

Scheduling of production systems with the approach of meta-heuristic algorithms

Roza Montazeri parchikolayi¹, Seyed Ahmed Shayannia^{2*}, Rasul Enayatifar³, Amir Gholam Abri⁴, Ebrahim Niknaqsh⁵

¹Ph.D. student, Department of Industrial Management, Firoozkooh Branch, Islamic Azad University, Firoozkooh, Iran

²Department of Industrial Management, Firoozkooh Branch, Islamic Azad University, Firoozkooh, Iran

³Department of Computer Engineering, Fi.C., Islamic Azad University, Firoozkooh, Iran

⁴Department of Mathematics, Firoozkooh Branch, Islamic Azad University, Firoozkooh, Iran

⁵Department of Industrial Management, Firoozkooh Branch, Islamic Azad University, Firoozkooh, Iran

Abstract

The main goal of the research is production timing with the approach of meta-heuristic algorithms. First, the mathematical model of the production schedule was presented, and then the model was solved with the genetic algorithm. All types of genetic operators were considered at this stage, and an attempt was made to achieve better answers by choosing appropriate methods. The result of applying these targeted selection methods was the rapid convergence of the population. However, this fast convergence did not provide an optimal solution because it quickly converged all the people of the population to a local optimal solution and did not allow the algorithm to search more of the solution space. Therefore, contrary to expectations, the targeted selection methods without a suitable generation method did not improve the algorithm's efficiency. At this stage, the generation methods were considered; the optimal solution for big problems was also obtained by implementing the selection methods. By finding the appropriate generation method, it was observed that even the operators who did not have much ability to see close to optimal solutions succeeded in finding optimal solutions.

Keywords: production scheduling, workshop production system, genetic algorithm

1- Introduction

In most industrialized societies, the market economy prevails. This type of economy is based on the supply and demand of goods and services. Production is one of the basic components of such societies, which, with its inherent characteristics, boosts economic activities and generates wealth. For example, a large space or chemical company directly creates employment opportunities for several thousand people. Indirectly, many job opportunities are created to provide materials and ancillary services. Trade and economic prosperity in societies are also influenced by income from production (Nozari et al., 2023). The

* Corresponding Author

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higher the income of the people in the society, the more money they spend on shopping, entertainment, travel, etc. In addition, the people of a society need houses, hospitals, schools, etc. Unfortunately, despite the above direct relationship, the reverse relationship is also established. In a society that does not have manufacturing industries, the members of the society do not have much income for their living expenses. In today's industrial world, due to the reduction of production resources, including machines and production equipment, the energy required for production, and the increase in the costs of using and setting up equipment and the idleness of machinery, the value of optimizing the utilization of resources and time in production systems is increasing day by day. One of the most prominent topics that has attracted the attention of researchers and industry researchers, especially in recent decades, is the category of scheduling. Creating effective and efficient planning to determine the production sequence has a fundamental relationship with increasing the efficiency of production systems.

Although the amount of employment in manufacturing industries has decreased in many developed countries in recent years, this does not mean a decrease in the importance of production, but it indicates the characteristics of modern technologies in which machines and automatic systems replace manual activities. It has become human. In addition, the success of non-manufacturing industries is strongly influenced by the strength of manufacturing sectors. As a result, it is necessary to maintain profitable and successful manufacturing industries to meet the needs of a country (Ghahremani-Nahr et al., 2022).

The best factors for evaluating a country's economy's wealth are gross national product and net national product. Gross national product is the total value of goods and services produced by a country's people (both inside and outside the country) in a year. Net national product is the gross national product produced inside the country (Fallah et al., 2021).

Two main goals are pursued in this research. The first goal is to increase the efficiency of production lines. This goal is pursued by using successful optimization methods and examining the results of applying these methods to sample problems. The second goal is to introduce and evaluate optimization methods usefully. This goal is due to the many applications of these methods in different fields and the complex nature of the investigated problem. If the studied methods provide suitable answers for this complex problem, they can be used for simpler problems as well, and the more successful method has more priority (Nozari et al., 2022).

The most important parameter in the design of production lines is timing. This issue is followed in the form of extensive research in all universities of the world, and providing more efficient algorithms to improve timing methods is the primary goal of scientific and research circles. On the other hand, this wide range of research shows the importance of this issue from both theoretical and practical aspects. In this thesis, the scheduling model is used to model production lines. This model is one of the most comprehensive and standard scheduling models. After choosing the model, it is essential to select optimization methods to achieve the above goals. The methods chosen to solve this problem are genetic algorithms, which are more comprehensive and successful than other methods proposed in this field. In this research, both methods are briefly explained, then algorithms are used to solve the problem. Due to the problem belonging to the group of the issues, examining the results of these methods and comparing them provides a suitable criterion for comparing these methods in similar applications. Also, the results show that finding suitable algorithms to solve this problem increases the efficiency of production lines.

2- Literature review

Bathae et al. (2023) use a hierarchical approach to solve the FJS scheduling problem. This approach divides the problem into two sub-problems: routing and scheduling. First, the routing sub-problem is solved by allocating the machine to each operation. As a result, the FJS problem becomes a scheduling problem.

Classic workshop production (JS) has been changed. Then, the scheduling sub-problem is solved. He proposes a forbidden search algorithm to solve the scheduling sub-problem. His hierarchical approach is designed in two versions. In the first version (Figure 1), the information flow between the routing sub-problem and the scheduling sub-problem is one-way and from routing to scheduling. First, an initial route is generated using a suitable prioritization rule. Then, the resulting JS problem is solved using the TS algorithm. After the TS algorithm is finished, the optimal scheduling program is found. For each selected route, a new route is generated for the routing sub-problem using a new prioritization rule, and this process is repeated until a termination condition is reached.

Gharachorloo(2021) modeled the FJS problem using linguistic terms and presented a thermal simulation algorithm to solve it. Operation classification is used. This research used numerical experiments to study the effect of selecting prioritization rules and the degree of flexibility on the workshop's performance. The workshop's performance was evaluated using objective functions. C_{max} , T_{max} . Flexibility in the workshop reduces the effect of choosing the prioritization rule on performance.

Movahed et al., (2023) use a symbiotic evolutionary algorithm search technique to integrate the two functions of process planning and scheduling in the flexible manufacturing and production system of workshop production. This algorithm assumes that a Parallel search of different parts of a solution is much more efficient than searching for a complete solution. Therefore, a problem can be considered a combination of several sub-problems with complex internal relationships. The answer of each sub-problem forms a part of the problem's solution. For each sub-problem, a population of partial answers is kept. Evaluating the fitness value of a chromosome in each population requires the selection of symbiotic partners. In the IPPS problem, the performance criteria can be evaluated when the information related to the process and schedule for all tasks is given. In this algorithm, a population is maintained for two sub-problems of process planning and scheduling, each of which has its own way of representing the answer, generating the initial population, and genetic functions. Also, by defining the appropriate strategy for local interactions within and between populations. The population has increased in various ways, and as a result, it is tried to avoid falling into the local optimum. The results of numerical experiments show that the proposed algorithm is based on two criteria, C_{max} , F, works better than the hierarchical method and another evolutionary algorithm. One of the characteristics of this research is considering three types of flexibility in the workshop.

Ghahremani-Nahr et al., (2023) discuss the importance of scheduling integration and process planning with the help of computer and provide an innovative method to do it. It is produced online. The environment of the production problem is a workshop where there are identical machines with different capabilities. The process planning module determines the sequence of operations of each part. A scheduling factor is defined to assign the machine to each operation among the available machines, which has a direct relationship with the cost of the machine and an inverse relationship with the cost of operations and cycle time. The value of this scheduling factor is calculated for all the machines that can operate, and the machine with the highest value is assigned to the operation.

Production scheduling covers a wide range of issues in most production and service systems, so the structure of this type of issue is very diverse. In advanced production environments, the flexibility of production is considered a competitive advantage. For this reason, in this article, a special type of flexibility is defined in the problem of the workshop production scheduling system, where each workstation may have several parallel machines for processing tasks. The processing speed of each machine for different operations can be different from others. The objective function of this problem is the minimization of the construction interval, and due to its NP-hardness, a meta-heuristic algorithm has been used to solve the

problem. Therefore, a new discrete method based on particle group optimization has been proposed due to the target problem's structure and its solution space's discreteness.

3- Research method

There are different research methods, and the descriptive method is one of them. Descriptive research, sometimes called non-experimental research, deals with relationships between variables, testing hypotheses, and developing general concepts and laws, principles, or theories that have universal validity. Such research is concerned with functional relationships. It is expected that if variable x is systematically related to variable y , the probability of predicting a phenomenon is high, and the results will probably suggest a new hypothesis that should be tested. Unlike the experimental design, the researcher does not manipulate the variables or create conditions for the occurrence of events in implementing a descriptive research design. In fact, if no observation or analysis was done, the events that are observed and described would have happened. The research method in this project is descriptive-mathematical. Because it shows us a mathematical model with specific functions, this function seeks to minimize cost and minimum time, the variables of the problem are in the form of the objective function $\min f(x)$, and this function has limitations. Because this model is a meta-heuristic or soft computing model, soft computing can be divided as follows:

Model:

In this section, the details of the scheduling problem in the flexible manufacturing and workshop production system, including assumptions, limitations, and performance criteria, are determined. The selected performance criteria's importance in terms of compatibility with the philosophy of just-in-time production and supply chain is discussed. Then, the scheduling problem with the use of mixed integer programming is modeled.

The scheduling problem in the flexible workshop manufacturing and production system is defined according to the position of the manufacturing unit in a manufacturing and manufacturing supply chain as follows:

Manufacturing and production issues consist of receiving a certain number of orders that must be created in a multi-project environment. Each product order reaches the assembly unit with a specified delivery date from the customer. The assembly of each order requires the manufacture of a set of parts, and the order is given to the construction unit. The construction of each part requires a set of specified operations. Between the operations of each part, there are defined prerequisite relationships displayed by a graph. The graph of the prerequisite relationships for each part is known. A possible part It has several sequences of different operations. One or more different machines are available to perform each operation. The length of processing time for each operation on alternative machines is different and known. Since this research focuses on planning and scheduling in the manufacturing unit, it is avoided to go into the details of other chain components. Assuming that the length of the assembly process is known By deducting this period from the final delivery date, the delivery date of each piece in the manufacturing unit is determined. External resources can be used to achieve the scheduling goals. It is assumed that the external resources have already been analyzed and selected. If used from external sources, round-trip time is added to the operation processing time. The goal is to provide an efficient model for scheduling in the manufacturing unit so that the technological and resource constraints are met and the objectives of the problem are optimized. In this model, the following decisions are necessary to be taken simultaneously:

- Determining the sequence of operations of each task
- Machine assignment to each operation

- Timing
- Outsourcing

$$\text{Min } C_{max} = \text{Max } C_i \quad (1)$$

$$\text{Min } \bar{C} = \frac{1}{N} \sum_{i=1}^N C_i \quad (2)$$

$$\text{Min } ET_{max} = \text{Max}(E_i, T_i) = \text{Max}[\alpha_i(D_i - C_i), \beta_i(C_i - D_i)] \quad (3)$$

Subject to:

$$Ft_{j+1k}^{(i, s_i)} - Ft_{jm}^{(i, s_i)} + L(1 - a_{(j+1)k}^{(i, s_i)}) X_{(j+1)k}^{(i, s_i)} \geq Pt_{(j+1)k}^{(i, s_i)} + T_k Z_k + T_m Z_m \quad (4)$$

$$Ft_{jk}^{(i, s_i)} - Ft_{qk}^{(r, s_r)} + L \times R_{jqk}^{(i, s_i)(r, s_r)} \geq Pt_{jk}^{(i, s_i)} X_{jk}^{(i, s_i)} \quad (5)$$

$$Ft_{qk}^{(r, s_r)} - Ft_{jk}^{(i, s_i)} + L(1 - R_{jqk}^{(i, s_i)(r, s_r)}) \geq Pt_{qk}^{(r, s_r)} X_{qk}^{(r, s_r)} \quad (6)$$

$$\sum_{s_i=1}^{P_i} Y_{is_i} = 1 \quad (7)$$

$$\sum_{k=1}^M a_{jk}^{(i, s_i)} X_{jk}^{(i, s_i)} = Y_{is_i} \quad (8)$$

$$Ft_{lk}^{(i, s_i)} \geq (T_k Z_k + Pt_{lk}^{(i, s_i)}) X_{lk}^{(i, s_i)} \quad (9)$$

$$Ft_{jk}^{(i, s_i)} \leq L \times X_{lk}^{(i, s_i)} \quad (10)$$

$$C_i \geq \sum_{k=1}^M \sum_{s_i=1}^{P_i} (Ft_{n_i k}^{(i, s_i)} + T_k Z_k) X_{n_i k}^{(i, s_i)} \quad (11)$$

$$Ft_{jk}^{(i, s_i)} \geq 0; Y_{is_i} = 0,1; X_{jk}^{(i, s_i)} = 0,1 \quad (12)$$

$$R_{jqk}^{(i, s_i)(r, s_r)} = 0,1 \quad (13)$$

Relations 1 to 3 respectively describe the performance criteria of the problem. If the early and late penalties are assumed to be a fixed value, the ETmax performance criterion is equivalent to the highest absolute value of the deviation from the delivery deadline.

The relation 4 guarantees that the set of operations of the sequence s_i for the piece i do not interfere in time. In other words, each operation of a sequence starts if its previous operation is completed. Also, this relation guarantees that if an operation is performed to external resources Let the shipping time be considered.

Relations 5 and 6 simultaneously guarantee that the set of operations performed on the same machine do not overlap in time.

Equation 7 guarantees that each part is assigned only one operation sequence from the possible sequences for it.

Equation 8 guarantees that each operation of a piece is assigned to only one of the possible machine alternatives for it.

Equation 9 guarantees that the completion time of the first operation of the sequence s_i for the largest piece i is equal to its processing time. If the source k is an external source, the carrying time is added to the operation time.

Equation 10 guarantees that if the machine k is not assigned to the operation j of the combination (i, s_i) , the completion time of the operation j on this machine is assumed to be zero.

Equation 11 calculates the completion time of each piece.

Relations 12 and 13 specify the types of variables.

4- Analysis of the results

The general structure of implemented genetic algorithms is shown in the figure below.

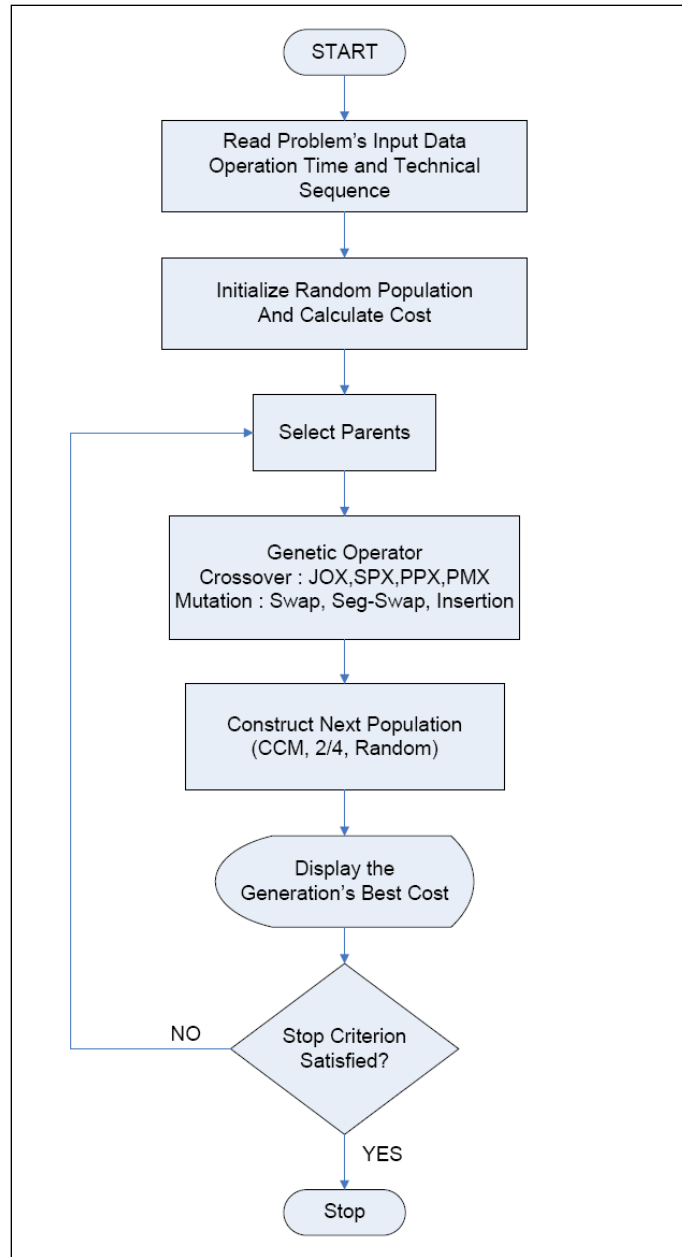


Figure 1: The overall structure of the genetic algorithm

The general structure above has many parameters. The most important parameters of this algorithm are the methods of selecting parents, genetic operators, and children and forming the next generation. With different choices, various algorithms are obtained. Here, we describe the general results obtained from the initial implementations, and then we introduce the algorithms that have provided optimal solutions for important example problems.

In the initial stages of the project, a suitable display was chosen for the problem. Then a quick method was used to calculate the cost of each chromosome. By choosing these two parameters, the speed of program execution increased to an acceptable level. After solving these initial problems, it was still not possible to reach the optimal or near-optimal solution for big problems like and. At this stage, all types of genetic operators were considered and an attempt was made to achieve better answers by choosing appropriate

methods. At this stage, it was found that the operator and provides better answers in comparison with the methods and. Mutation operators and were also used in this step. However, the problem of obtaining the optimal solution for big problems was still not solved. At this stage, selection methods were considered and methods were applied instead of the random method. The result of applying these targeted selection methods was the rapid convergence of the population. But this fast convergence did not provide an optimal solution, because it quickly converged all the people of the population to a local optimal solution and did not allow the algorithm to search more of the solution space. Therefore, contrary to expectation, the targeted selection methods without having a suitable generation generation method did not improve the efficiency of the algorithm. At this stage, the generation methods were taken into consideration, by implementing the selection method, the optimal solution for big problems was also obtained. By finding the appropriate generation generation method, it was observed that with this method, even the operators who did not have much ability to find close to optimal solutions, succeeded in finding optimal solutions.

Different algorithms and their application to sample problems:

1- (2/4)SPX: The first algorithm implemented by the researcher, which has relatively acceptable answers, is using as and and as the mutation operator. In the reviewed sources, the operator was one of the best operators. The method has been used to produce the next generation. We call this method The results of applying this algorithm to solve sample problems are shown in Table 1.

Problem	Opt. Cost	Best Cost	Avg. Cost	CPU time(sec)
FT06	55	55	55	1
FT10	930	937	960.4	32
FT20	1165	1178	1183	49

Table 1: Method results for problems in 10 implementations

This algorithm is the best algorithm implemented without using This algorithm has been implemented with other operators including PPX, PMX and JOX operators. The answers obtained from these operators do not improve the obtained answers, and we refrain from mentioning their details here. Studies and surveys have shown that one of the most important disadvantages for solving problems without combining with methods such as SB, pdrs, SA and other neighborhood search methods is premature convergence to a local optimal solution. This problem is the most important defect in the generation method. To solve this problem, the CCM algorithm is a suitable option, and in the following algorithms, this method is used to select people and generate generations.

2- CCMJOX : The CCM method is the generation method chosen for this algorithm. This algorithm provides suitable answers for the problem FT10 but does not get the optimal answer. The sample results are as follows:

Problem	Opt. Cost	Best Cost	Avg. Cost	CPU time(sec)
FT06	55	55	55	1
FT10	930	930	933.3	390
FT20	1165	1178	1180	510

Table 2: Method results for problems in 10 implementations

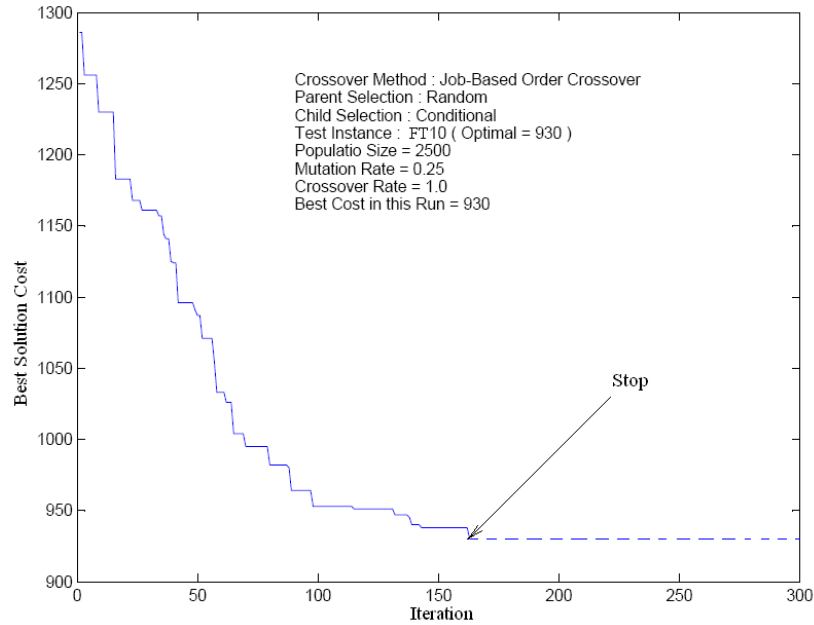


Figure 2: The optimal solution to the problem FT10 with the algorithm CCMJOX

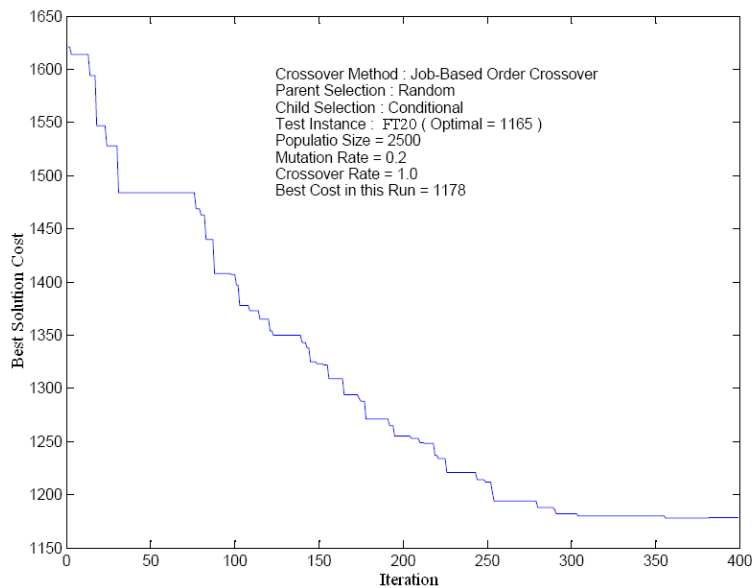


Figure 3: The optimal solution to the problem FT20 with the algorithm CCMJOX

LA(1 - 20) Problems and some bigger problems:

The implementation algorithms do not provide suitable answers for bigger problems, and their results have been avoided here. In none of the investigated studies bigger issues have not been solved by "GA," and there is no possibility of comparison. By comparing the presented results, it can be concluded that the "CCMJOX" algorithm is the best-implemented algorithm. Here, we compare the results of the "CCMJOX"

method for the LA (1-20) with the results of Kim et al (1994) (30). The sign * indicates that the obtained answer is the optimal answer.

Problem	Opt. Sol.	Kim et al	CCMJOX
LA01	666	666	666*
LA02	655	655	655*
LA03	597	597	697*
LA04	590	590	590*
LA05	593	593	593*
LA06	926	926	926*
LA07	890	890	890*
LA08	863	863	863*
LA09	951	951	951*
LA10	958	958	958*
LA11	1222	1222	1222*
LA12	1039	1039	1039*
LA13	1150	1150	1150*
LA14	1292	1292	1292*
LA15	1207	1207	1207*
LA16	945	-	946
LA17	784	-	784*
LA18	848	-	848*
LA19	842	-	852
LA20	902	-	907

Table 3: The results of CCMJOX

This algorithm can be used for bigger problems, but it does not provide suitable results. Table 5-5 shows the results of applying the CCMJOX method for some large sample problems. Although for some problems we reach the optimal solution by spending a lot of time, but in general it can be said that GA does not have the ability to find the optimal solution for large problems.

Problem	Opt.Solution	CCMJOX
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ABZ8	645 – 665	734
LA30	1355	1355*
LA31	1784	1784*
LA33	1719	1719*
LA37	1397	1449
LA39	1233	1291
ORB01	1059	1086

Table 4: The results of "CCMJOX" for some big problems

5- Conclusion

Two main goals are pursued in this research. The first goal is to increase the efficiency of production lines. This goal is pursued by using successful optimization methods and examining the results of applying these methods to sample problems. The second goal is to introduce and evaluate optimization methods in a useful way. This goal is due to the many applications of these methods in different fields and the complex nature of the investigated problem. If the studied methods provide suitable answers for this complex problem, they can also be used for simpler problems, and the more successful method has more priority. The same can also be used. Different models that are used for production lines were compared with each other and the model was selected as a comprehensive model of production lines. The basic parameters of this model, display methods, types of schedules and sample problems were discussed. The main result of these studies can be stated as follows:

- The JSP problem belongs to the group of NP problems, except for special cases.
- Among all the methods used to solve the problem, creative methods have provided the best results.
- In the group of creative methods, local search methods (neighborhood) have been more successful than other methods.
- Genetic algorithms do not have much ability to solve big problems without being combined with other creative methods.
- The main problem of genetic algorithms is to reach the optimal solution.
- Genetic algorithms is a population method and this process makes it slower compared to single point methods.
- Genetic algorithms converge to local optimal solutions for large problems without applying appropriate generation methods that apply multilevel search.
- Applying strict generation methods (multilevel search), although it prevents premature convergence, it increases the calculation time.
- Choosing methods and to reach the right answers are very important.
- The genetic algorithms implemented by the researcher as well as the results of other studies show that this method is not a suitable method for problems with a very large solution space, and even applying the method and the best genetic operators does not yield a suitable solution.
- According to the above points, it can be said that every algorithm has a special capability and ability, and genetic algorithms are no exception to this rule. The results of simulations show the ability of genetic algorithms. If there is another problem under study, with these results it can be estimated whether genetic algorithms are suitable for this problem or not.

- Despite the successful results of the implemented algorithms and their better results compared to other methods, there were some very big problems for which the optimal solution was not found.

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