workers can be easily detected. Improvements can be made to the bottlenecks found and balances of job assignments to the machines and workers can be eliminated and the problem of workload imbalances can be solved. However, in order to improve transport times, which is another data we have obtained, the layout of the plant needs to be designed in accordance with the processes. In this article, process analysis will be carried out to explore the bottlenecks of the enterprise in the light of the information to be obtained, to find solutions for the determination of workload imbalances and to eliminate them, and finally to find the optimum plant layout suitable for the processes and to minimize transport times.

2. CONCEPTUAL REVIEW

2.1. Process Mining

Every business/factory with a commercial purpose wants to make decisions by predicting the future based on various information about the past. These decisions need to be based on scientific inference. Process mining is engaged in this phase. Process mining includes; process discovery, conformance checking, social network/organization mining, model extension, model repair, case prediction and history-based recommendations [1]. The planned process flow may not be fully experienced in real life. In addition, unpredictable flows can be experienced depending on the system needs [2]. With process mining, all flow in the system can be revealed. In short, the system may be more complex than anticipated.

Today, most of the company have problems with extracting the information from their huge raw data. The digital universe may allow recording and analyzing events [3]. Process mining is kind of a process management technique that analysis business processes via recorded events [4]. Process mining gives the answers about process like what happened, why it happened, what will happen, what is the best that can happen [5]. According to these questions' answers, companies direct their future and take their decisions more accurate. There are various analysis methods and approaches [4, 6].

Process mining starts with collecting data-keeping event log. In process mining, the event log is analyzed under case names, and every process under each case is called as activity [5]. Below, there is an example of the event log (Figure 1).

	A	B	C	D	E
1	Case ID	Activity	Resource	Start Timestamp	Complete Timestamp
2	1.04.D.65.31.262.1	MONTAJ31	Bağlantı Flanşı Montajı	2019-06-28 11:32:15.000	2019-06-28 13:06:37.000
3	1.04.D.65.31.262.1	MONTAJ31	Bağlantı Flanşı Montajı	2019-06-28 14:00:01.000	2019-06-28 15:00:11.000
4	1.04.D.65.31.262.1	MONTAJ31	Bağlantı Flanşı Montajı	2019-06-28 15:25:46.000	2019-06-28 16:30:02.000
5	1.04.D.65.31.262.1	BOYAKAB2	Boyaya Hazırlık	2018-03-30 12:00:42.000	2018-03-30 13:03:01.000
6	1.04.D.65.31.262.1	BOYAKAB2	Boyaya Hazırlık	2018-05-08 10:45:12.000	2018-05-08 10:46:09.000
7	1.04.D.65.31.262.1	BOYAKAB2	Boyaya Hazırlık	2018-07-12 08:55:54.000	2018-07-12 09:30:07.000

Figure 1: Example of the event log

For process mining analysis, the event log file may upload to the DISCO program [7,8]. The DISCO program is used to create the process flow. In addition, this program process is visualized. Data visualization is accepted in engineering fields by obtaining behavioral character with an analysis of data [9,10]. This program performs an analysis of cases with time and frequency data [11]. The program needs some manufacturing information to create the process flow. The essential ones are Case ID, Activity, Resource, Start & End Times. Other information such as the number of parts, description of parts are optional. In line with this information, the DISCO program creates performance and frequency flow based on machine and worker. While DISCO creates the process flow; machines, which has long waiting time, can be shown in a darker color compared to the other machines. Under the presented process flow, it can be seen which machines have bottlenecks, and therefore which workers have a high workload. An example of the frequency process flow based on the machine is shown in Figure 2.

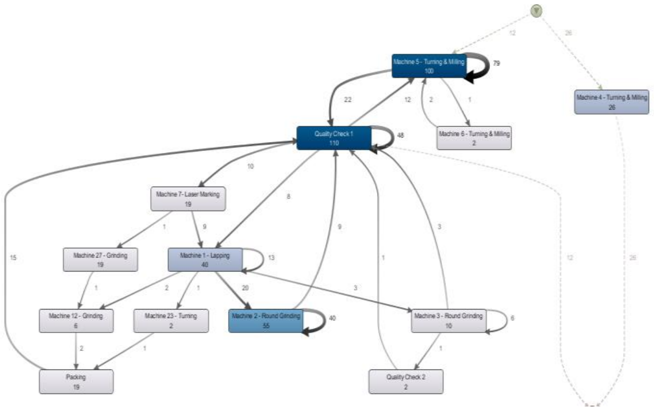

Figure 2: View of frequency between machines

In Figure 3, there is a flow that shows the bottleneck in the system. The machine which colored by dark red has a long waiting time compared to other machines.

The bottleneck can be observed for two essential reasons. One reason is that the part waits for the machine. Another reason is that the part waits for the worker.

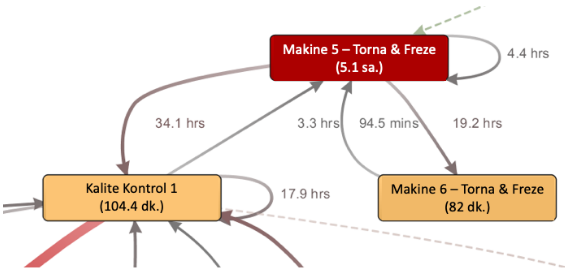

Figure 3: View of the bottleneck.

The part of the observed bottlenecks how they are fixed explained in the Section 3.2.

2.2. Facility Layout Planning

The purpose of facility layout problems is to minimize the costs affected by this layout in the production system. The main limitation encountered in doing this is the limited space of the facility [23]. The facility layout is affected by the features of the production system and the features of the product produced [24]. These should be taken into account in a study on the facility layout plan.

Although there are differences in production systems and products, what is fundamentally common is the continuous realization of transportation operations [27]. In some production facilities, the machines perform their operations without the need for constant control of the operator. Cellular production units are frequently seen in these production facilities. Some machines perform various operations inside these cells and these machines are controlled by one or more operators [25]. The purpose of the cells is to gather the necessary machines in a cell and shorten the transport distance.

In some production systems, transportation is provided by forklifts or marching bands. The biggest challenge in this type of production facility is to regulate this transport traffic [26]. Failure to do the layout of the facility in accordance with the processes results in transportation costs and dissatisfaction with the excess transportation of the employees [12]. In recent years, interest in facility layout planning, which is a study that reduces these costs, which can be considered as important cost items for enterprises, has increased [17,18]. Performing the facility layout after the process analysis gives useful results. Because the facility layout, which is done without eliminating the workload imbalance between the co-departments, will not remain optimal when this imbalance is eliminated in the future. In this study, the process analysis of an enterprise will be made with the DISCO program. The bottlenecks indicated by the program will be examined and workload imbalance will be eliminated. In addition, a mathematical model will be created that will be used to find the most suitable plant layout suitable for the processes of the enterprise, and a suitable plant layout will be found for a sample factory.

There are different approaches in the literature as facility planning of equal-sized and different sized machines or sections [13]. The MIP model developed by Heragu and Kusiak (1991) for machines of unequal size and the model developed by Das (1993) with restrictions compared to the input and output points in the settlement are sample models.

Also, there are facility layout studies where the shapes of the machines are regular or irregular [14-16]. The first mathematical model to be examined in this study will cover the case where the machines or departments are rectangular and of equal size. It will then focus on how to adapt this model for non-uniform and rectangular-shaped machines or sections. In this study, the smallest conveying distance will be tried to be obtained by considering the number of parts (frequency) flowing between machines. Some approaches make machines interrelated according to the amount of part transport between each other and reduce the distance between these machines [19-22]. The subject discussed in this article is not just a study specific to the production facilities. The study also applies to all organizations that have distribution between working processes. Because in an organization with a distribution process, the primary purpose is to arrange the placement of the distributed parts in a way that minimizes the transport distance [28,29]. In this respect, it is original enough to set an example for future studies in the literature.

2.2.1. Facility Layout Model

In order to set up the facility layout model, firstly the floor area of the enterprise on which our machines or departments will be placed must be defined mathematically. In the model, integer programming will be used. The number of machines or sections to be placed will be defined by the index i and the facility floor is divided into "i" pieces and numbered. The Figure 4 shows that an exemplary facility floor area is divided into 8 identical parts for i = 8.

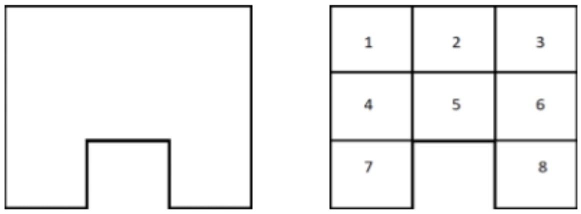

Figure 4: Sample operating floor area divided into 8 identical parts

2.2.2. Parameters, variables, indices

İndices:
i: $i'th$ machine or department
j: $j'th$ machine or department
k: $k'th$ location
l: $l'th$ location

Parameters:
fij: Number of parts transported from $i'th$ machine to $j'th$ machine
d_{kl}: Distance between $k'th$ and $l'th$ location

Binary variables:
x_{ikjl}: if $i'th$ machine is at the $k'th$ location and $j'th$ machine is at the $l'th$ location 1; otherwise 0
y_{ik}: if $i'th$ machine is at the $k'th$ location 1; otherwise 0
y_{jl}: if $j'th$ machine is at the $l'th$ location 1; otherwise 0

In the model, both the index i and j define the machines. The reason for specifying the machine with two separate indices is that it allows us to define the number of parts carried between the $i'th$ machine and the $j'th$ machine in the fij parameter as well as the definition of other parameters and variables. Similarly, the locations are defined by two identical indices, k and l, so that the parameter d_{kl}can be defined. When indexes are identified in this way, the variable $y_{ik}$and the same variable y_{jl}should be defined. In the constraints section, x_{ikjl} will be defined by y_{ik} and y_{jl}.

2.2.3. Mathematical Formulation of the Model

The Mathematical formulation of the model in the study is as follows:

$$min \sum_{ijkl} f(i,j) * d(k,l) * x(i,j,k,l) \quad (1)$$

s.t.

$$\sum_{i} y(i,k) = 1, \forall k \quad (2)$$

$$\sum_{k} y(i,k) = 1, \forall i \quad (3)$$

$$y(i,k) = y(j,l), \forall i = j, k = l \quad (4)$$

$$x(i,k,j,l) \geq y(i,k) + y(j,\mathrm{l}) - 1, \ \forall i,j,k,l \quad (5)$$

The solver tries to find the minimum objective function value by changing the value of x_{ikjl} binary variable in the program objective function. If any x_{ikjl}: =1;

Multiplication of parameters d_{kl}:, including the distance between location k and location l, and fij, including how many parts have been transported between machine i assigned to location k and machine j assigned to location l, indicates the total distance traveled from the machine i to machine j to carry parts (see objective function (1)).

The model should not assign more than one machine to any location, and since we have as many locations as our number of machines, no location should be free. In the constraint (2), the sum of the i values for each k (location) value is equal to 1, so that only one machine is assigned to a location.

As in the case of assigning only one machine to each location, each machine must be assigned to only one location. In the constraint (3), the sum of k values for each i (machine) values equals to 1, so that one machine is assigned to only one location.

Constraint (4) defines y_{ik} and y_{jl} are covariates.

The constraint defining the variable x_{ijkl} in our objective function is constraint (5). According to values of y_{ik} and y_{jl}, x_{ijkl} means:

- $x_{ijkl}$is forced to be 1 by the constraint if y_{ik}=:1, which means that the $i'th$ machine is assigned to the $k'th$ location, and y_{jl}= 1, which means that the $j'th$ machine has been assigned to the $l'th$ location. In this case, the x_{ijkl}variable indicates that the $i'th$ machine is assigned to the $k'th$ location and the $j'th$ machine to the $l'th$ location.
- If only one of the variables y_{ik}or y_{jl}has a value of 1 and the other variable has a value of 0, the variable $x_{ijkl}$is forced to take a value greater than 0. Since the objective function is a minimization function, the model assigns 0 to x_{ijkl}. Thus, variable x_{ijkl}means that assignment of $i'th$ machine to $k'th$ location, and assignment of $j'th$ machine to $l'th$ location, is not achieved.
- If both the variables $y_{ik}$and y_{jl}have a value of 0, the constraint forces $x_{ijkl}$to take a value greater than -1. The objective function sets $x_{ijkl}$to 0. Because x is a binary variable. So again, variable x means that assignment of $i'th$ machine to $k'th$ location, and assignment of $j'th$ machine to $l'th$ location, is not achieved.

2.2.4. Adapting the Model to Different Rectangular Shaped Machines or Departments

Figure 5 shows how a different size machine can be placed horizontally and vertically.

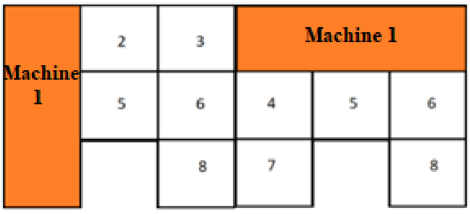

Figure 5: The horizontal or vertical placement of different sized machines in the layout

The machine is divided into pieces as small as the size of other machines, as shown in Figure 6.

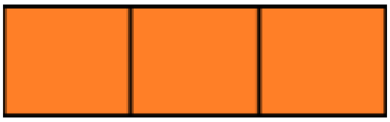

Figure 6: The machine divided into identical pieces

When determining i values, a value is assigned to each divided part of the machine as in Figure 7.

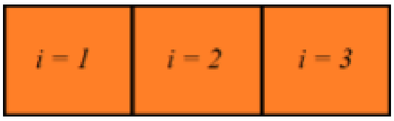

Figure 7: Machine with assigned *i* values

When entering the value of the parameter fij, the values of f_{12} and f_{23} are entered in a relatively large value and the value of f_{13} is entered in a negative number, which has small absolute value. Thus, the model will try to keep part 1 close to part 2, part 2 close to part 3, and try to keep away part 1 and part 3.

Thus, the model will be adapted for non-equal rectangular machines without a mathematical change in the model.

3. APPLICATION

3.1. Data Organization

After getting the process flow chart, we started to organize the data according to which machine has the bottlenecks. This operation can be named as workload balancing. In order to obtain machine positioning most healthily, our source should be healthy at first. For this reason, the job assignment between the machines needs to be balanced.

The performance (time) process flowchart generated by the DISCO program was used to determine the bottleneck on which machines. Figure 8 presents the performance. There are color differences: the dark red ones have more workload density than the light colors. In order to workload balancing, we assigned the possible jobs from busy machines to less occupied machines.

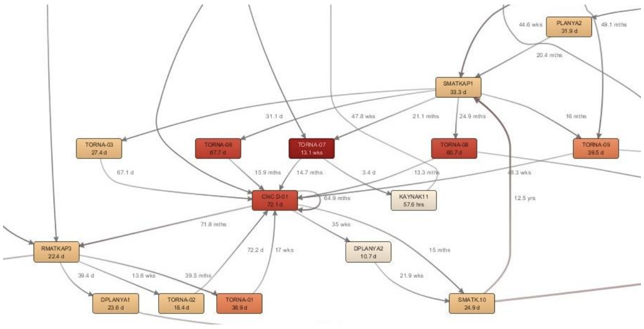

Figure 8: Bottleneck locations, according to data in the DISCO program

In Table 1, there is an example of workload balancing. The data consist of the total work time of individual turning machines. In the first case, workload distribution is not fair enough. However, in the second case, the machine’s total work times almost equal. The difference in terms of machine’s and worker’s performance can be seen in the Figures 9, 10, 11, 12.

Table 1: Turning machines' first and last working times

Turning Machine	Approximate total work time on the machine in the first case (min)	Approximate total work time on the machine in the last case (min)
Turning Machine - 4	21500	36000
Turning Machine – 5	312	36000
Turning Machine – 6	48000	32000
Turning Machine - 7	67500	32000

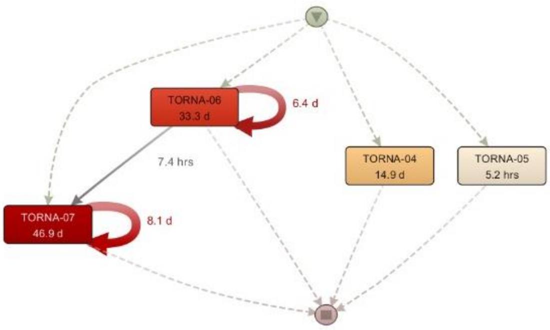

Figure 9: The first performance workflow of turning machines before the work balance is done

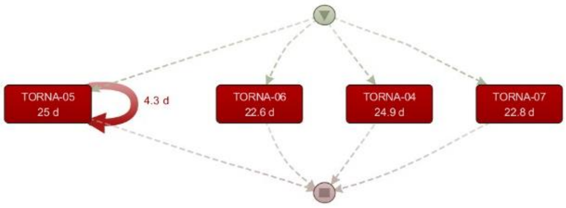

Figure 10: The last performance workflow of turning machines after the work balance is done

Workload imbalance problems in the machine also occur for workers. There is one employee assigned to each machine. In this case, workload imbalance is observed in the workers as the work assignment is not done in a balanced way. With the workload balancing process applied to the machines, the workload imbalance problem in the workers was eliminated.

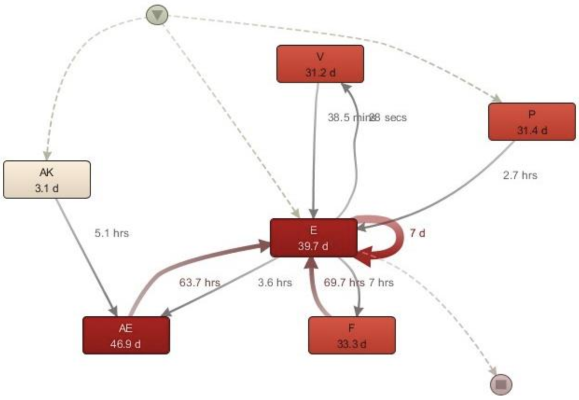

Figure 11: Worker’s performance workflow before doing workload balancing

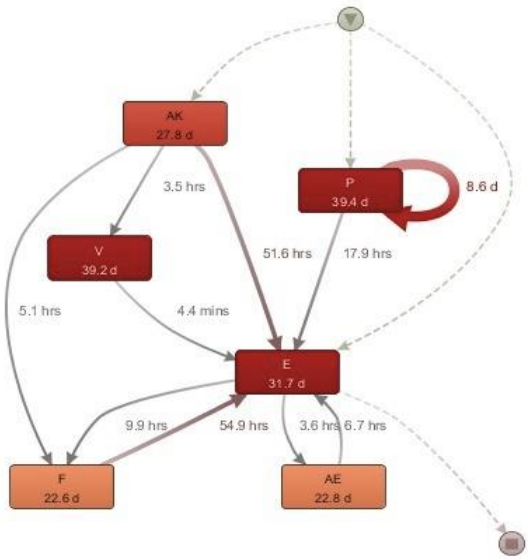

Figure 12: Worker’s performance workflow after doing workload balancing

Once the data is cleared and edited, we may start implementing it in our GAMS model.

3.2. Application of the Optimization Model

The first thing to do before optimizing the layout of the facility is to solve the workload imbalance between the machines and alleviate the bottleneck problem. The flow of parts will need to be changed to solve the bottleneck problem. Since this information is necessary for optimization, optimization should be started after the necessary changes are made. Otherwise, the facility layout plan will not remain optimal.

The discovery of bottlenecks using the DISCO process mining program and how these bottlenecks are resolved by arranging work orders assigned to the machines are shown in the previous sections. For this purpose, the performance function of the DISCO program was used.

The frequency function is utilized during the planning of the facility layout. In the optimization model, the piece flow between the machines needs to be used. DISCO provides this information as follows.

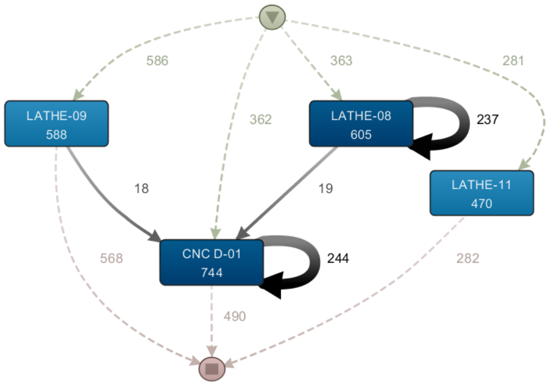

Figure 13: Frequency information is given for the lathe 7 machine

As shown in the Figure 13, the number of parts between the machines is shown on the arrows. The numbers shown in the boxes indicate the number of parts machined on that machine.

3.3. Model Inputs

3.3.1. Locations

The current layout of the facility is shown below. By this plan, it is necessary to divide the factory floor into co-squares based on the machine having the largest dimension in the factory.

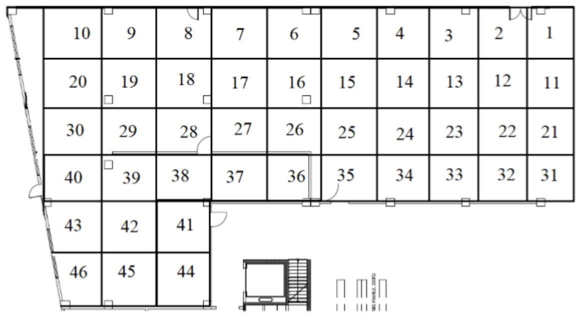

Figure 14: The facility layout is divided into 46 parts in equal divisions

Then these squares have to be numbered. As shown in the Figure 14, 46 different positions are formed. The position information in the model was indicated by *k* and *l* indices.

3.3.2. Machines

When the data of the last six months are examined, there are 39 machines used in the factory and wanted to be investigated. In the model, the machines are defined by the indices *i* and *j*. Although there are 39 machines, in order for the model to work correctly, which of the machines and locations are large, the other input must be written in that number.

Therefore, 7 virtual machines should be added to the model and thus, the number of machines should be increased to 46. The locations to which these virtual machines are assigned will remain empty. The following image shows the entries of these indices in the GAMS program.

The Alias formula allows us to create a copy index of an index. In our model, the indices *i* and *j* are both machines and have the same content. The indices *k* and *l* are like the indices *i* and *j* (see Figure 15).

```
sets
i /1*46/
k /1*46/;
alias(i,j);
alias(k,l);
```

Figure 15: Alias formulation on GAMS.

3.3.3. Frequencies

The information entered as the frequency is the number of parts flow between the machines. When this information from DISCO is transferred to an Excel file, the first thing to do is to enter the number values instead of the names of the machines. Because the indices are indicating the machines, *i* and *j* take values from 1 to 46. In the Figure 16, there is a part of the Excel file in which frequency information is entered.

	A	B	C	D	E	F	G
1		1	2	3	4	5	6
2	1	0	591	0	0	0	0
3	2	0	0	0	0	0	0
4	3	0	0	0	21	21	101
5	4	0	0	0	0	0	41
6	5	0	0	0	0	0	0
7	6	0	0	0	0	0	0

Figure 16: Frequency information between machines in the Excel table

While filling this table, the first index of f_{ij} parameter *i* index values should be filled in the first column and *j* index should be filled in the first row. Note that the parameter f_{ij} is defined as the amount of part flow from *i* to *j*.

3.3.4. Distances

On the factory floor, which we divided into co-squares, their positions were numbered. It is now necessary to define the information of the distances between these positions. In this section, the rectilinear measurement method was used. In this form of measurement, the distance between two opposing corners of the square is not calculated from the hypotenuse, but from the sides. In the Figure 17, a part of the Excel sheet where distance information is entered is given.

	A	B	C	D	E	F	G
1		1	2	3	4	5	6
2	1	0	1	2	3	4	5
3	2	1	0	1	2	3	4
4	3	2	1	0	1	2	3
5	4	3	2	1	0	1	2
6	5	4	3	2	1	0	1
7	6	5	4	3	2	1	0

Figure 17: Distance information between machines in the Excel table

Distance information is specified in our model by the parameter d_{kl} and this parameter is defined as the distance from k to l.

```
table
f(i,j)
$call xls2gms r=Sayfa1!A1:AU47 i=frekans.xlsx o=frekans.inc
$include frekans.inc
;

table
d(k,l)
$call xls2gms r=Sayfa1!A1:AU47 i=uzaklik.xlsx o=uzaklik.inc
$include uzaklik.inc
;
```

Figure 18: Formulation of transferring frequency and distance information in Excel file to GAMS program

This Figure 18 shows the formulation needed to import the created Excel files into the GAMS program.

3.3.5. Variables and Constraints

Two binary variables in the model and the variable z in which the objective function is assigned in the GAMS program are entered into the program. In addition to the constraints of general modeling, some constraints have been added for some machines that do not want to be relocated at the factory. These constraints work to keep these machines in their current position.

```
obj.. z=e= sum((i,k,j,l), f(i,j)*d(k,l)*x(i,k,j,l));
eq1(k).. sum((i), y(i,k)) =e= 1;
eq2(i).. sum((k), y(i,k)) =e= 1;
eq4(l).. sum((j), y(j,l)) =e= 1;
eq5(j).. sum((l), y(j,l)) =e= 1;
eq3(i,k,j,l).. x(i,k,j,l) =g= y(i,k) + y(j,l) -1;
eq6.. y("1","31") =e= 1;
eq7.. y("39","36") =e= 1;
eq8.. y("15","34") =e= 1;
eq9.. y("4","33") =e= 1;
eq10.. y("46","1") =e= 1;
eq11.. y("45","11") =e= 1;
eq12.. y("30","21") =e= 1;
eq13.. y("38","37") =e= 1;
eq14.. y("37","38") =e= 1;
eq15.. y("7","39") =e= 1;
eq16.. y("40","40") =e= 1;
eq17.. y("36","43") =e= 1;
eq18.. y("21","46") =e= 1;
eq19.. y("41","42") =e= 1;
eq20.. y("22","45") =e= 1;
eq21.. y("33","44") =e= 1;
eq22.. y("42","41") =e= 1;
```

Figure 19: Definition formulation of constraints to the GAMS program

In the Figure 19, the formulation of the constraints is shown.

When the model is operated in order to minimize the objective function, it will give the facility plan, which will minimize the distance of moving the parts from the machine to the machine in the factory.

3.3.6. Output and interpretation of model

It is the variable *y* that should be output as a model. The variable *y* will indicate which machine is assigned to which location. In Figures 20, 21, 22 show the GAMS output.

```
----    197 VARIABLE y.L

              1           2           3           4           5           6

13                                1.000
17                                                        1.000
28                                                                    1.000
29                    1.000
43                                            1.000
46        1.000

  +           7           8           9          10          11          12

10                                            1.000
11        1.000
12                                1.000
19                    1.000
44                                                                    1.000
45                                                        1.000

  +          13          14          15          16          17          18

3                     1.000
23                                                        1.000
24        1.000
26                                1.000
27                                            1.000
34                                                                    1.000

  +          19          20          21          22          23          24
```

Figure 20: Problem solution of GAMS program Part I

+	19	20	21	22	23	24
6						1.000
8		1.000				
14					1.000	
25	1.000					
30			1.000			
32				1.000		

+	25	26	27	28	29	30
5	1.000					
9						1.000
16		1.000				
18					1.000	
20				1.000		
35			1.000			

+	31	32	33	34	35	36
1	1.000					
2		1.000				
4			1.000			
15				1.000		
31					1.000	
39						1.000

+	37	38	39	40	41	42
7			1.000			
37		1.000				

Figure 21**:** Problem solution of GAMS program Part II

9						1.000
16		1.000				
18					1.000	
20				1.000		
35			1.000			

+	31	32	33	34	35	36
1	1.000					
2		1.000				
4			1.000			
15				1.000		
31					1.000	
39						1.000

+	37	38	39	40	41	42
7			1.000			
37		1.000				
38	1.000					
40				1.000		
41						1.000
42					1.000	

+	43	44	45	46
21				1.000
22			1.000	
33		1.000		
36	1.000			

Figure 22**:** Problem solution of GAMS program Part III

In this output, the indices given along the column represent the machines and the indices are given along the line indicate the positions. For example, machine 13 is assigned to position 3 and machine 17 is assigned to position 5(see Figure 20, 21).

It will be useful to see the current layout of the factory and the positioning of the model.

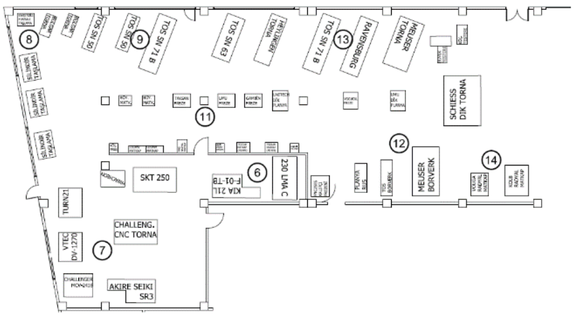

Figure 23: Current machine positioning in the factory

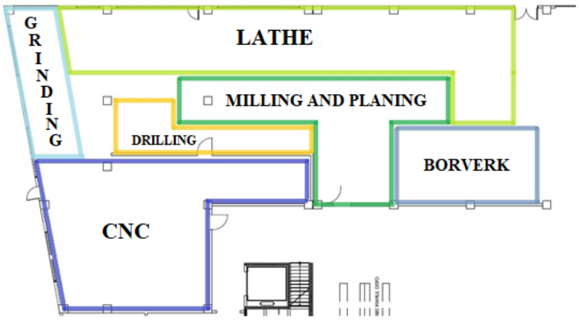

Figure 24: Current functional machine positioning of the factory

When Figure 23 is examined, it can be observed that the positioning of the machines in the factory is done in functional groups. Functional groupings are shown in the same settlement area in Figure 24 for easier viewing.

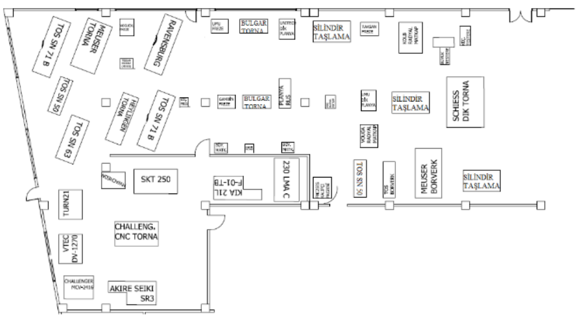

Figure 25: Machine positioning recommended to the factory

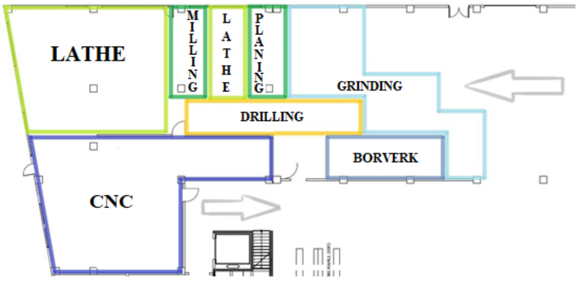

Figure 26: Machine positioning according to the workflow recommended to the factory

In this image, the layout optimized by the model is shown (Figure 25). When the part flows are examined (Figure 26), it is seen that there is an intensive part flow between lathe machines and CNC machines (Figure 27). The current positions of CNC machines are not intended to be changed due to the size of these machines. Therefore, the model has positioned the lathe machines near the CNC machines, behind the factory.

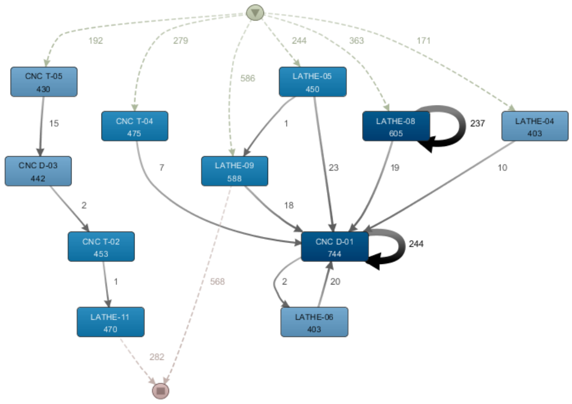

Figure 27: Frequency flow chart between lathes and CNC machines

Instead of functional grouping, a positioning is made in the direction of flow of the parts. This is foreseen from the fiction of the model.

3.3.7. Productivity Analysis

An Excel study was conducted to examine the effect of the model result on the transport distance. The current settlement is associated with the layout plan divided into identical parts. Since the distance between the locations is known, the distance between the machines is reached at present (Figure 28). In the following image, a part of the Excel table showing the distance between the machines at present is given. For the sections that do not coincide with any machine in the positioning, “space” is used. Rows and columns are ordered from position 1 to position 46. For the sake of better understanding, for example, "space" in position 1, and lathe 3 in position 2.

	MILLING2	MILLING3	RDRILL3	CDRILL10	CDRILLP9	PRESS1	EXIT	CNC D-01
SPACE	6	7	6	7	8	9	8	14
LATHE3	5	6	5	6	7	8	7	13
LATHE4	4	5	4	5	6	7	6	12
LATHE5	3	4	3	4	5	6	5	11
LATHE6	2	3	2	3	4	5	4	10
LATHE7	1	2	3	2	3	4	3	9
LATHE8	2	1	4	3	2	3	4	8
LATHE9	3	2	5	4	3	2	5	7
LATHE10	4	3	6	5	4	3	6	6
LATHE11	5	4	7	6	5	4	7	5
LATHE1	5	6	5	6	7	8	7	13

Figure 28: Currently, the distance between the machines

In the next step, the frequency information between the machines should be arranged in the same way as the sequence in the distance table (Figure 29). It was stated that the virtual machines were created in the model and the positions they were assigned would be spaces. Since virtual machines should not exchange any parts with other machines, these values should be entered as 0 in the frequency table. A part of this table is given in the image.

	MILLING2	MILLING3	RDRILL3	CDRILL10	CDRILLP9	PRESS1	EXIT	CNC D-01
SPACE	0	0	0	0	0	0	0	0
LATHE3	0	0	0	0	0	0	0	3
LATHE4	0	0	0	0	0	0	0	10
LATHE5	0	0	0	0	0	0	0	23
LATHE6	0	0	0	0	0	0	0	20
LATHE7	0	0	0	0	0	0	0	6
LATHE8	18	0	0	0	0	0	0	21
LATHE9	0	0	0	0	0	0	588	18
LATHE10	6	0	0	0	0	5	0	0
LATHE11	0	0	0	0	14	0	0	0
LATHE1	0	0	0	0	0	0	0	5

Figure 29: Frequency information between machines in the current situation

After making the current frequency and distance information to perform efficiency analysis, these frequency values and distance values are multiplied (Figure 30). The table shows how many units have been moved between the machines in the last six months. The following table provides some of this information.

	MILLING2	MILLING3	RDRILL3	CDRILL10	CDRILLP9	PRESS1	EXIT	CNC D-01
SPACE	0	0	0	0	0	0	0	0
LATHE3	0	0	0	0	0	0	0	39
LATHE4	0	0	0	0	0	0	0	120
LATHE5	0	0	0	0	0	0	0	253
LATHE6	0	0	0	0	0	0	0	200
LATHE7	0	0	0	0	0	0	0	54
LATHE8	36	0	0	0	0	0	0	168
LATHE9	0	0	0	0	0	0	2940	126
LATHE10	24	0	0	0	0	15	0	0
LATHE11	0	0	0	0	70	0	0	0
LATHE1	0	0	0	0	0	0	0	65

Figure 30: Frequency * distance information between machines

When the values in each cell of this table are sum up, the total transport amount of information is reached in the factory in the last six months. In the last six months, 14,923 units transport were carried out at the factory.

After optimization, the same procedure is repeated over the new layout. There is no change in the values of the frequency table. Only rows and columns are revised according to the order in the distance table (see Figures 31, 32, 33).

	MILLING3	MILLING2	PRESS1	CDRILL9	RDRILL3	CDRILL10	EXIT	CNC D-01
SPACE	0	0	0	0	0	0	0	0
RDRILL1	0	0	0	0	0	0	0	0
MILLING3	0	0	0	0	0	0	0	0
SPACE	0	0	0	0	0	0	0	0
VPLANING2	0	0	0	0	0	5	0	0
LATHE10	0	6	5	0	0	0	0	0
MILLING2	0	0	0	0	0	4	0	0
LATHE3	0	0	0	0	0	0	0	3
MILLING6	3	0	0	8	0	0	0	0
LATHE4	0	0	0	0	0	0	0	10

Figure 31: New status frequency table

	MILLING3	MILLING2	PRESS1	CDRILL9	RDRILL3	CDRILL10	EXIT	CNC D-01
SPACE	2	6	8	9	5	7	8	14
RDRILL1	1	5	7	8	4	6	7	13
MILLING3	0	4	6	7	3	5	6	12
SPACE	1	3	5	6	2	4	5	11
VPLANING2	2	2	4	5	3	3	4	10
LATHE10	3	1	3	4	4	2	3	9
MILLING2	4	0	2	3	5	3	4	8
LATHE3	5	1	1	2	6	4	5	7
MILLING6	6	2	2	1	7	5	6	6
LATHE4	7	3	3	2	8	6	7	5

Figure 32: New status distance table

	MILLING3	MILLING2	PRESS1	CDRILL9	RDRILL3	CDRILL10	EXIT	CNC D-01
SPACE	0	0	0	0	0	0	0	0
RDRILL1	0	0	0	0	0	0	0	0
MILLING3	0	0	0	0	0	0	0	0
SPACE	0	0	0	0	0	0	0	0
VPLANINC	0	0	0	0	0	15	0	0
LATHE10	0	6	15	0	0	0	0	0
MILLING2	0	0	0	0	0	12	0	0
LATHE3	0	0	0	0	0	0	0	21
MILLING6	18	0	0	8	0	0	0	0
LATHE4	0	0	0	0	0	0	0	50

Figure 33: Frequency * distance table in the new state.

When all cells in the frequency * distance table in the new state are sum up, the value found is 7589. As a result, if the factory had operated with an optimized facility layout plan in the last six months, it would have carried out approximately 49.2% fewer parts transport, saving more from non-value-added works, and thus producing a leaner production.

4. CONCLUSION

Process analysis is one of the most important projects that companies need to do to increase their added value. They must plan their processes very well in order for an organization to perform all its functions completely and flawlessly. It is important to constantly update this study by considering the change of processes over time. According to the processes, companies need to edit their parameters and even adjust the facility layout. In this study, first of all, the processes of a company are analyzed from the DISCO program and how to discover machine densities, worker densities and bottlenecks are emphasized. It was then shown that the values found could be improved by arranging work orders. After the work orders were issued, the model was run to ensure optimum facility layout by considering the parts flow in the company. The resulting facility layout plan will remain optimal as long as no change is made to the work orders. The most important non-value-added activities of the companies have been minimized. Thus, one of the arrangements to e made in lean production was examined and realized in this study. In this study, the point that companies should pay attention to is that the data must reflect reality. All personnel in their companies should be provided with the necessary information and training.

The study shows how application of process mining analysis improves the manufacturing processes of a company. Applying process analysis tools and changing facility layout according to the adopted process improvement methods, reduce cycle and lead times, increase the life span of the machines per product, reduce customer complaints by ensuring quality standardization. All these advantages contribute to the competitive advantage of the companies by limiting the cost of manufacturing process costs.

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REFERENCES

[1] W.M.P. Van der Aalst, A. Adriansyah, A.K. Alves De Medeiros, F. Arcieri, T. Baier, and T. Blickle, “Process Mining Manifesto,” *Business Process Management Workshops*, pp. 169-194, 2012, doi: 10.1007/978-3-642-28108-2_19.

[2] A.K. Alves De Medeiros, B.F. Dongen, W.M.P. Van der Aalst, and A.J.M.M. Weijters, “Process Mining: Extending the α-algorithm to Mine Short Loops,” *Information Systems IE&IS*, Mathematics and Computer Science, 2004.

[3] W.M.P. Van der Aalst, *Process Mining.* Berlin Heidelberg: Springer, 2011.

[4] W.M.P. Van Der Aalst, *Process Mining: Discovery, Conformance and Enhancement of Business Processes.* Berlin Heidelberg: Springer, 2011.

[5] B. Pham, E. Bagheri, P. Rios, A. Pourmasoumi, R.C. Robson, J. Hwee, A.C. Tricco, et al “Improving the conduct of systematic reviews: a process mining perspective,” *Journal of Clinical Epidemiology*, vol.103, pp. 101–111., doi: 10.1016/j.jclinepi.2018.06.011, 2018.

[6] W.M.P. Van der Aalst and A.J.M.M. Weijters. “Process mining: a research agenda,” *Computer in Industry*; vol. 53(3), pp. 231-244, 2004.

[7] B.F. Van Dongen, A.K.A. Alves De Medeiros, H.M.W. Verbeek, A.J.M.M Weijters and W.M.P. Van Der Aalst. “The ProM framework: a new era in process mining tool support,” in *ICATPN 2005: Applications and Theory of Petri Nets*, pp.444-454, 2005.

[8] Fluxicon, Disco. Discover your processes 2022. Available at: https://fluxicon.com/disco/ (Accessed December 18, 2022).

[9] R.J. LeBlanc, “Event-Driven Monitoring of Distributed Programs,” in *Proceedings of the Fifth International Conference on Distributed Computing Systems*, Denver CO, May 1985, pp. 515–522.

[10] J.E. Cook, and A.L. Wolf, “Discovering models of software processes from event-based data,” *ACM Transactions on Software Engineering and Methodology*, 7(3), pp 215–249, doi: 10.1145/287000.287001, 1998.

[11] P. Zerbino, D. Aloini, R. Dulmin, and V. Mininno, “Process-mining-enabled audit of information systems: Methodology and an application,” *Expert Systems with Applications*, vol. 110, pp. 80-92, 2018.

[12] S.H.R. Pasandideh, S.T.A. Niaki, and V. Hajipour, “A multi-objective facility location model with batch arrivals: two parameter-tuned meta-heuristic algorithms,” *Journal of Intelligent Manufacturing*, vol. 24, pp.331-348, 2013.

[13] Y. Xiao, Y. Seo, and M. Seo, “A two-step heuristic algorithm for layout design of unequal-sized facilities with input/output points,” *International Journal of Production Research*, vol. 51, no. 14, pp. 4200-4222, 2013.

[14] A. Houshyar, and B. White, “Exact optimal solution for facility layout: deciding which pairs of locations should be adjacent,” *Computers & Industrial Engineering*, vol. 24, no. 2, pp. 177-187, 1993.

[15] A. Houshyar, and B. White, “Comparison of solution procedures to the facility location problem,” *Computers & Industrial Engineering*, vol. 32, no. 1, pp 77-87, 1997.

[16] M. Hifi, and R. M'Hallah, “A hybrid algorithm for the two-dimensional layout problem: the cases of regular and irregular shapes,” *International Transactions in Operational Research*, vol. 10, no. 3, pp. 195-216, 2003.

[17] A. Ahmadi, M.S. Pishvaee, and M.R.A. Jokar, “A survey on multi-floor facility layout problems,” *Computers & Industrial Engineering,* vol. 107, pp. 158-170, 2017.

[18] M. F. Anjos, and M.V.C. Vieira, “Mathematical optimization approaches for facility layout problems: The state-of-the-art and future research directions,” *European Journal of Operational Research*, vol. 261, no. 1, pp. 1-16, 2017.

[19] G. Q. Zhang, and K.K. Lai, “Tabu search approaches for the multi-level warehouse layout problem with adjacency constraints,” *Engineering Optimization*, vol. 42, no. 8, pp. 775-790, 2010.

[20] B. Montreuil, H.D. Ratliff, and M. Goetschalckx, “Matching based interactive facility layout,” *IIE Transactions*, vol. 19, no. 3, pp. 271-279, 1987.

[21] G. Q. Zhang, J. Xue, and K. K. Lai, “A genetic algorithm based heuristic for adjacent paper-reel layout problem,” *International Journal of Production Research*, vol. 38, no. 14, pp. 3343-3356, 2010 doi: 10.1080/002075400418289

[22] K.K. Lai, J. Xue, and G. Zhang, “Layout design for a paper reel warehouse: A two-stage heuristic approach,” *International Journal of Production Economics*, vol. 75, no. 3, pp. 231-243, 2002.

[23] V.J. Mawson, and B.R. Hughes, “The development of modelling tools to improve energy efficiency in manufacturing processes and systems,” *Journal of Manufacturing Systems*, vol. 51, pp. 95-105, 2019.

[24] C. Guan, Z. Zhang, S. Liu, and J. Gong, “Multi-objective particle swarm optimization for multi-workshop facility layout problem”, *Journal of Manufacturing Systems*, vol. 53, pp. 32-48, 2019.

[25] P.S. Wang, T. Yang, and M.C. Chang, “Effective layout designs for the Shojinka control problem for a TFT-LCD module assembly line,” *Journal of Manufacturing Systems*, vol. 44, no. 1, pp. 255-269, 2017.

[26] S. Lee, H.G. Kahng, T. Cheong, and S.B. Kim, “Iterative two-stage hybrid algorithm for the vehicle lifter location problem in semiconductor manufacturing,” *Journal of Manufacturing Systems*, vol. 51, pp. 106-119, 2019.

[27] M. M. Azevedo, J.A. Crispim, and J.P. De Sousa, “A dynamic multi-objective approach for the reconfigurable multi-facility layout problem,” *Journal of Manufacturing Systems*, vol. 42, pp. 140-152, 2017.

[28] F.M. Defersha, and A. Hodiya, “A mathematical model and a parallel multiple search path simulated annealing for an integrated distributed layout design and machine cell formation,” *Journal of Manufacturing Systems*, vol. 43, no. 1, pp. 195-212, 2017.

[29] F. Halawa, S.C. Madathil, M.T. Khasawneh, “Integrated framework of process mining and simulation-optimization for pod structured clinical layout design,” *Expert Systems with Applications*, vol.185, 2021, doi: 10.1016/j.eswa.2021.115696