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Research Paper

Modeling and Solving Flow Shop Scheduling Problem Considering Worker Resource

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ABSTRACT

In this paper, an uninterrupted hybrid flow scheduling problem is modeled under uncertainty conditions. Due to the uncertainty of processing time in workshops, fuzzy programming method has been used to control the parameters of processing time and preparation time. In the proposed model, there are several jobs that must be processed by machines and workers, respectively. The main purpose of the proposed model is to determine the correct sequence of operations and assign operations to each machine and each worker at each stage, so that the total completion time (Cmax) is minimized. Also, this paper, fuzzy programming method is used for control unspecified parameter has been used from GAMS software to solve sample problems. The results of problem solving in small and medium dimensions show that with increasing uncertainty, the amount of processing time and consequently the completion time increases. Increases from the whole work. On the other hand, with the increase in the number of machines and workers in each stage due to the high efficiency of the machines, the completion time of all works has decreased. Innovations in this paper include uninterrupted hybrid flow storage scheduling with respect to fuzzy processing time and preparation time in addition to payment time. The allocation of workers and machines to jobs is another innovation of this article.

1. Introduction

The problem of flow workshop scheduling is one of the most common machine scheduling issues with extensive engineering communication, using almost a quarter of production systems, assembly lines, and information service facilities. In a traditional workshop schedule, it is an indivisible task and can not be transferred to the next machine before processing is complete. However, this may not be the case in many practical situations where a job is made up of many similar cases. To reduce machine waiting time, a task is allowed to overlap its operations between consecutive machines by dividing it into a number of smaller subdirectories (Bukchin, Hanany, 2020). The system dynamics in the decision-making process of the reservoir management not only have the ability to analyze the complex systems based on reality, but it also provides the opportunity for the user's participation in the development of the model (Nozari et al, 2021)

Scheduling is an important decision-making process in manufacturing and various scheduling problem has been dealt with (Liu et al, 2019). As a frequently investigated problem, hybrid flow shop scheduling problem (HFSP) is not uncommon one in many real-life manufacturing industries such as electronics, paper, textile and semiconductor and has attracted much attention in the past decades. Many works have been done on HFSP with practical constraints such as no-wait, dedicated machines, batching and scheduling assembly, renewable resources, multiprocessor task and preventive maintenance (Meng et al, 2019).

Meta-heuristic is the main path to deal with HFSP for its high complexity. HFSP has been extensively solved by using genetic algorithm, artificial bee colony (Meng et al, 2019), shuffled frog-leaping algorithm and imperialist competitive algorithm (Rabiee et al, 2014). The scheduling in a flow shop situation, where all the jobs pass through all the machines in the same order, is one of the most important problems in the field of production planning (Hu et al, 2020).

In the practical industrial environment, this type of manufacturing is employed due to the many advantages it has for the planning and management of production activities, which are enabled by technological developments such as general-purpose machines and flexible manufacturing systems (FMS). This problem can be formulated generally by the sequencing of n jobs (J1 ... J,) on m machines (M1 ... Mm) under the precedence condition. As the processing time of job i on machine j is given by Tij (i = 1 ..., n; j = 1... m), the objective function is usually to minimize the maximum flow time or make span (Fontes, Homayouni, 2019).

- HFS

Hybrid flow shops (HFS) are common manufacturing environments in which a set of n jobs are to be processed in a series of m stages optimizing a given objective function. There are a number of variants, all of which have most of the following characteristics in common (Long et al, 2018):

1. The number of processing stages m is at least 2.

2. Each stage k has machines in parallel and in at least one of the stages.

3. All jobs are processed following the same production flow: stage 1, stage 2, …, stage m. A job might skip any number of stages provided it is processed in at least one of them.

4. Each job j requires a processing time in stage k. We shall refer to the processing of job j in stage k as operation.

In the "standard" form of the HFS problem all jobs and machines are available at time zero, machines at a given stage are identical, any machine can process only one operation at a time and any job can be processed by only one machine at a time; setup times are negligible, preemption is not allowed (Jonker et al, 2021).

The real world problems are usually associated with uncertainty, so programming challenges in these situations can be one of the reasons why researchers are less likely to be involved with such problems (Asgharizadeh et al, 2019). In fact, uncertainty is an integral part of disaster conditions, and the research problem formulates the fuzzy robust stochastic optimization model under the hybrid uncertainty (Nahaei et al, 2021). A fuzzy chance-constrained programming approach is suggested to deal with the uncertainty (Nahaei et al, 2021),

The HFS problem is, in most cases, NP-hard. For instance, HFS restricted to two processing stages, even in the case when one stage contains two machines and the other one a single machine, is NP-hard, after the results of Gupta. Similarly, the HFS when machines are allowed to stop processing operations before their completion and to resume them on different time slots (something referred to as preemption) results also in strongly NP-hard problems even with m = 2. Moreover, the special case where there is a single machine per stage, known as the flow shop, and the case where there is a single stage with several machines, known as the parallel ma- chines environment, are also NP-hard, However, with some special properties and precedence relationships, the problem might be polynomial solvable (Wei et al, 2019).

• Hybrid flow shop classification and notation

The modification, removal, or addition of assumptions and/or constraints to the standard problem described above leads to different HFS variants. To refer to them, the classification and nomenclature from Ref (Vignier et al, 1996), is adopted. The problems are classified according to their shop configuration (x), constraints and assumption (β), and the objective function considered (ʎ). Each problem then is described with a triplet α|β|ʎ. Elements Cj; Fj, etc. and their weighted counterparts wjCj; wjFj, etc. are frequently used to describe objective functions. Some

• FSMP

The hybrid flow store is also known as the flow Store with multiple processors (FSMP) widely studied in the literature. Most recently Linn Zhang in 2019, provides an overview of FSMP research. However, more is considered the problems are theoretical models. (Lin, Wang, 2019)

Research work has also been done in the generalized FSMP case where the number of stages and the number of machines at each stage are not restricted. The logic on how the rules in these papers were developed will be of great value to us in developing good heuristic. Kochhar and Morris, presented heuristics to minimize the mean flow time for the scheduling problem, which consists of two sub-problems: entry point sequencing and dispatching. Various optimization techniques, including myopic and local search methods, and dispatching methods, trying to minimize the effects of setup time and blocking, were investigated for the two sub-problems, respectively. (Kochlar, Morris, 1987)

• HFSMO

The HFSMO problem has not been widely analyzed in the literature. Most often, it has been addressed as an ordinary HFS problem assuming that a missing operation is tantamount to an operation with zero processing time. Nevertheless, this assumption implies that every job has to be processed in every stage even with zero processing times, therefore the completion time of the job's increases (Dios et al, 2018).

The HFSMO problem with make span objective can be stated as follows: considering a set of n jobs, {1,… , n} that have to be pro-N cussed in s different stages,{1,..,s } Each stage is composed of a set S of m identical parallel machines,{1,… , m}. The processing time M of the job on all machines within a stage is the same. Thus, the processing time of a job on a specific stage can be denoted as pij, where i (∈ i N) denotes the job, and j (∈ j S) the stage. Every job has the same routing through the stages, but some of them can be skipped, i.e. there may be missing operations. Jobs are processed by exactly one machine at each stage. The objective is to find the sequence of jobs on each stage so the maximum completion time (makespan) is minimized (Dios et al, 2018).

• DHFSP

In DHFSP, a set of jobs is assigned to a set of identical factories for processing. Each task must cross a path with a set of steps, and each step must have several machines in parallel, and at least one of the steps must have more than one machine. To solve DHFSP, in a research by Shoa et al in 2020, proposes two algorithms: DNEH with the smallest mean rule and the greedy iterative multi-neighborhood iterative algorithm. DNEH, with its least-average law-making exploratory exploration, first produces a grain sequence with decomposition and the smallest-average law, and then uses a greedy iteration to assign jobs to factories. In the repetitive greed algorithm, a multi-search structure is proposed which, after inserting a new task, re-applies the greedy insert in the factory. Then, a multi-neighborhood local search is used to increase the local search capability. The proposed algorithms are evaluated with a comprehensive comparison and the experimental results show that the proposed algorithms for solving DHFSP are very competitive (Shao et al, 2020).

Uncertainty in decision-making processes is also a major factor that may affect effectiveness (Ghahremani Nahr et al, 2019). Distributed scheduling with uncertainty attracted limited attention in hybrid flow shop. Uncertainty always exists in the real-life manufacturing process and is an unavoidable property of manufacturing process. Most of the time data in disaster management are uncertain and quick decisions are made based on just a fraction of the required information (Sadeghi et al, 2021). The obtained schedule may be invalid if uncertainty is neglected in scheduling problem. Thus, it can be concluded from the above analyses that it is important to study HFS with uncertainty in problems. Fuzzy language descriptions (often called fuzzy systems, or more simply language descriptions) are common representations of systems that are constructed fuzzy if-then rules (Parviznejad, Bahrami, 2021). Fuzzy theory is often adopted in fuzzy scheduling to depict uncertainty and a number of works have been done on fuzzy scheduling problem (Abdullah, Abdolrazzagh-Nezhad, 2014).

2. Literature review

Flowshop scheduling problems have been largely studied in the literature during the last 50 years. Due to a rising demand of products, both in variety and quantity, it is commonplace that companies increase their capacity by adding new resources (both physical and human) to some stages in the manufacturing process (Ribas et al, 2010).

Several researchers studied the fuzzy methods for solving the permutation FS problem, for instance, Tirkolaee et al, studied a multitrip green capacitated are routing problem with an application to urban services. They proposed a FS scheduling problem with outsourcing option on subcontractors. They considered the just-in-time criteria in model formulation. They also investigated the pollution-routing problem with cross-dock selection. They used the Pareto-based algorithm to deal with the multi objective optimization problem (Tirkolaee, et al, 2020). Afterwards, Khalifa and Kumar proposed the fuzzy solution approach to fully neutrosophic linear programming problem. They also presented an application to stock portfolio selection (Khalifa et al, 2021). Very recently, Tirkolaee et al, presented a FS scheduling problem with outsourcing option. They used fuzzy programming and artificial fish swarm algorithm. They investigated a fuzzy production-scheduling model. They considered the automated guided vehicles as well as human factors.

The issue of flow workshop scheduling (FSS) is a major part of production planning in any manufacturing organization. Its purpose is to determine the optimal sequence of processing tasks in the machines in a given customer order. In this paper, a mixed integer linear programming (MILP) model for FSS with the option of outsourcing and timely delivery is proposed to minimize the cost of the entire production system and total energy consumption simultaneously. Each job is considered to be either internally planned or outsourced to one of the potential subcontractors. To effectively solve the problem in a paper by Tirkolaee et al, A hybrid technique based on an interactive fuzzy solution method and a self-adapting artificial fish swarm algorithm (SAAFSA) is proposed. The proposed model is used as a one-objective MILP using a multi-objective fuzzy mathematical programming technique based on the ε constraint, and SAAFSA to provide Pareto optimal solutions. The results obtained in this paper indicate the usefulness of the proposed method and the high efficiency of the algorithm in comparison with the CPLEX solver in different cases. Finally, a sensitivity analysis is performed on the main parameters to study the behavior of the targets according to the real world conditions ((Tirkolaee, et al, 2020).

Many supply chains consist of manufacturers, suppliers, carriers and customers. These factors must be coordinated to reduce waste and work time. Production and distribution are two essential steps in most supply chains. Hence, improving the coordination of these steps is critical. An article examines a combined problem of hybrid flow and vehicle routing. The production phase is modeled as a hybrid flow shop configuration. In the second stage, the produced jobs must be delivered to a set of customers. Delivery in product categories is done using limited capacity vehicles. In order to minimize end-user service time, we propose a random-random variable neighborhood descent algorithm. Various test factors, such as the use of alternative solutions, solution demonstrations, and loading strategies, are considered and analyzed (Sioud, Gagné, 2018).

Hybrid workshop scheduling (HFS) has been extensively studied and the main goal has been to improve production efficiency. However, with the advent of green production, limited attention has been paid to energy consumption. In a study by Shao and et al, a new meta-innovation of ant colony optimization (MOACO) is proposed that considers not only production efficiency but also electricity cost (EPC) in the presence of TOU prices. The solution is coded as job permutation. A timeline algorithm is applied to build the sequence by the artificial ants and create a complete program. A right-shift method is then used to set the start-up time to minimize EPC for the program. In terms of theoretical research, the results of computational experiments show that the efficiency and effectiveness of the proposed MOACO is comparable to NSGA-II and SPEA2. From a practical point of view, instructions on how to prioritize multiple goals have been studied. This result has significant managerial implications for actual production. Parameter analysis also shows that the duration of TOU periods and the processing speed of machines have a large effect on scheduling results, as longer off-peak periods and the use of faster machines provide more flexibility to transfer high-energy operations to off-peak periods (Dios et l, 2018).

Distributed scheduling problems have attracted a great deal of attention in recent years. However, the problem of distributed combined flow storage (DHFSP) scheduling is rarely considered. In a study by Cai and et al, DHFSP is studied with multiprocessor tasks, and a dynamic cluttered frog mutation (DSFLA) algorithm is proposed to minimize the time interval. The dynamic search process runs on each memeplex with at least two improved solutions. Global search and dynamic multi-neighborhood search are applied in which the neighborhood structure is selected based on its optimization effect. A new construction demolition process has hybridized with DSFLA, and population composition is performed when mixing conditions are met. Reached the bottom and fixed. A number of experiments are performed on a set of samples. The computational results confirm the effectiveness of the new DSFLA strategies and competitive practices in the DHFSP solution (Cai et al, 2020).

Given the uncertainties in distributed generation systems, this paper addresses a problem of scheduling a multi-objective fuzzy distributed hybrid flow workshop with fuzzy processing times and fuzzy maturities. To optimize the delay and total fuzzy robustness simultaneously in a study by Zheng, a common evolution algorithm with specific problem strategies with the logical combination of distribution algorithm estimation (EDA) and repetitive greedy search (IG) is proposed. In EDA mode search, a specific problem probability model is created to reduce solution space, and a sample mechanism is proposed to create new people. To increase exploitation, a specific local search is designed to improve the performance of non-dominated solutions. In addition, demolition and reconstruction methods are used in IG mode search to make better use of better solutions. To balance exploration and exploitation capabilities, a state-of-the-art collaboration scheme is designed based on information entropy and a variety of elite solutions. The effect of key parameters on the performance of the proposed algorithm is investigated using the Taguchi design experimental method. Comparative results and statistical analysis show the effectiveness of the proposed algorithm in solving the problem (Zheng et al, 2020).

Hybrid workshop scheduling problems have received increasing attention in recent years due to their widespread applications in real production systems. Most previous studies assume that job processing time is fixed. In practice, work processing times are usually difficult to determine precisely in advance and can be affected by many factors such as machine wear and work characteristics, resulting in uncertain and variable processing times. In a study by Fu, a worse scheduling problem than a two-purpose random hybrid flow workshop was proposed with the aim of minimizing build time and overall latency. In the formulated problem, the normal processing time of tasks follows a known random distribution, and their actual processing time is a linear function of their starting time. In order to solve it effectively, this paper develops a hybrid multi-objective optimization algorithm that maintains two populations that perform global search across solution space and local search in promising areas, respectively. The information sharing mechanism and resource allocation method are designed to increase the ability to explore and exploit it. Simulation experiments are performed on a set of samples and several classical algorithms are selected as their counterparts for comparison. The results show that the proposed algorithm has a great advantage in dealing with the problem under study (Fu et al, 2019).

Increasing environmental awareness and the relevance of energy costs in many industries has led to the need to improve energy efficiency in operations management. Hence, energy conscious scheduling (EAS) is important. Three basic strategies can be identified in EAS. First, a large part of research activities are carried out with the aim of reducing energy consumption. Second, energy costs can be reduced by using different energy prices. Third, an aspect that is rarely considered is load leveling, which is used to reduce demand or network utilization costs. For this reason, in one paper, all three strategies are first integrated into a model to solve a multi-objective hybrid flow workshop scheduling problem. A new multiphase repetitive local search algorithm (ILS) has been developed to determine a three-dimensional Pareto front for three purposes: construction length, total energy cost, and peak load. Taboo lists, several time- and energy-dependent list scheduling algorithms, a right-shift method, and a reference point-based proportionality function make high-quality solutions possible. A computational study is presented that analyzes the interdependencies of the targets and compares the proposed algorithm with the well-known NSGA2 heuristic. ILS has been proven to be appropriate in targeted search in the solution space, enabling practical decision support (Schulz et al, 2019).

One study examines a complex two-stage complex hybrid scheduling problem encountered during the construction of aerospace composite components. There are a number of new limitations that need to be considered in this particular hybrid store, in particular the limited physical capacity of the intermediate buffer, the limited waiting time between processing steps, and the limited tools / molds used in both stages of each production cycle. We propose a linear programming model of discrete mixed integers with a branch and boundary algorithm to solve small and medium problems (up to 100 jobs). To solve large problem samples (up to 300 jobs), a genetic algorithm with a new crossover operator has been developed. A new heuristic method for generating the initial population of genetic algorithms has been introduced. The results show the high level of computational efficiency and accuracy of the proposed genetic algorithm compared to the optimal solutions obtained from the mathematical model. The results also show that the proposed genetic algorithm performs better (Azami et al, 2018).

In one study, the problem of flow shop hybrid scheduling was investigated with the aim of minimizing life expectancy. Missing operations considered in this research. That is, some steps are ignored, a situation inspired by a realistic problem found in a plastic manufacturer. The main contribution of research is dual. On the one hand, a computational analysis is performed to study the difficulty of the hybrid flow shop scheduling problem with lost operations compared to the classical hybrid flow shop problem. On the other hand, a set of explorations is proposed that depicts some specific features of missing operations and compares these algorithms with pre-existing discoveries for the classic hybrid flow shop, and for the hybrid flow shop problem with lost operations. Extensive computational experience has shown that this proposal works better than existing methods for the problem, and shows that the length of construction can be improved by interacting with tasks that have lost operations (Kochhar, Morris, 1987).

A study by Yu et al in 2018, a genetic algorithm has been developed to solve the hybrid flow workshop scheduling problem to minimize overall latency. Practical assumptions are considered as unrelated machines and machine eligibility. The proposed algorithm includes a new decoding method developed for the purpose of general delay, which can achieve intensive programming while ensuring the effect of the chromosome on the program. The proposed algorithm is calibrated with a complete factorial design and compared with several advanced algorithms calibrated on 450 samples of different sizes and correlation patterns of operation processing time. The results confirm the performance of the proposed algorithm (Yu et al, 2018).

The parallel flow store scheduling (PFSP) problem is conceptually similar to another problem known in the literature as the distributed permutation flow-scheduling problem (DPFSP), which allows modeling the scheduling process in companies with more than one factory, each factory with Provides a flow. Store Configuration Thus, the proposed methods can solve the scheduling problem under the blocking constraint in both situations, which, as far as we know, has not been studied before. In a study by Ribas et al., A mathematical model with some constructive and improved discoveries to solve the problem of parallel flow blocking store (PBFSP) and thus minimizing the maximum completion time between lines with the aim of minimizing the length of time, The maximum time for completing all the work in the flow shops is suggested. The proposed constructive procedures use two approaches that are quite different from the proposed methods in the literature. These methods are used as the primary solution procedures for an iterative local search (ILS) and a greedy iterative algorithm (IGA), both of which are combined with a variable neighborhood search (VNS). The proposed constructive method and the improved methods take into account the characteristics of the problem. Computational evaluation shows that both of them - especially IGA - perform significantly better than algorithms adapted from the DPFSP literature (Ribas et al, 2017).

In a research, a discrete artificial bee colony (DABC) algorithm has been proposed to solve the problem of flow workshop scheduling with the criterion of sum of early weighted fines and latency in both unemployment and non-unemployment cases. Unlike the original ABC algorithm, the proposed DABC algorithm represents a food source as a discrete job permutation and uses discrete operators to generate new neighbor food sources for working bees, spectators, and scouts. An efficient prototype, based on the earliest time limit (EDD), the shortest latency in the last machine (LSL) and the shortest overall latency (OSL), is presented to build a quality, defined initial population. Diversity In addition, a self-adaptive strategy for producing neighboring food sources based on insertion and exchange operators has been developed to enable the DABC algorithm to work on discrete / hybrid spaces. In addition, a simple but effective local search approach is embedded in the proposed DABC algorithm to increase local resonance capability. Through the analysis of experimental results, the very effective performance of the proposed DABC algorithm against the best efficient algorithms from the literature is shown (Pan et al, 2011).

Scheduling workshops with multiple parallel machines at each stage, commonly known as hybrid current storage (HFS), is a complex hybrid problem encountered in many real-world applications. Due to its importance and complexity, the subject of HFS has been extensively studied. In a study reviewing the literature, precise, innovative and meta-innovative methods are proposed to solve it. The results of the research briefly discuss several types of HFS problems, each of which in turn considers different assumptions, constraints, and objective functions. Research opportunities in HFS are also discussed (Ruiz, Vázquez-Rodríguez, 2010).

Research focuses on multi-objective resolution of a hybrid stream store scheduling problem (RHFS). In a research, the two goals are to maximize the bottleneck rate and to minimize the maximum completion time. This problem is solved by a new multi-objective genetic algorithm called L-NSGA, which uses Lorenz's dominant relationship. L-NSGA results are compared with NSGA2, SPEA2 and an accurate method. A random model of the system is proposed and used with a discrete event simulation module. An experimental protocol is applied to compare four methods in different problem configurations. The comparison was made using two standard criteria for multiple purposes. The Lorenz dominance relationship provides a stronger choice than Pareto dominance and gives better results than the latter. Computational tests show that L-NSGA offers better solutions than NSGA2 and SPEA2. In addition, its solutions are closer to the optimal front. The efficiency of our method has been confirmed in an industrial field experiment (Dugardin et al, 2010).

In a study aimed at scheduling a Flow Store with Available Limits (FSPAC), machines are not continuously available for processing due to a preventive maintenance activity. There are few methods of solving in the literature to solve problems with a maximum of two machines, and as far as the author knows, only a few of them use non-preventive constraints. Therefore, two types of FSPAC are considered non-preventive. In the first type, the start time of maintenance tasks is fixed, while in the second type, maintenance tasks must be performed in regular time windows. Since FSPAC stands for NP-hard, an exploratory approach based on a genetic algorithm and a taboo search has been proposed to solve the almost time-minimization problem. Computational tests are performed on randomly generated samples to demonstrate the efficiency of the proposed methods (Dugardin et al, 2010).

Research Methods

In this paper, a mathematical model of uninterrupted combined flow programming is designed based on Figure 1. It is acknowledged that uncertainty exists regarding the estimated parameter values (ALIAHMADI, A., & NAHAEI, 2010).

In the problem, there are several jobs (J) and several sections (I) that must be processed sequentially by machines (K) and workers (O). Each stage has several parallel machines. The main purpose of this paper is to minimize the total completion time (Cmax), by specifying the correct sequence of operations and assigning operations to each machine and worker at each stage. Due to the uncertainty of processing time in this paper, fuzzy programming method has been used to control this parameter.

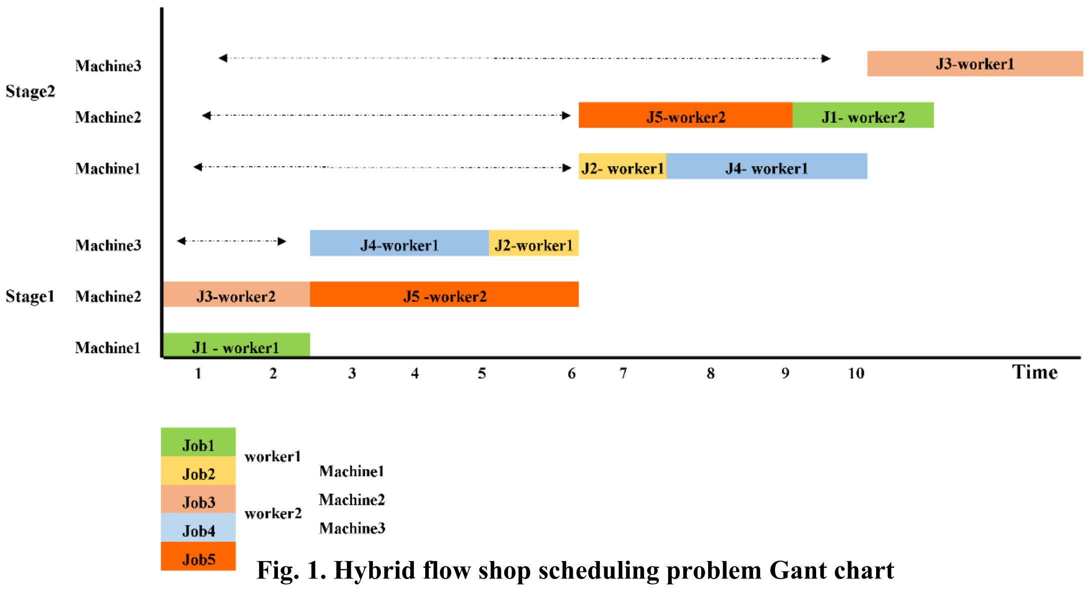

Fig. 1. Hybrid flow shop scheduling problem Gant chart

The model has two objective functions. One of them is minimize C_{max} and the other is minimize C_j (the sum of job delayed time) and E_j which all common possibilities and objective functions, parameters and decision variables used in modeling has been shown in Table 1. The workshop is shown with I, Number of jobs with J. Total number of machines with K and also the number of workers is indicated by O.

Table1: List of Sets, Parameters and decision Variables

	type	explain
Sets	I	Number of sections
	J	Number of Jobs
	K	Total number of machines
	O	Number of workers
Parameters	s_{ij}	Work preparation time j in section i
	t_{ij}	Job processing time j in section i
	M	Very large positive number
Decision Variables	X_{ikjo}	If work j is processed on machine k from section i and prepared by worker o, it takes 1, otherwise it takes 0.
	F_{ilj}	If the same worker before task j in section prepares I, task l it takes 1, otherwise it takes 0.
	D_{ilj}	If the same process work l machine before work j in section i, it takes 1, otherwise it takes 0.
	U_{ij}	Start time work j in section i
	C_{ij}	Time to complete work j in section i

Table2: Model Equations

$Min\ C_{max}$	1
$F_{ilj} + F_{ijl} \geq \sum_{k=1}^{K} \left(X_{ikjo} + X_{iklo}\right) - 1\,, \quad \forall i \in I, j \neq l \in J, o \in O$	2
$D_{ilj} + D_{ijl} \geq \sum_{o=1}^{O} \left(X_{ikjo} + X_{iklo}\right) - 1\,, \quad \forall i \in I, j \neq l \in J, k \in K$	3
$U_{ij} \geq C_{il} - M\left(1 - D_{ilj}\right), \quad \forall i \in I, j \neq l \in J$	4
$U_{ij} \geq U_{il} + [\frac{\alpha}{2}\left(\frac{S_{il}^2 + S_{il}^3}{2}\right) + \left(1 - \frac{\alpha}{2}\right)\left(\frac{S_{il}^1 + S_{il}^2}{2}\right)] - M\left(1 - F_{ilj}\right), \quad \forall i \in I, j \neq l \in J$	5
$C_{ij} \geq C_{i-1,j} + [\frac{\beta}{2}\left(\frac{t_{ij}^2 + t_{ij}^3}{2}\right) + \left(1 - \frac{\beta}{2}\right)\left(\frac{t_{ij}^1 + t_{ij}^2}{2}\right)], \quad \forall i \in I, j \in J$	6
$C_{ij} \geq U_{ij} + [\frac{\alpha}{2}\left(\frac{S_{ij}^2 + S_{ij}^3}{2}\right) + \left(1 - \frac{\alpha}{2}\right)\left(\frac{S_{ij}^1 + S_{ij}^2}{2}\right)] + [\frac{\beta}{2}\left(\frac{t_{ij}^2 + t_{ij}^3}{2}\right) + \left(1 - \frac{\beta}{2}\right)\left(\frac{t_{ij}^1 + t_{ij}^2}{2}\right)], \quad \forall i \in I, j \in J$	7
$C_{max} \geq C_{Ij}, \quad \forall j \in J$	8

Modeling assumptions are the following:

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. Jobs in two stages can be done in parallel.

G. Machines can operate in two stages in parallel.

According model assumptions, the model equations are as shown in Table 2.

• Equation (1) shows the objective function.

• Equation (2) that the sum of the two tasks l and j performed in section i by the same worker must be greater than the sum of the tasks j and l performed on machine k in section i.

• Equation (3) shows that the sum of the two tasks l and j performed in section I by the same machine must be greater than the sum of the tasks j and l performed on machine k in section i.

• Equation (4) shows that the start time of the next work by the same machine must be after the completion of the previous work.

• Equation (5) and (6) show that to start the next job, the start time of the next job by the same machine must be completed after the time of the previous job and the preparation of the previous job.

• Equation (7) shows that the completion time of the work by the machine must be greater than the completion time of the work in the previous machine.

• Equation (8) shows that the total time of completion of the work must be equal to or greater than the time of completion of the last work in the last machine.

3.Analysis of sample model

In this section, a small sample problem including 5 jobs and 2 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, which can operate in two stages in parallel.

In this problem, we have two variables, S and T, which S represents the preparation time and T represents the processing time by the machine. The uncertainty of the variables is considered to be a triangular fuzzy, the values of which are shown in Table 3.

Table3: Interval of the processing time parameter

Parameter	Pessimistic	Probable	Optimistic
s	~ 5-10	~ 10-15	~ 15-20
t	~ 7-10	~ 10-13	~13-18

Due to the uncertainty of the problem, the value of the uncertainty rate in this sample analysis is considered for both alpha and beta 0.5. Therefore, Table 4 shows the processing time of each activity by each machine. The value of the objective function, the minimum completion time after execution, is equal to 74.315.

Table 4: The final processing time of each job by each machine and worker in sample problem

	Job	U.L	C.L
Stage1	Job1	-	21.18
	Job2	41.184	63.594
	Job3	42.055	63.359
	Job4	10.23	31.542
	Job5	21.224	42.055
Stage2	Job1	-	31.644
	Job2	53.208	74.315
	Job3	42.507	74.315
	Job4	-	42.507
	Job5	31.644	53.208

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

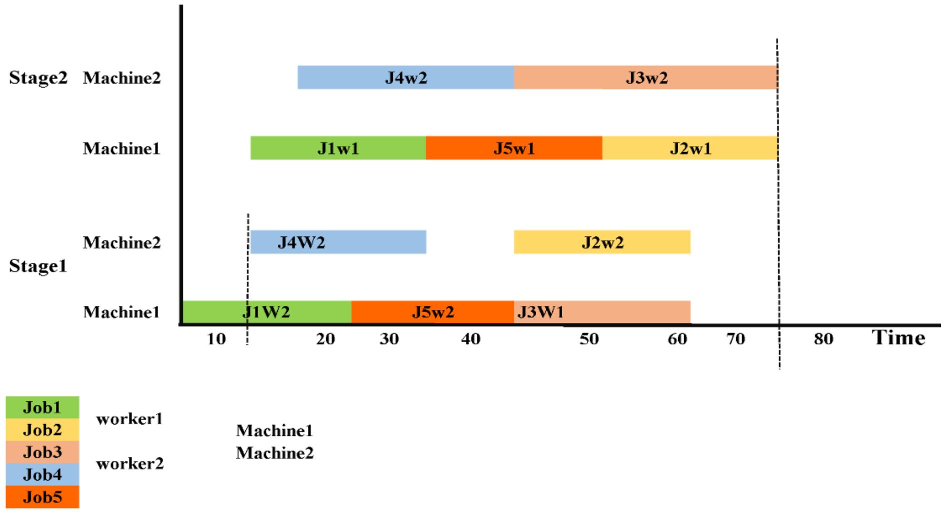

Fig. 2. Gantt chart of flow shop scheduling in the small sample problem with GAMS

As shown in Figure 2, in the first stage1 jobs1, 3 and 5 are assigned to machine 1 and worker 2. Jobs 4 and 2 are assigned to machine 2 and worker 2. In stage 2, jobs 1, 2 and 5 are assigned to machine 1 and worker1. Jobs 4 and 3 are assigned to machine 2 and worker 2. in the first stage. It is also observed that the U.L time of job 4 is performed by worker 2, who performs job 1 by machine 1, starts after the preparation time of job 1 by the same worker. This does not mean that a worker is processing in two jobs. Completion time of all jobs in this issue is 74.315 time units. Considering the value of the uncertainty rate of 0.5 in both α and β, 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.

Sensitivity analysis of model

To investigate the effects of uncertainty on the results of the uninterrupted hybrid flow scheduling model, the uncertainty rate is changed in the range of 0.1 to 0.9 for alpha and 0.2 for beta, and the value of the objective function for each uncertainty rate is shown in Table 5.

Table5: Changes in the value of the objective function at different rates of uncertainty

α	β	C_{max}	Percentage of Changes
0.5	0.2	74.315	
0.1	0.2	73.249	-1.43
0.2	0.2	72.647	-2.24
0.3	0.2	75.561	1.67
0.4	0.2	74.938	0.83
0.5	0.2	75.023	0.95
0.6	0.2	74.4	0.11
0.7	0.2	78.021	4.98
0.8	0.2	79.52	7.00
0.9	0.2	76.766	3.29

The other two analyzes are performed in different ranges for alpha and beta, once with values of 0.1 to 0.9 for alpha with a constant value of 0.5 for beta. In another analysis, the alpha and beta values change. The values obtained from C_{MAX} in both cases have shown in Table 6. In addition, the trend of changes in the figure has shown in figure3.

Table6: Changes in value of α and β

α	β	C_{max}	Percentage of Changes
0.5	0.1	71.624	-3.62
	0.2	72.286	-2.73
	0.3	72.949	-1.84
	0.4	73.611	-0.95
	0.5	74.315	0.00
	0.6	75.023	0.95
	0.7	75.73	1.90
	0.8	76.437	2.86
	0.9	77.144	3.81
0.1	0.5	71.247	-4.13
0.2		72.004	-3.11
0.3		72.760	-2.09
0.4		73.524	-1.06
0.5		74.315	0.00
0.6		75.107	1.07
0.7		75.899	2.13
0.8		76.691	3.20
0.9		77.483	4.26

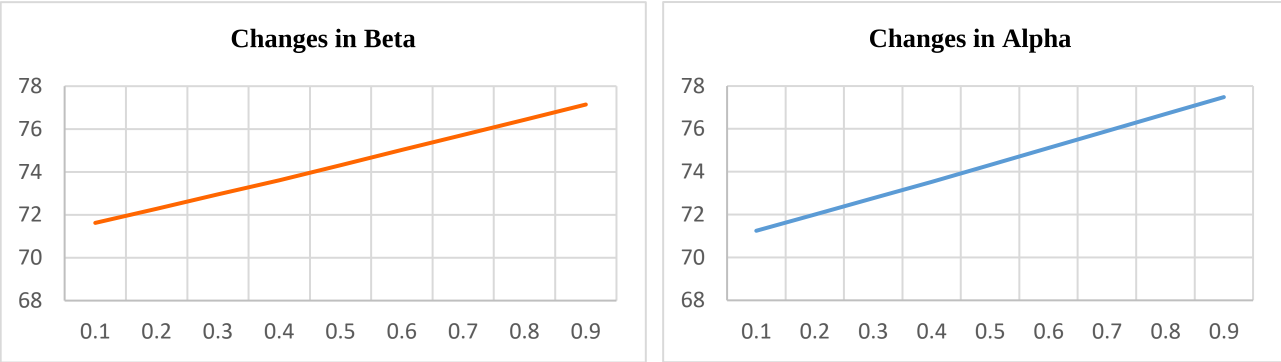

Fig. 3. The trend of changes in the figure

As shown in Figure 6, in both cases, the value of C_{max} increases with increasing α and β, and changes of value of C_{max} in both cases is slightly different.

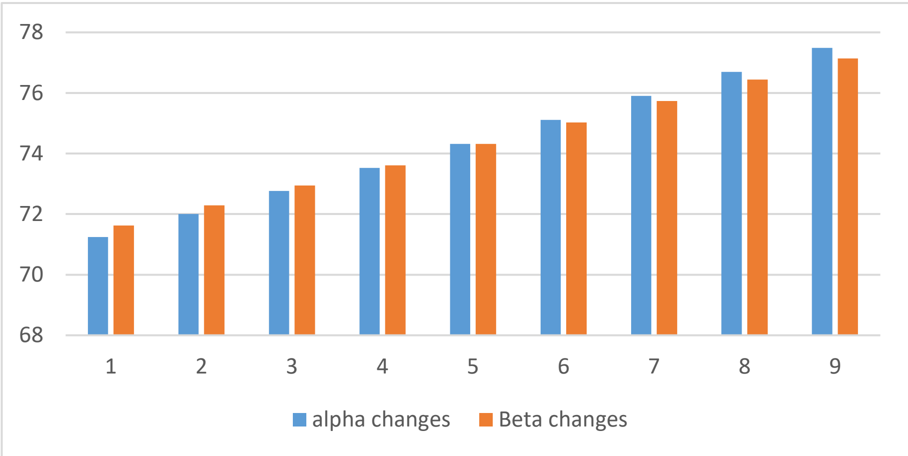

Fig. 4. Compare of changes in α and β

Another sensitivity analysis is related to the change in the number of machines at each stage of processing. Obviously, as the number of machines increases, the total processing time decreases. Changes in the value of the objective function for changes in the number of machines have been shown in Table (6) and figure 5.

Table6: Changes in number of machines

Number of Machines	C_{max}	Percentage of changes
1	119.07	60.22337
2	74.315	0
3	53.442	-28.0872
4	52.869	-28.8582
5	51.67	-30.4716

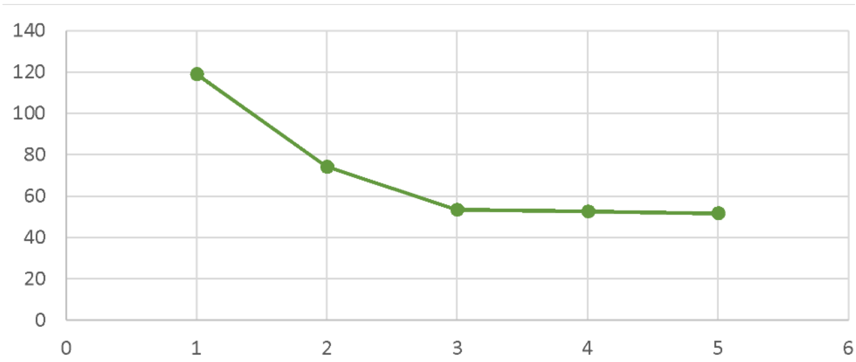

Fig. 5. Process of changing in number of machines

As shown in Figure 6, increasing the number of machines and the number of workers reduces the total completion time (C_{max}).

Then other problems are solved by changing the number of stages, workers and machines. Table (5) shows five examples of problems designed in this section at the same time as solving them by GAMS software. Table 8 shows the trend of changes in the value of the objective function and computational time in different sample problems with GAMS software.

Table7: Changes in number of both machines and workers

Number of Machines	Number of Workers	C_{max}	Percentage of changes
1	1	119.07	60.22
2	2	74.315	0
3	3	53.442	-28.08
4	4	52.869	-28.85
5	5	33.132	-30.47

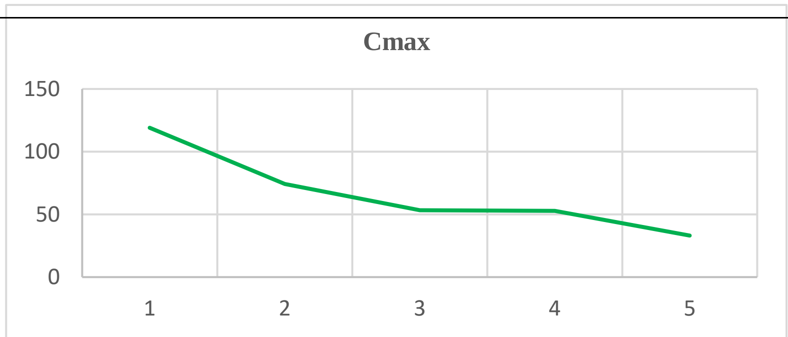

Fig. 6. The trend of C_{max} changes

Table 8: Solving the sample problem with GAMS software

Stage	Job	Worker	Machine	C_{max}	Computational Time
3	5	2	3	84.138	5.6
4	6	3	3	75.204	10.38
4	7	3	3	75.204	10.39
5	8	4	3	81.485	883
5	8	5	4	86.878	1003

4.Finding

In this paper, an unspecified model of the problem of uninterrupted hybrid flow scheduling is presented. Due to the processing time uncertainty, fuzzy programming method has been used to control the processing time uncertainty parameter. The proposed model seeks to minimize the maximum processing time of all jobs in two parts. In this case, in addition to the time of job by the machine, time and assignment of job to the worker is also considered.

For this purpose, GAMS software has been used to solve the problem. The computational results of small-scale problem solving show that with increasing uncertainty rate, the amount of processing time as well as the completion time of all tasks has increased. By analyzing the sensitivities and changing the alpha and beta values in the range of 0.1 to 0.9, it was observed that with increasing values, the uncertainty increases and affects the value of the objective function and decreases its value.

In addition, the sensitivity analysis of the problem showed that with increasing the number of machines and the number of workers in each stage due to the high efficiency of machines and workers, the completion time of all works has decreased. Due to the high problem solving time by GAMS software, the use of super-creative algorithms to solve the problem in larger sizes is recommended.

Conflicts of Interest

All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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