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An Effective Heuristic Algorithm for Flexible Flow Shop Scheduling Problems with Parallel Batch Processing

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Abstract: In this study, a firm's scheduling problem optimized using the genetic algorithm method and it aimed to reach the schedule that gives the smallest time in the production schedules. Considering the scheduling of the solenoid part produced by the company, a schedule with a shorter production time than the current production time of the part obtained and the production times of the company were improved. A genetic algorithm developed to solve the parallel batch processing problems. The developed genetic algorithm is an effective heuristic algorithm for the flexible flow type problem. Parameter optimization study carried out to improve the solution performance of genetic algorithms. Genetic operators examined in detail and compared with each other, and the most appropriate parameter set was determined because of research and experiments. The best parameters found for each problem with suggested algorithm. In order to reach the optimum solution of the part to produce in the scheduling problem, chromosomes created and sequence sizes randomly assigned. These assigned dimensions are in ascending order and converted to actual rows. Then, the total production times were determined by generating solutions sequentially from the generated chromosomes.

1. Introduction

Due to today's competitive environment, businesses must respond to customer requests in terms of quality, price and time as soon as possible in order to continue their life. The fact that production systems have grown and become more complex in today's conditions has made it very difficult to follow up and control production with traditional methods. Resources also necessary use people, machinery and materials in the most efficient way. From this point of view, before scheduling techniques that allow the most appropriate work loadings to be made by making production plans. Establishment place and facility location of an enterprise, placement of machinery and equipment in the facility, recruitment of suitable personnel definitely addressed.

In production systems, many different resources needed to perform production. Besides, the amount of resources and the time required to complete the jobs are very limited. Within the framework of these constraints, the time when the works need to be completed requires that they are placed in a certain order. The scheduling process carried out within the framework of all these constraints is a very complex process. Production facilities use production schedules in their activities from the raw material supply to the delivery of the product to the customer.

The main purposes of scheduling are responding to customers' demands and needs as quickly as possible, using production facilities in the most effective way, completing the delivery of the work done immediately, minimizing overtime work and semi-finished product stocks. Some of the issues that scheduling helps to solve are late delivery orders, excess inventory, not fully utilizing operational capacity, prolongation in production stages and time, identification of bottlenecks in production, customer satisfaction or dissatisfaction, loss of customer stock, inefficiency and high production costs. In any production system, the observation of a large number of semi-finished products in the workshop and / or the observation of situations such as when some machines are running while others are idle reveal the existence of scheduling problems. In addition, statistics such as high levels of overtime, presence of delayed jobs, low bench / workforce utilization rates, which seen when production records analysed, are also signs of scheduling problems. Efficient scheduling and control for customers means meeting customer orders on time. With a well-planned production schedule, the problems listed above minimized. Production activities need to follow by a specific order and schedule. Sorting customer orders, assigning jobs to machines, stock tracking, etc activities need to be scheduled. The real case flexible shop floor scheduling problem solved and analysed with the genetic algorithm solution method.

The remainder of the study is divided into the following sections: Section 2 includes a literature review; Section 3 includes the proposed conceptual model together with the purpose of the study. Section 4 includes the mathematical programming structure of the proposed model. Chapter 5 provides information on situations that encountered during the development and application of the mathematical model in the context of a case study. Finally, Chapter 6 presents a conclusion of the study.

2. Flexible Flow Shop Scheduling (FFSS) Problem

Scheduling is the allocation of resources to processes over time to optimize one or more objectives. Two key problems in production scheduling are prioritization and capacity. In other words, "What action will be done first?" and "Who will do this job?" [1, 2].

Scheduling of works and how do is closely related to the structure of the workshop. The structure of the workshops in a facility can be examined under 3 main headings):

- According to the Number of Machines in the Workshops
- According to the Way the Works Flow in the Workshop
- According to the Arrival of the Works to the Workshop.

Parallel machines called parallel identical machines if they do the same job for the same time and feature, and parallel identical machines with different speeds if they do it at different times. Workshop structures according to the flow of the works in the workshop; flow type, workshop type, flexible workshop type and open workshop [3]. Often, these operations done in the same sequence so that each job takes the same route. It assumed that the machines arranged in series and this manufacturing environment is called flow shop. It assumed that the stocking capacity of semi-finished products between consecutive machines is unlimited. This is generally valid in cases where the processed products are physically small and large quantities of products are easy to stock between machines [4]. Figure 1 represents the classical flow type workshop where all jobs require one process on each machine [5, 6].

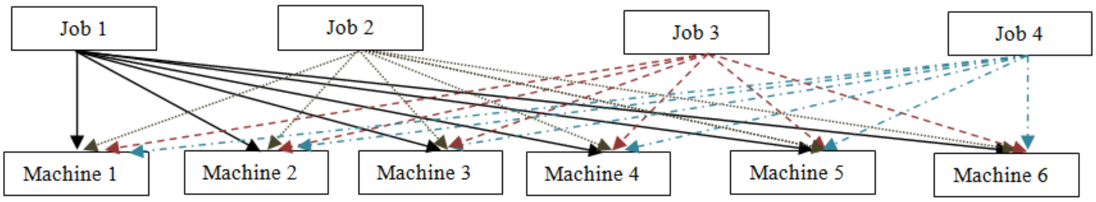

Figure 1: Jobs and using of the alternative machines

In the parallel machine-scheduling problem, there are a number of identical machines and they are all at the same stage. In the flexible flow type-scheduling problem, there is a group of machines placed in a series of stages with each other. In stage l there are l = 1,…, s, Ml machines parallel to each other. Job j, j = 1,…, n, must be processed on any of the machines at each stage. The processing time of job j in different stages is shown as p_{1j}, p_{2j},…, p_{sj} if parallel machines are identical [7, 8]. If the processing times in one stage are significantly higher than in other stages, it is common to add a new machine to that stage. When there is a change in demand, new machines purchased over time and their speeds are usually different. If machines or resources are costly, they continue to be used even if they are not as fast as the new purchased machine, since the old versions still have economic value [9, 10]. Each job processed on a machine at each stage and goes through one or more stages (in Fig.2). Parallel machines at each stage may be the same, different speed, or unrelated [11].

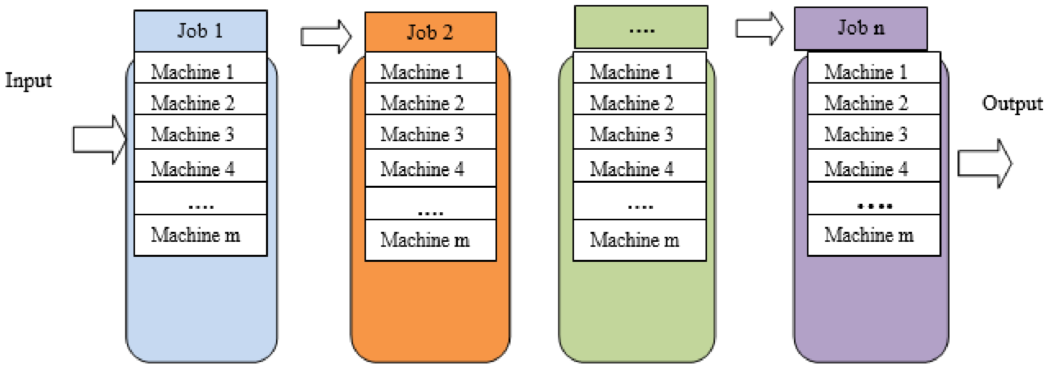

Figure 2: Flexible flow shop structure

Two main problems arise with flexible workshop planning. These are the problem of determining in which order the jobs will be processed, which we can call the routing problem, and determining which machine will process the jobs that we will call the assignment problem.

The limitations of FFSS are:

(1) All N jobs to be scheduled are independent and processed in zero time.

(2) A job processed by one machine at each production stage.

(3) After a job started on a machine, it processed until it completes without interruption

(4) A machine can process at most one process at a time.

(5) Each operation of a job executed on a machine at a certain speed for each stage.

(6) For the same process, the processing time differs in different unrelated parallel machines at one production stage [11].

2.1 Definition and Formulation of Problem

The PFFS scheduling problem discussed in this study explained as follows. There are n jobs, N =

{1, 2, ... , n } to be processed through g serial stages, G = {1, 2, ... , g }. Each stage i ∈ S has m parallel identical machines with the property that all jobs are processed from all stages in the same order, M = {1, 2, … , m}.

The parameters and definitions used in the model are as follows:

Objective function:

$$\min: WT * \sum_{j \in J \cup J'}^{I} T_j + C_{max} \tag{1}$$

Constraints:

$$T_j = max\left(G_{j(g-1)} + P_{j(g-1)M_{j(g-1)}} - D_j, 0\right) \qquad j \in J \cup J' \tag{2}$$

$$C_{max} = max\left(G_{j(g-1)} + P_{j(g-1)M_{j(g-1)}}\right) \qquad j \in J \cup J' \tag{3}$$

$$C_{max} \geq \ _{m,k} R_j \qquad j \in J \cup J' \tag{4}$$

$$G_{jg} \geq G_{j(g-1)} + P_{j(g-1)M_{j(g-1)}} \qquad j \in J \cup J',\ g \in G,\ g > 0 \tag{5}$$

$$G_{jg} + P_{jgM_{jg}} \leq G_{ig} \qquad j \in J \cup J',\ g \in G,\ j \neq i$$

$$M_{jg} = M_{ig}, S_{jg} \leq S_{ig} \tag{6}$$

$$u_{jgt} = \begin{cases} 1 & j \in J \cup J',\ g \in G, g_{jg} \leq t < g_{jg} + P_{jgM_{jg}} \\ 0 \ otherwise & \end{cases} \tag{7}$$

$$RG \leq G_{js} \qquad j \in J \cup J',\ g \in G \tag{8}$$

Each j ∈ N job consists of s sequential operations O_{ij} (i ∈ G; j ∈ N), and each operation requires a processing time $p_{ij} = p_j$ on any of the machines in phase i and has a positive weight w_j (or priority). The goal is to find a viable program that minimizes total weighted time to completion in Eq (1). The WT variable expresses the priority of the task, and Constraints 2 and 3 show the delay and completion times of the jobs. Constraint 4 and 5 used to express priority status between processes. Constraint 6 represents the causal priority of job sequences on machines. Constraint 7 shows that if the variable value is 1, the work has done at time t and it is active. Constraint 8 represents the rescheduling function limit.

3. Genetic Algorithms

Genetic algorithms, like other evolutionary algorithms, use an initial population of some of the solutions found in the research space. The starter population successively improved with each generation through natural selection and reproduction processes. The most suitable, that is, the highest quality individual of the last generation is the optimal solution for the problem. This solution may not always be optimum, but it is definitely an optimal solution close to optimum [12]. The genetic algorithm begins with the creation of the starting population. Each individual in the starting population is a candidate solution and each individual calls as a chromosome. According to the objective function, the chromosomes with the best degrees of suitability transferred to the next population (generation). Chromosomes with low degrees of fitness not allowed surviving. New individuals produced from good chromosomes to replace low-fidelity chromosomes. Inspired by nature, crossing and mutation operators used in the production of 50 new individuals. These steps repeated until the best solution reached according to the determined objective function.

Although there is no exact ranking in genetic algorithm applications, the functioning given as follows:

Step 1. Build an initial population of solutions.

Step 2. Compute the fitness value of each solution in the population.

Step 3. Stop investigation if the stop criteria met.

If not, perform the following steps.

Step 3.1 Apply the natural selection process (solutions with higher fitness values more represented in the new population.)

Step 3.2 Apply the crossover process (two new structures are generated from the existing two solutions.)

Step 3.3 Apply the mutation process (the solutions are randomly changed.)

Step 4. Go to step 2.

Genetic algorithm parameters do not have fixed values but now, researchers who have worked on the subject have identified values that give the best or near-best solutions according to the type of problem (in Table 1).

Table 1: Genetic Algorithm Parameters

Parameters	Negnevitsky	D. Jong	Michalewicz	Schaffer	Grefenstte
Population Size	50	50-100	50-100	20-30	30
Crossover Rate	0.7	0.6	0.5-0.1	0.75-0.95	0.95
Mutation Rate	0.001-0.01	0.001	0.001-0.01	0.005-0.01	0.01

The steps are carried out according to the probability rules. It is not known exactly how well the program will work before, but it can be calculated with probability. Genetic algorithms have been developed as a method seeking solutions to optimization problems by imitating nature.

4. Case Study

Scheduling is the determination of when and how the resources that uses and how to do certain works. With the help of effective scheduling, the possibility of performing the specified activities with less time and less resource usage arises. The products produced or to be processed belonging to the sub-industry come to the production facility where the production makes the same time or at different times, and the processing mechanisms and processing times of the incoming materials are different. It is possible to use time efficiently, therefore, by obtaining optimum efficiency from the employees with the usage costs of CNC machines as soon as possible. It examines how to implement it with minimum cost. In all processes, the processing time of the products, the use of CNC machines and the overtime of the personnel have an important role in the increase of costs. For this reason, when faced with this type of scheduling problem, production companies have to make an optimal scheduling decision that reduces costs with using CNC machines efficiently to prevent overtime. This scheduling decision determines which CNC machine uses with which personnel and in what order. In such scheduling problems, as the number of variables increases, the time to reach an optimum solution increases at least exponentially [13, 14].

This work applied in real case study for the SME Machine Factory. The problem of scheduling of the solenoid engine part produced by the company n addressed. The company has a flexible job shop and a large part of its production consists of solenoid engine parts. It aimed to find the schedule that minimizes the total production time. CNC machining centres, CNC lathes, milling machines are used in the production of the parts and there are 6 machines in total. The process routes of the parts have been determined and it has been determined on which machines these parts are processed [15]. The company has a flexible job shop production, the process routes of the parts are different from each other and there are more than one machine where some parts can be processed. The flexible shop floor scheduling problem modelled with mixed integer linear programming (MILP), but as the number of jobs and machines increases, the solution of the model becomes more complex and the time to reach the solution increases. With this study, a schedule with a shorter production time than the current production time of the part dealt with obtained and an improvement made in the production times of the company. From the chart obtained, the number of machines arranged in such a way that machine idle waiting minimized, and a new factory layout was prepared accordingly. According to the layout of the factory, the parts transportation between the machines minimized and time losses eliminated. The scheduling problem discussed was adapted to the genetic algorithm solution method and a solution obtained. Processing times in the problem fixed and predetermined. The data given in Table 2 shows how many processes each job consists of and which machine can be processed respectively. According to these determined data, the schedule that minimizes the production time obtained by using the genetic algorithm method.

Table 2: Production Time of the Part and Total Minutes of Distance between Machines

	M1	M2	M3	M4	M5	M6
M1	0	31	43	14	25	16
M2	19	0	12	32	50	44
M3	33	9	0	41	23	29
M4	41	27	38	0	34	49
M5	5	43	45	35	0	19
M6	28	15	7	23	16	0

The final product includes the 6 processes. Table 3 shows the sum of the production time of the part and the distance between the machines. For instance, the part processes first in the second machine and then in the third machine during the production process, the production time is 12 minutes.

Table 3: Initial Solution

Initial Solution	M1	M2	M3	M4	M5	M6	Total Time
Time (min):	31	12	41	34	19	28	165

The initial solution of the produced part is given in Table 4. The part starts machining from the 1st machine and goes to the 2,3,4,5 and 6th machines respectively, and then returns to the 1st machine where it starts machining again. The operation time between 1st and 2nd machine is 31 minutes. 2nd and 3rd machine's operation time is 12 minutes. 3rd machine and 4th machine's operation time is 41 minutes, 4th machine and 5th machine's operation time is 34 minutes. The processing time between the 5th machine and the 6th machine is 19 minutes, and the operation time between the 6th machine and the 1st machine is 28 minutes. The production route given in the initial solution is M1-M2-M3-M4-M5-M6 and the total production time analysed as 165 minutes. The new random values formed after crossing in Table 4 and arranged in ascending order then converted into real rows.

Table 4: New Chromosome Structure after Crossing Processes

	M1	M2	M3	M4	M5	M6
Krom.1	0,76227	0,33344	0,58718	0,2461	0,72941	0,37081
Krom.2	0,65665	0,2247	0,72982	0,64822	0,33682	0,26589
Krom.3	0,1363	0,08021	0,40249	0,62845	0,03326	0,73767
Krom.4	0,69155	0,85251	0,72192	0,1095	0,3864	0,4991

In New Chromosome 1, the part starts to be processed from the 6th machine and goes to the 2,4,1,5 and 3rd machines respectively, and then returns to the 6th machine where it starts to process again. The production route determined in New Chromosome.1 is M6-M2-M4-M1-M5-M3 and the total production time has found as 187 minutes.

In New Chromosome 2, the part starts to be processed from the 5th machine and goes to the 1,6,4,3 and 2nd machines, respectively, and returns to the 5th machine where it starts to process again. The production route determined in New Chromosome.2 is M5-M1-M6-M4-M3-M2 and the total production time calculated as 141 minutes.

In the new Chromosome 3, the part starts to be processed from the 3rd machine and goes to the 2,4,5,1 and 6th machines respectively, and then returns to the 3rd machine where it starts to process again. The production route determined in New Chromosome.3 is M3-M2-M4-M5-M1-M6 and the total production time analysed as 103 minutes.

In New Chromosome 4, the part starts to be processed from the 4th machine and goes to the 6,5,1,2 and 3rd machines respectively, and then returns to the 3rd machine where it starts to process again. The production route determined in New Chromosome.4 is M4-M6-M5-M1-M2-M3 and the total production time calculated as 154 minutes. (Table 5)

Table 5: Processing Times of the Part from New Production Routes after Crossing

Total Time	M1	M2	M3	M4	M5	M6
187	15	32	41	25	45	29
141	5	16	23	38	9	50
103	9	32	34	5	16	7
154	49	16	5	31	12	41

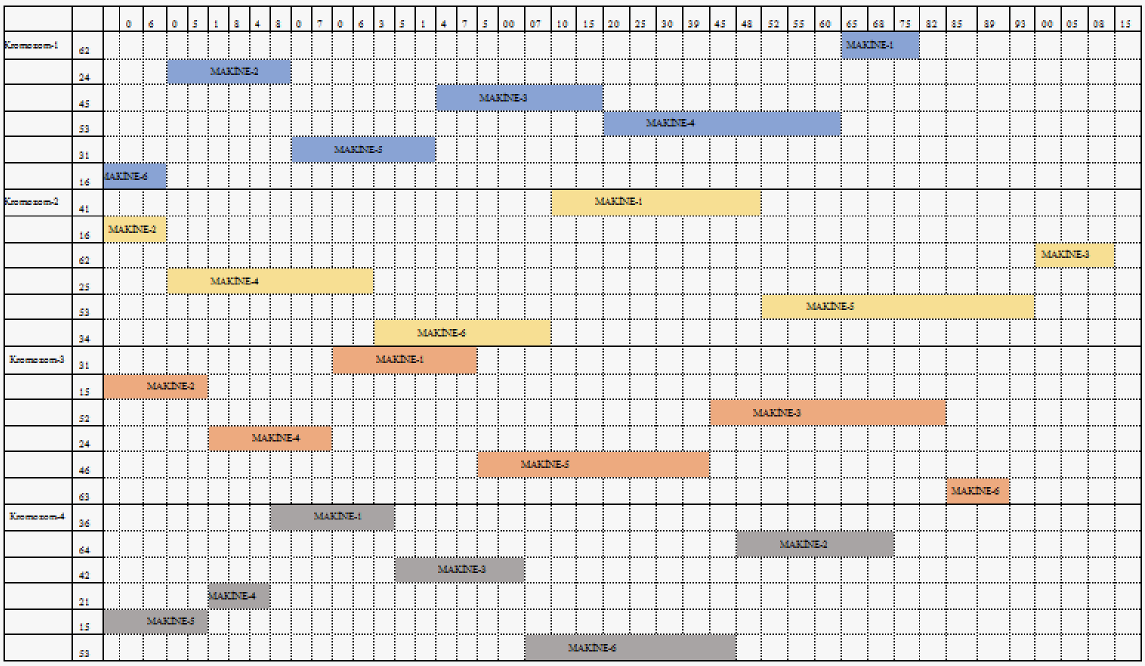

Figure 3: Sequence as a Result of Random Assignment

The production route determined in New Chromosome 3 is M3-M2-M4-M5-M1-M6 and the total production time computed as 103 minutes (in Figure 3). In New Chromosome 4, the part starts to be processed from the 4th machine and goes to the 6,5,1,2 and 3rd machines respectively, and then returns to the 3rd machine where it starts to process again. The operation time between the 4th machine and the 6th machine is 49 minutes. Also the operation time between the 6th machine and the 5th machine is 16 minutes, the operation time between the 5th machine and the 1st machine is 5 minutes, the operation time between the 1st machine and the 2nd machine 31 minutes. In addition, the operation time between the 2nd machine and the 3rd machine is 12 minutes, and the operation time between the 3rd machine and the 4th machine is 41 minutes. The production route determined in New Chromosome. Job 4 is M4-M6-M5-M1-M2-M3 and the total production time estimated as 154 minutes. As can be seen from the Table 6 results, it has been determined that the generation times vary between 102 minutes and 120 minutes according to the crossover rate and mutation rate values. According to these values, the optimum generation time was determined as 102 minutes at crossover rate = 0.825 and mutation rate = 0.05, crossover rate = 0.90 and mutation rate = 0.10.

Table 6: Comparing of the Cross Rate and Mutation Rate

Crossover Rate	Mutation Rate		Total Time (min)
0.90	0.05	M1-M4-M2-M3-M6-M5	103
	0.10	M1-M4-M5-M6-M3-M2	102
	0.15	M1-M4-M2-M5-M6-M3	103
0.825	0.05	M1-M4-M5-M6-M3-M2	102
	0.10	M1-M6-M4-M2-M3-M5	106
	0.15	M1-M4-M2-M3-M6-M5	103
0.75	0.05	M1-M4-M2-M3-M6-M5	103
	0.10	M1-M6-M3-M2-M4-M5	102
	0.15	M1-M4-M2-M6-M3-M5	120

5. Conclusion

The number of jobs and machines in the production of the enterprise is extremely important in terms of scheduling problems. As a one-unit increase in the number of work and machine will affect the scheduling problems exponentially, it causes the solution pool to grow much larger than the pool owned. For this reason, the solution of scheduling problems becomes more difficult and prolonged solution times occur. The special algorithms developed for systems with less than three machines to solve scheduling problems. However, there is no exact solving algorithm for scheduling more than 3 machines and n jobs. Heuristic methods used in such problems can find exact and / or near-exact solution values. As a result, the production time of the company reduced from 165 minutes to 103 minutes and a saving of 62 minutes per piece achieved. The enterprise gained 37.57% of production time per piece. While the company produces 3 solenoid parts by working 9 hours a day, it has been observed that it has become able to produce 5 solenoid parts by working 9 hours a day with the optimum solution achieved by the genetic algorithm method. There has been an increase in the production capacity of the enterprise. For this reason, business stock and purchasing policies can be determined at an optimum level. Since the production time of the solenoid part of the enterprise shortened, the deadline given to the customers can also be shortened and customer satisfaction will increase. Since the business can increase its production capacity without using any additional resources, its profitability will increase. In this way, the competitive advantage in the parts market produces will increase and it will reflect positively on its profitability.

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