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The Problem of Uninterrupted Hybrid Flow Shop Scheduling with Regard to the Fuzzy Processing Time

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ARTICLE INFO	ABSTRACT
Received: 25 November 2020 *Reviewed: 25 December 2020* *Revised: 30 December 2020* *Accept: 15 January 2021* ***Keywords: Hybrid Flow shop Scheduling, Uncertainty, Fuzzy Planning Method***	**Purpose:** In this paper, an uninterrupted hybrid flow shop scheduling problem is modeled under uncertainty conditions. Due to the uncertainty of processing time in workshops, which is due to delays in receiving raw materials or machine failure, fuzzy programming method has been used to control the processing time parameter. In the proposed model, there are several jobs that must be processed by machines in sequence. The main purpose of the proposed model is to determine the correct sequence of operations and assign operations to each machine at each stage, so that the total completion time (Cmax) is minimized. **Methodology:** In this paper, the fuzzy programming method is used to control the uncertain parameter. Also, The GAMS software and CPLEX solver have also been used to solve the sample problems. **Findings:** The results of solving the problem in small and medium size show that with increasing the rate of uncertainty, the amount of processing time increases and therefore the completion time of the whole work increases. On the other hand, with the increase in the number of machines in each stage due to the high efficiency of the machines, the completion time of all works has decreased. **Originality/Value:** The most important innovation of this article is the design of uninterrupted hybrid flow shop scheduling with regard to the fuzzy processing time.

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1. Introduction

Scheduling is actually the allocation of resources to activities with the aim of optimizing one to several performance criteria, which can appear in different forms depending on the characteristics of resources and activities. Sources may be the number of machines on a factory production line, CPU, memory and input and output factors in a computer system, runways at an airport, mechanics at a machinery repair shop, or the like [1]. Activities may include the number of operations in a manufacturing process, the execution of a computer program, the landing and take-off of an aircraft, and the repair of machinery. Also, various performance criteria are used for optimization [2]. Minimizing completion time or minimizing the number of delays are among a variety of performance metrics. The study of scheduling has a history of over half a century. Researchers in the field of operations research, managers and industrial engineers are among the people who turned to this field after encountering problems in managing various activities. Scheduling algorithms reduce production costs and ultimately lead to market survival by creating a competitive advantage. In other words, efficient use of limited resources available reduces costs, and this is the most important reason and economic justification for using scheduling and study in this area. The importance of scheduling in recent years has become increasingly important due to increased diversity in customer demand, reduced product life cycle, rapid development of new processes and technologies, and as a result of rapid changes and fluctuations in competitive markets. These trade and economic pressures of the market require a system that, despite minimizing inventory, is able to meet a high level of customer satisfaction with products and orders, so these systems need a timely, efficient and enforceable schedule [3]. Of course, it should not be overlooked that scheduling is at the lowest level in terms of planning and is influenced by strategic planning and medium-term planning, so any change in higher levels of planning will have significant effects on scheduling. In other words, to optimize scheduling, inventory control, production and order forecasting, resource allocation, and other high-level decision-making must first be optimized, because the results of decisions made by the aforementioned functions affect scheduling optimization [4]. In addition, it should be noted that contingencies in the flow shop, such as machine breakdowns or changes in work process time, invalidate previous predictions and thus leave important effects on schedules. Scheduling issues are usually considered, modeled, and modeled. Sometimes the time to enter the machine work environment or the process time or other factors influencing the problem is uncertain [5]. Scheduling problems are very complex even in the simplest case where the models are definite and all times have fixed values. For example, if 4 pieces of work in a flow shop need to be processed on 5 machines, and if we do not impose any restrictions on the problem, the above example means having ($4!^5$) or 7962624 different arrangements on these 5 machines, However, in practice we know that many cases must be eliminated according to the conditions of production. In a typical car factory, we have at least one hundred work pieces and more than 252 different machines in each production department, so any technique that leads us to optimization is very valuable [6]. Accordingly, and due to the high importance of flow shop scheduling, in this paper, the modeling of a hybrid flow shop scheduling problem without interruption in conditions of uncertainty is discussed.

2. Literature review

Hybrid flow shop consists of two or more stages with a flow shop, each consisting of several uniform or unrelated parallel machines. Some steps may involve only one machine, but at least one step must involve several machines. One of the first studies conducted in a mixed flow shop environment was in 1971 by Arthanary. The researchers used a branch-bound method to solve the problem and showed that for at least one set of answers, the maximum completion time ($Cmax$) is obtained using this method, which they called the preferred scheduling [7]. In addition, in this paper, a method for calculating the lower limit was proposed, which was later upgraded by Portman et al. [8]. In solving two-stage mixed-workflow problems, placing activities with longer processing times at the beginning of the scheduling as well as activities with shorter processing times at the end of the scheduling will reduce the efficiency. Activities with the shortest processing times are selected in both stages [9]. Naderi et al. Have proposed four different complex integer linear programming mathematical models for this problem. They have also used particle swarm optimization algorithm to solve this problem in which they have presented an acceptance criterion and an innovative local search method [10]. Lin and Chen modeled the flow shop scheduling problem for the semiconductor manufacturing company. For this purpose, they used a genetic algorithm to solve the problem and minimize the flow time [11]. Dios et al. Sought to minimize the completion time of all activities by presenting an article entitled Efficient Innovative Algorithms for Mixed Flow shop Scheduling Problems. Comparing different innovative algorithms, they showed that the algorithm presented by them is highly efficient in terms of computational time as well as relative difference to the optimal value [12]. Lee et al. Proposed a two-objective mathematical model for modeling the problem of scheduling a flow shop mixed with the time of normal activity. Their objective functions were to minimize both waiting time and total early / late time. They used the NSGA II dual-objective algorithm to solve the problem [13]. Sun et al. Examine the previous and most advanced approaches of MFSP. Innovative and meta-innovative methods and combined methods have proven to be much more useful than other methods in large and complex situations. Their survey shows that the algorithms developed for MFSP still pay considerable attention to research from a theoretical and practical point of view [14]. Engin et al. Have proposed an effective hybrid ant cloning algorithm based on cross-mechanism and mutation for uninterrupted flow shop problems with the aim of minimizing the completion time and its performance has been compared with adaptive learning algorithm and heuristic genetic algorithm. Computational experiments show that the proposed hybrid ant colony algorithm gives better results than other algorithms [15]. Ribas et al. Have extensively reviewed recent articles on flow shop scheduling (HFS) problems. Articles are first classified according to HFS characteristics and production constraints. Second, the articles are categorized according to the proposed solution approach. These two classifications provide an overview of the problem situation and can guide the reader in future research [16]. To solve the flow shop scheduling problems, Zheng et al., proposed a hybrid Discrete Fruit Eater Optimization (HDFOA) algorithm. Each generation of evolution in the algorithm includes four stages of search: odor-based search, vision-based search, synchronous search, and refrigeration simulation. The simulation and comparison results based on the standard test sets show the effectiveness and robustness of the proposed algorithm [17]. Davondra introduces a discrete migration algorithm to solve the flow shop by blocking the scheduling problem. The two sets of criteria Karler, Heller, Reeves and Taylard are solved using a new algorithm [18]. Wang et al., presented a job scheduling program with production waiting time as the optimization goal and the basis of the Differential Evolution (DE) algorithm to shorten the existing production waiting time in the Combined flow shop Scheduling (HFSP) problem [19]. Zhang et al., proposed a bird migration optimization algorithm to solve the hybrid flow shop scheduling problem. They compared the performance of their algorithm with seven other algorithms and concluded that the bird migration optimization algorithm has a high efficiency in problem solving [20]. komaki et al. Modeled the problem of two-stage combined flow shop scheduling with the aim of minimizing the total completion time. They used a meta-heuristic algorithm and two heuristic methods to solve the problem. The computational results showed that the heuristic algorithm can search the lower bound for the problem

[21]. Chamnanlor et al., Modeling the problem of combined flow shop scheduling with respect to time window constraints. The model presented by them was mostly used in the sliding part of hard disk products. They used a combined ant colony optimization algorithm with genetics and finally demonstrated the efficiency of their algorithm [22]. Lu et al., used a multi-objective wolf optimization algorithm to solve the hybrid flow manning problem. In their model, in addition to energy production and consumption efficiency, noise pollution was also examined. The algorithm presented by them was also compared with other multi-objective evolutionary algorithms, which resulted in the high efficiency of the multi-objective gray wolf optimization algorithm [23]. Qin et al., used an improved ant colony algorithm to solve the problem of dynamic hybrid flow shop scheduling by considering uncertainty during processing. They implemented their model on a real manufacturing industry [24]. Shao et al., modeled the hybrid flow shop scheduling problem and solved it with a greedy search algorithm. The main purpose of the proposed model was to reduce the completion time of the entire work, which was a problem for a model distribution product store. They showed that the algorithm they provide is competitive with other existing algorithms [25]. Fernandez et al., used an automated algorithm to solve the hybrid flow shop scheduling problem. They proved that the problem they designed was NP-Hard. Therefore, the use of meta-heuristic algorithms should be considered. Statistical calculations showed that the designed automatic algorithm is more efficient than other algorithms in solving the problem [26]. Lee et al., modeled a hybrid flow shop scheduling model using sequence-dependent preparation times. They used honeydew optimization algorithm to minimize Cmax [27]. Shao et al., modeled a hybrid flow shop scheduling problem with the aim of minimizing premature crop time, performance, and total workload. They proposed a multifunctional evolutionary algorithm MOEA-LS to solve the model. The computational results showed a very high efficiency of the proposed algorithm compared to other algorithms [28]. According to the literature, a small number of articles have considered the uncertainty in processing times. Therefore, the design of a new model of the problem of uninterrupted hybrid flow shop scheduling, in which the processing time is in the form of triangular fuzzy numbers, is addressed in this paper.

3. Research method

In this paper, a mathematical model of uninterrupted combined flow shop scheduling is designed based on Fig. 1. In this system, uninterrupted means that the works are processed by existing machines without any interruption. The reason for non-interruption can be considered in cases such as the pipe production system, which must be processed immediately after the heating stage. In the problem, there are several jobs (J) that must be processed sequentially by machines (I). Each stage has several parallel machines marked with the symbol (m_i). The main purpose of this paper is to determine the correct sequence of operations and assign operations to each machine at each stage so that the total completion time (*Cmax*) is minimized. Due to the uncertainty of processing time in this paper, fuzzy programming method has been used to control this parameter.

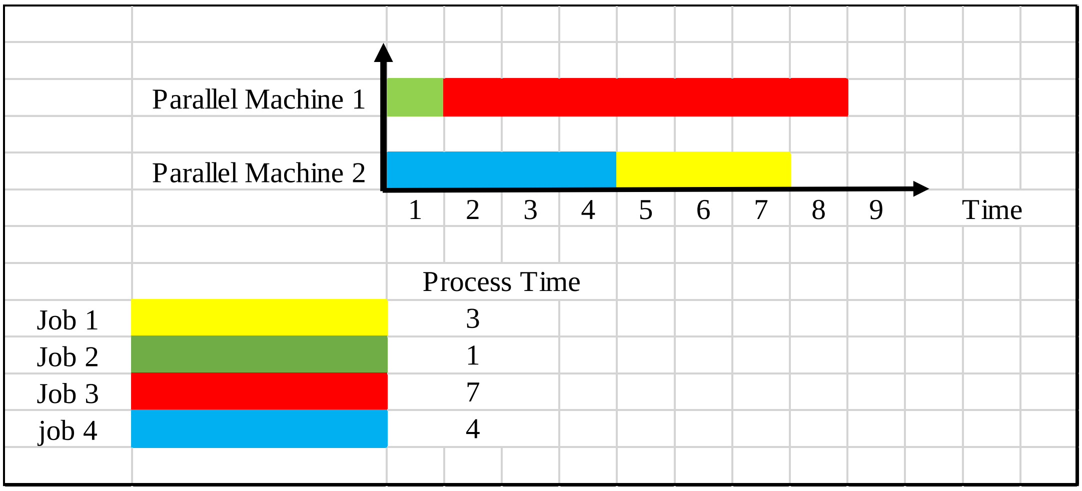

Figure 1. An overview of the uninterrupted hybrid flow shop scheduling problem

According to the following assumptions, the problem of scheduling the combined flow shop can be modeled without interruption:

A. The machines are always available and the machines are never damaged.

B- The problem data is considered as indefinite and fuzzy triangular,

C- The jobs must be done one after the other and without interruption,

D- All jobs and machinery are available at the same time at the beginning of the planning period;

E- Jobs have no special priority over each other and are independent of each other,

F- Each jobs will be ready to perform the process in the next stage immediately after completing the operation process in each stage.

According to the stated assumptions, sets, parameters and decision variables are defined as follows.

Sets and parameters

M	Set of machines $i \in \{1,2,\dots,M\}$
N	Set of Jobs $j,k \in \{1,2,\dots,N\}$
m_i	Set of machines in each stage $l \in \{1,2,\dots,m_i\}$
$\tilde{P}_{ji}$	processing time of job j by machine i
M	Negative large number
α	Uncertainty rate

Decision variables

X_{jik}	If job j is processed by machine i after job k, it takes 1, otherwise it takes 0
Y_{jil}	If work j is processed by machine l in stage i, it takes 1 and otherwise it takes 0
C_{ji}	Time to complete job j by machine i
$Cmax$	Completion time of all jobs

$$minZ = Cmax \quad (1)$$

$S.t.$:

$$\sum_{l=1}^{m_i} Y_{jil} = 1, \quad \forall j, i \quad (2)$$

$$C_{j,1} \geq \alpha \left[\frac{P_{ji}^3 + P_{ji}^2}{2}\right] + (1-\alpha)\left[\frac{P_{ji}^1 + P_{ji}^2}{2}\right], \quad \forall j \quad (3)$$

$$C_{j,i} = C_{j,i-1} + \alpha \left[\frac{P_{ji}^3 + P_{ji}^2}{2}\right] + (1-\alpha)\left[\frac{P_{ji}^1 + P_{ji}^2}{2}\right], \quad \forall j, i > 1 \quad (4)$$

$$C_{j,i} = C_{k,i-1} + \alpha \left[\frac{P_{ji}^3 + P_{ji}^2}{2}\right] + (1-\alpha)\left[\frac{P_{ji}^1 + P_{ji}^2}{2}\right] - M\left(3 - X_{jik} - Y_{jil} - Y_{kil}\right), \quad \forall j < N, k > j, i, l \quad (5)$$

$$C_{k,i} = C_{j,i} + \alpha \left[\frac{P_{ki}^3 + P_{ki}^2}{2}\right] + (1-\alpha)\left[\frac{P_{ki}^1 + P_{ki}^2}{2}\right] - M.X_{jik} - M.\left(2 - Y_{jil} - Y_{kil}\right), \quad \forall j < N, k > j, i, l \quad (6)$$

$$Cmax \geq C_{j,i}, \quad \forall j, i = M \quad (7)$$

$$C_{ji} \geq 0, \quad \forall j, i \quad (8)$$

$$X_{jik}, Y_{jil} \in \{0,1\}, \quad \forall j, i, l, k \quad (9)$$

Equation (1) shows the value of the first objective function of the problem and includes the minimization of the completion time of all jobs. Equation (2) shows that each job at each stage should be assigned to only one machine. Equation (3) shows the processing time of the jobs by the first machine. Equation (4) to (6) ensures that all job must be done non-stop between machines and that the processing time of each process is calculated by each machine. Equation (7) shows that the total completion time of jobs is equal to the maximum processing time of machines. Relationships (8) and (9) show the type of decision variables.

4. Analysis of Sample Problem

In this section, a small sample problem including 5 jobs and 3 machines is considered, which is the interval of the uncertain processing time parameter as described in Table (1). Also in this example, for each stage, two types of parallel machines are considered the same.

Table 1. Interval of the processing time parameter

Parameter	Pessimistic	Probable	Optimistic
$\tilde{P}_{ji}$	$\sim U(2,4)$	$\sim U(4,6)$	$\sim U(6,8)$

Due to the uncertainty of the problem, the value of the uncertainty rate in this analysis is considered 0.5. Therefore, Table (2) shows the processing time of each activity by each machine. The value of the objective function, ie the completion time of all jobs, is equal to 24.

Table 2. The final processing time of each job by each machine in the small sample size problem

	Machine 1	Machine 2	Machine 3
Job 1	15.00	19.75	24.00
Job 2	10.50	15.00	19.50
Job 3	5.00	10.00	14.25
Job 4	10.00	15.75	20.00
Job 5	5.00	10.50	14.75

Fig. 2., shows the flow shop scheduling problem of the small sample size and how to assign each job to each machine in each stage separately.

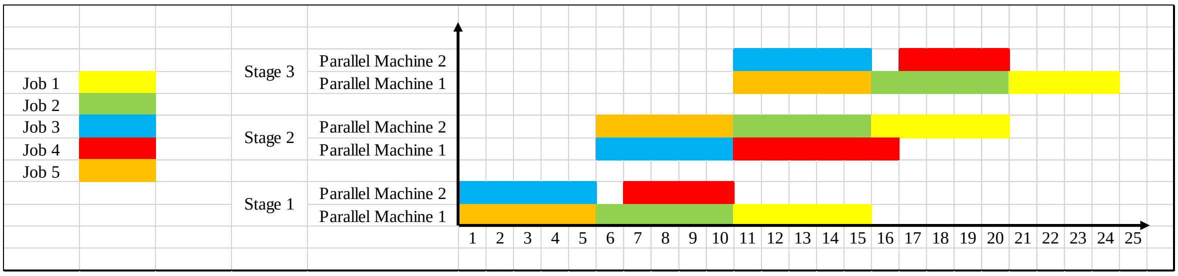

Figure 2. Gantt chart of flow shop scheduling in the small sample problem with GAMS

As shown in Fig. 2., jobs 1, 2 and 5 are assigned to machine 1 in the first stage and jobs 3 and 4 are assigned to machine 2 in the first stage. It is also observed that the sequence of operations is observed in all stages of processing. Completion time of all jobs in this issue is 24 time units.

Considering the value of the uncertainty rate of 0.5, then the changes in the completion time of the whole job (the value of the objective function) in exchange for changes in the uncertainty rate are discussed.

4.1. Sensitivity analysis of the value of the objective function in conditions of uncertainty

In order to investigate the effects of uncertainty on the results of the uninterrupted combined flow shop scheduling model, the uncertainty rate is changed in the range of 0.1 to 0.9 and the value of the objective function corresponding to each uncertainty rate is shown in Table (3). Considering the basis of the uncertainty rate of 0.5, the percentage change of the value of the objective function from the base value of the objective function, ie 24, is also shown in Table (3).

Table 3. Changes in the value of the objective function at different rates of uncertainty in the small size sample problem

Uncertainty rate	Cmax	Percentage of changes
0.1	19.60	-18.33
0.2	20.70	-13.75
0.3	21.80	-9.167
0.4	22.90	-4.583
0.5	24.00	0.000
0.6	24.80	3.333
0.7	25.65	6.875
0.8	26.60	10.83
0.9	27.30	13.75

According to the results of Table (3), it can be seen that with the increase of uncertainty rate due to the increase of processing time, the completion time of all jobs has increased. This increase in the value of the objective function was 13.75% in the most pessimistic case and -18.33% in the most optimistic case. Fig. 3., shows the trend of changes in the value of the objective function in exchange for changes in the rate of uncertainty in the small sample size problem. Fig 4., also shows the Gantt chart of the flow shop scheduling for the uncertainty rates of 0.3, 0.5 and 0.7 to clearly show the changes resulting from the uncertainty on the flow shop scheduling.

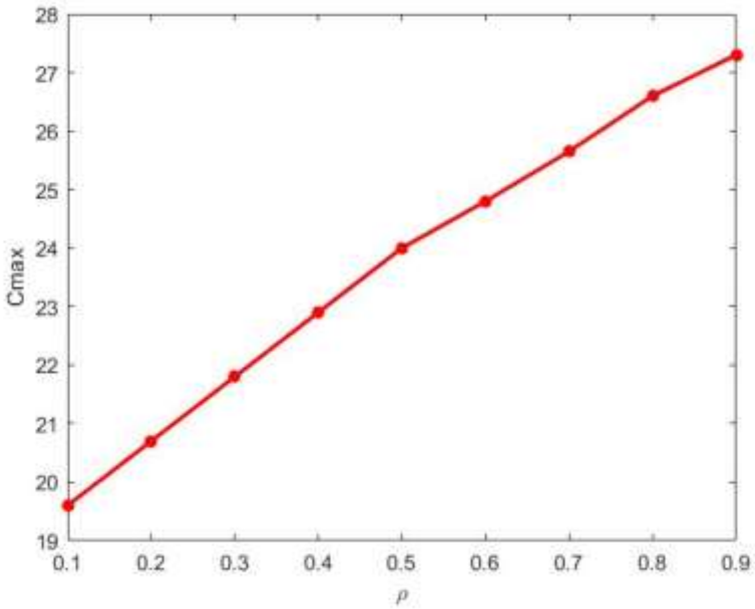

Figure 3. Trend of changes in the value of the objective function in exchange for changes in the rate of uncertainty in the small sample size problem

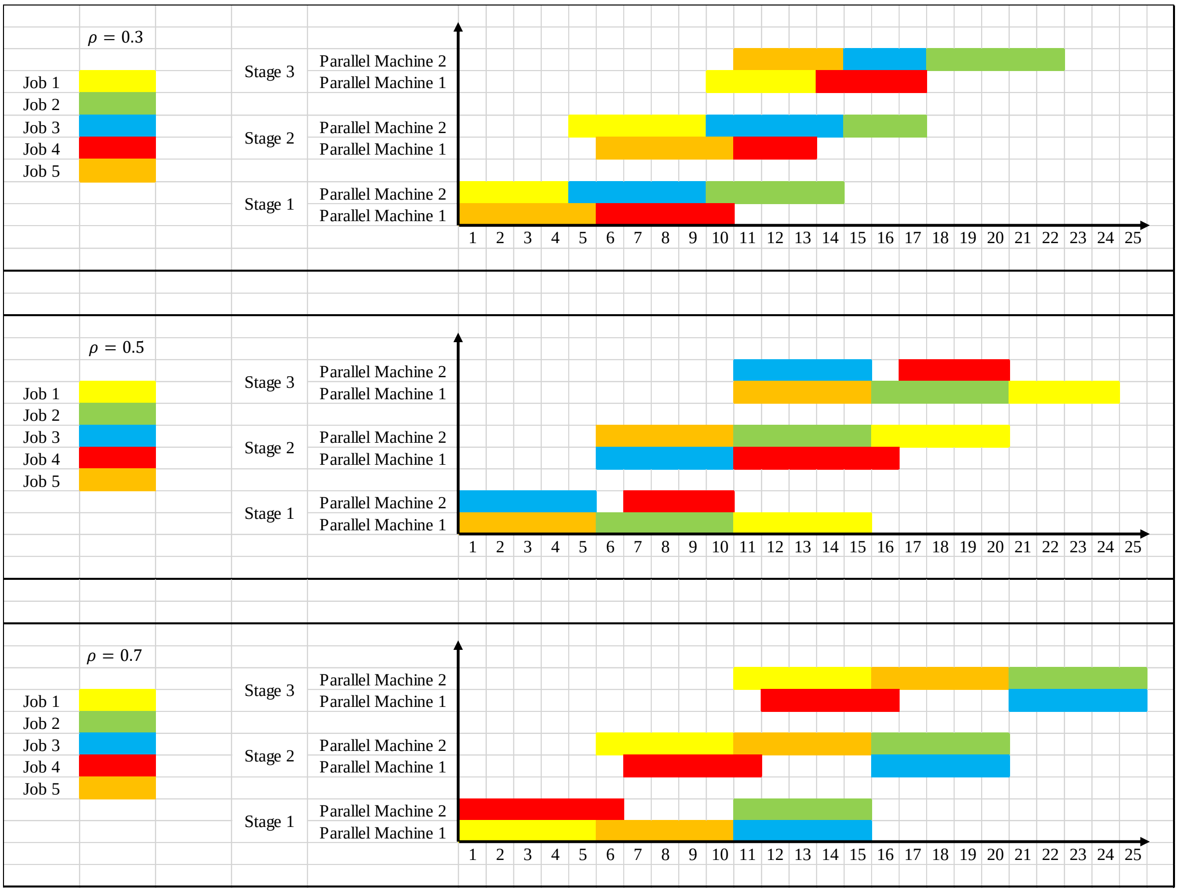

Figure 4. Gantt chart for the flow shop scheduling problem at different rates of uncertainty

The following is another sensitivity analysis regarding the change in the number of machines in each processing stage. Obviously, as the number of machines decreases, the total processing time will increase. Changes in the value of the objective function for changes in the number of machines in each stage are shown in Table (4).

Table 4. Changes in the value of the objective function in different numbers of machines in the small size sample problem

Number of cars in each stage	Cmax	Percentage of changes
1	34.75	44.79
2	24.00	0.000
3	19.25	-19.79
4	19.25	-19.79

According to Table (4), it can be seen that with increasing the number of machines, the amount of improvement of the objective function cannot be more than 19.79%, and in the case of a single machine, a 44.79% increase in the amount of the objective function can be observed. Fig (5) and (6) show the trend of changes in the value of the objective function in exchange for changes in the number of machines in the stage and the Gantt chart of these changes, respectively.

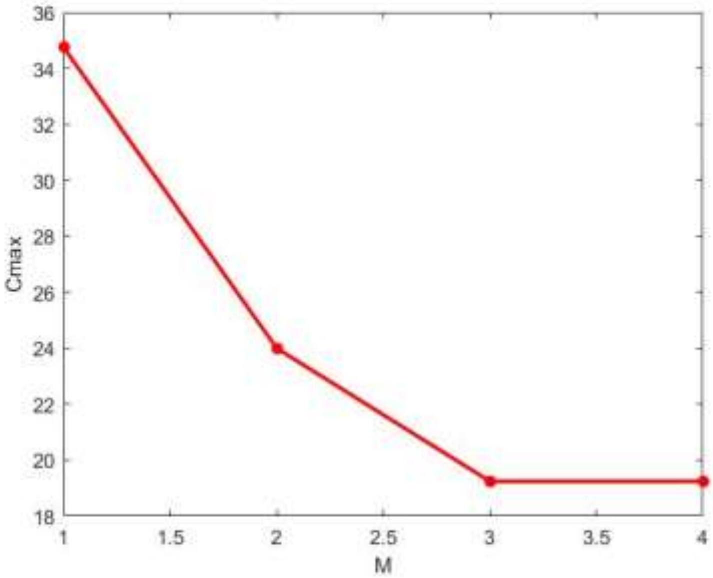

Figure 5. Process of changing the value of the objective function in exchange for changes in the number of machines in the small sample size problem

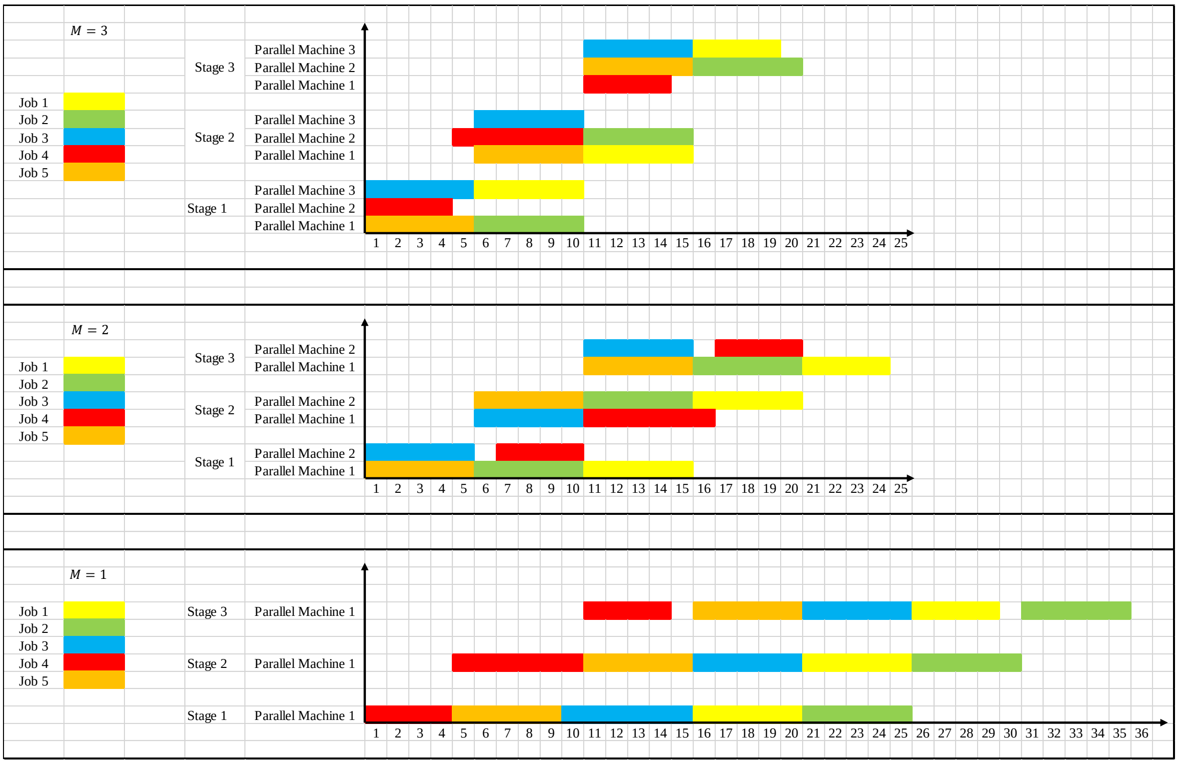

Figure 6. Gantt chart for the flow shop scheduling problem in different machines at each stage

4.2. Solve sample problems in other sizes with GAMS software

In the following, other sample problems are solved by GAMS software. Table (5) shows the five sample problems designed in this section.

Table 5. Size of sample problems in other sizes with GAMS software

Sample Problem	Number of jobs	Number of machines
1	5	3
2	6	3
3	7	4
4	8	4
5	10	5

Table (6) shows the optimal value of the obtained objective function (time of completion of all jobs) and the computational time obtained from solving these problems. According to the results of Table (6), it can be seen that the problem solving time has increased exponentially with increasing the size of the problem and GAMS software is not able to solve the problem larger than the size stated in Table (5).

Table 6. The value of the objective function and the computational time obtained from solving the sample problem with GAMS software

Sample Problem	Cmax	Computational time
1	19.25	0.694
2	19.75	1.652
3	27.25	149.27
4	28.50	420.06
5	32.50	1736.29

Fig (7) shows the trend of changes in the value of the objective function and computational time in different sample problems with GAMS software.

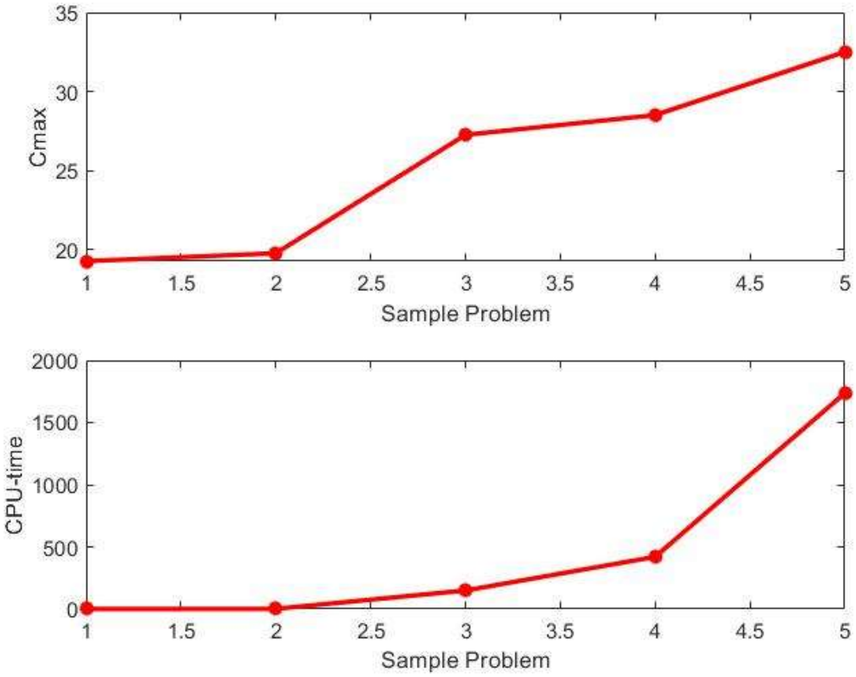

Figure 7. The process of changing the value of the objective function and computational time in different sample problems with GAMS software

5. Conclusion

In this paper, an indefinite model of the uninterrupted hybrid flow shop scheduling problem is presented. Due to the uncertainty of processing time, fuzzy programming method has been used to control the uncertainty parameter of processing time. The proposed model seeks to minimize the maximum processing time of all jobs. For this purpose, GAMS software has been used to solve the problem. The computational results of solving the problem in small sizes show that with increasing uncertainty rate, the amount of processing time has increased and therefore the completion time of all jobs has increased. Also, the sensitivity analysis of the problem showed that with the increase in the number of machines in each stage due to the high efficiency of the machines, the completion time of all works has decreased. Due to the high problem solving time by GAMS software, the use of ultra-innovative algorithms to solve the problem in larger sizes is recommended. It is also proposed to consider other objective functions such as minimizing latency along with maximum processing time as model development.

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