RESOURCE-CONSTRAINED PROJECT SCHEDULING PROBLEM FOR LARGE COMPLEX EQUIPMENT: A HYBRID APPROACH USING PARETO GENETIC ALGORITHM AND INTERVAL-VALUED INTUITIONISTIC FUZZY SETS

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ABSTRACT: Many uncertainties and dynamics can affect the project scheduling and increase the complexity of project scheduling, First, we established Resource-constrained project scheduling problem under dynamics and uncertainties model by considering interval-valued intuitionistic fuzzy number, simultaneously considers the membership and hesitation of dynamics and uncertainties of activity duration and resource requirement in large complex equipment manufacturing project. Additionally, the novel approach of modified Pareto Genetic Algorithm is proposed to optimize the Pareto optimal solutions of the bi-objective FRCPSP problem.

KEY WORDS: project scheduling, fuzzy schedule, generation schemes, interval-valued intuitionistic.

1. INTRODUCTION

With the development of project management theory and applications, many enterprises adopt the way of project management for enterprise management, particularly for large complex equipment (LCE) manufacturing enterprises [1-4]. Project scheduling has always been considered as a key factor to project management [5,6]. Effective scheduling of the project determines the effective use of corporate resources and whether the project can be completed as required. Resource-constrained project scheduling problem (RCPSP) plays an important role in project scheduling problem and has been widely studied, However, in practice, many uncertainties and dynamics can affect the project scheduling and increase the complexity of project scheduling [7,8]. These uncertainties and dynamics can be divided into three aspects: the dynamics and uncertainties in project resources; the dynamics and uncertainties in project implementation; the dynamics and uncertainties in project external environment. As a kind of complex product system, LCE has long manufacturing duration, complicated structures and parts, complex manufacturing processes and large number of manufacturing participants, hence, in practice, RCPSP under dynamics and uncertainties (FRCPSP) for LCE manufacturing project has a great demand.

To deal with dynamics and uncertainties in project scheduling, considerable prior research has been done in five areas: reactive scheduling; stochastic project scheduling; stochastic project networks, fuzzy project scheduling and robust scheduling [6]. Fuzzy project scheduling play a key role in FRCPSP for LCE manufacturing project to deal with its long manufacturing duration, complicated structures and parts, complex manufacturing processes. Traditionally, probability theory and fuzzy set theory are two different main approaches in the management and modelling of the activity duration times and resource requirement in scheduling [9]. Probability theory defines dynamics and uncertainties by probability functions based on historical data and application of statistical techniques. In the context of LCE manufacturing project, the background of each project is almost different, each project has a unique requirement and it is hardly made historical data available for activity duration and resource requirement in the new project. In practice, activity duration and resource requirement are always estimated by project manager using imprecise linguistic terms. Fuzzy set theory can deal with imprecise linguistic terms by membership function. The membership of an element is a single value between zero and one, so it can be calculated easily. For this advantage, a large body of literature has provided support for

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FRCPSP by using fuzzy set. However, membership function can only represent the degree of truth, lack of the degree of hesitation, which is also important to express the dynamics and uncertainties. To overcome this limitation, we propose a model for FRCPSP by interval-valued intuitionistic fuzzy number. Here, the membership and hesitation of dynamics and uncertainties of activity duration and resource requirement in LCE manufacturing project are both considered which is closer to reality. A new approach is also provided to solve the proposed model by Pareto Genetic Algorithm (Pareto-GA).

The remainder of this paper is organized as follows. In the next section we review the relevant literature related to fuzzy project scheduling model and the solution. Preliminary knowledge, problem description and the model are developed in Section 3. Section 4 is Solution approach of the proposed model. A case study of FRCPSP by interval-valued intuitionistic fuzzy number (IVIFN) is demonstrated in Section 5 and conclusions are given in Section 6.

2. LITERATURE REVIEW

Our work is related to fuzzy project scheduling model and the solution for the model. A considerable amount of literatures have been made towards these problems. In this section, relative research domain is summarized as follows.

2.1. Fuzzy project scheduling model

There are lots of researches have been made towards fuzzy project scheduling model. To allocate resources among the dependent activities, Hapke et al. [10,11] presented a fuzzy project scheduling decision support system applied to software project scheduling. In the model, fuzzy time parameters was modelled by means of L-R fuzzy numbers. To transform the fuzzy scheduling problem into a set of associate deterministic problems, alpha cut set was used. Considering the uncertainty of activity duration may lead to incorrect scheduling decisions, Juite Wang [12] developed a fuzzy scheduling methodology with consider schedule risk by trapezoidal fuzzy number and possibility theory. Ke et al. [13] considered a type of project scheduling problem with fuzzy activity duration times. To achieve management goals, expected cost model, α-Cost minimization model and credibility maximization model were built. To overcome the vagueness and impreciseness of information dependency between activities, Shi et al. [14] proposed a fuzzy dependency structure matrix model for project scheduling. Huang et al. [15] introduced a Fuzzy Time-dependent Project Scheduling Problem and developed a computational formula for estimating activity duration times by alpha cut set and triangular fuzzy numbers. Masmoudi et al. [3] provide a new technique using alpha cut set and trapezoidal fuzzy number that considering a fuzzy modelling of the workload. The model keeps uncertainty at all steps of the modelling and solving procedure. Dixit et al.[2] built a procurement scheduling model for complex products manufacturing project. The model calculated fuzzy holding and shortage costs by alpha cut set and L–R triangular fuzzy number.

2.2. The solution for fuzzy project scheduling model

A large body of literature has provided support for giving the solution for fuzzy project scheduling model. On the basis of using fuzzy priority heuristics, Hapke et al [10,11] firstly extended the serial and parallel scheduling procedures to fuzzy RCPSP which usually operate on classic RCPSP. Fuzzy priority heuristics provide new tools useful for fuzzy RCPSP. Juite Wang [12] developed fuzzy beam search algorithm which modified from the enumerative branch-and-bound method. The solution constructs a fuzzy schedule with the minimum schedule risk by adding precedence constraints to resolve resource conflicts. The above solutions are based on the exact algorithm, which can get the optimal solution, but there is a “combinatorial explosion” phenomenon with problems scale expansion. To fill this gap, Heuristic algorithm was used for fuzzy project scheduling model. Ke et al. [13] designed a hybrid intelligent algorithm which integrated Genetic Algorithm (GA) and fuzzy simulation to simulate functions with fuzzy variables. GA was also introduced to solve the Fuzzy RCPSP combined with mechanisms of fuzzy simulation Huang et al. [15]. Considering fuzzy resource and fuzzy precedence constraints, Masmoudi et al. [3] proposed a method combined fuzzy Parallel Schedule Generation Schemes (SGS) and GA for Fuzzy RCPSP and Fuzzy Resource Leveling Problem.

2.3. Interval-valued intuitionistic fuzzy sets (IVIFSs)

Fuzzy set theory has been widely used in many areas to express the fuzzy degree of membership since it put forward by Zadeh in 1965 [16]. Atanassov [17-19] expanded the concepts of fuzzy set theory and presented Intuitionistic fuzzy sets (IFS), which can express the fuzzy degree of membership and the fuzzy degree of non-membership. IFS can handle hesitancy and vagueness information better in dealing with ambiguity and uncertainty. Dou to the complexity and uncertainty of the real world, the real numbers are often difficult to accurately express IFS membership values and non-membership values, but interval numbers are more appropriate. Thus, Atanassov et al. [20,21] proposed the concept of IVIFSs and defined some basic operators for IVIFSs. After that, many researchers have paid great attention to IVIFSs in many areas, for example, Xu [22] introduced some relations and operations of IVIFSs and developed distance measure for group decision making with IVIFSs. Yu et al.[23] investigated the group decision making in different priority level under IVIFSs environment and proposed some IVIFSs aggregation operators. Extensive research can be found in the field of group decision-making and multi criteria decision making based on IVIFSs [24-31].

2.4. Literature summary

Significant research efforts in the modeling of fuzzy RCPSP based on fuzzy sets have been made. However, few studies have been focused on IVIFSs for fuzzy RCPSP. Moreover, to solve the fuzzy RCPSP, most of studies are respectively to consider the exact algorithm and Heuristic algorithm, especially GA combined with fuzzy SGS. However, the chromosomes of GA are prone to illegal in evolution for the constraints of precedence of LCE projects. Thus, our work is different from the aforesaid works in two major aspects. First, we established FRCPSP model considering IVIFSs, simultaneously consider the membership and hesitation of dynamics and uncertainties of activity duration and resource requirement in LCE manufacturing project. Additionally, the novel approach of modified Pareto-GA is proposed to optimize the Pareto optimal solutions of the bi-objective FRCPSP problem (i.e., the shortest project tardiness and the minimum uncertainty).

3. MODEL FORMULATION

3.1. Preliminary

Here a brief review of some basic preliminaries are given as follows:

Definition 1. IFS[17-19].

Let domain X is a non-empty set, $A=\{x,\mu_A(x),\nu_A(x)\,|\,x\in X\}$ be an IFS, where $\mu_A(x)$ and $\nu_A(x)$ represent the membership and non-membership of the element x to the set A respectively.

$\mu_A : X \to [0,1]$, $\mu_A(x)\in[0,1]$, $\nu_A : X \to [0,1]$, $\nu_A(x)\in[0,1]$, and satisfy the condition $0\le \mu_A(x)+\nu_A(x)\le 1$,

$1-(\mu_A(x)+\nu_A(x))$ represents the hesitation degree of the element x to the set A.

Definition 2. IVIFS [20,21].

$A=\{x,\tilde{\mu}_A(x),\tilde{\nu}_A(x)\,|\,x\in X\}$ be an IVIFS, where $\tilde{\mu}_A(x)$ and $\tilde{\nu}_A(x)$ are intervals. $\tilde{\mu}_A(x)\subset[0,1]$, $\tilde{\nu}_A(x)\subset[0,1]$ and satisfy the condition $0\le \sup\tilde{\mu}_A(x)+\sup\tilde{\nu}_A(x)\le 1$.

For convenience, the general form of IVIFNs is abbreviated as follow: $([a,b],[c,d])$, where, $[a,b]\subset[0,1]$, $[c,d]\subset[0,1]$,

$0\le b+d\le 1$.

Definition 3. some operators of IVIFNs[22].

Let $\tilde{m}=[a_1,b_1],[c_1,d_1]$, $\tilde{n}=[a_2,b_2],[c_2,d_2]$ then

$\tilde{m}+\tilde{n}=([a_1+a_2-a_1a_2,b_1+b_2-b_1b_2],[c_1c_2,d_1d_2])$;

$\lambda\times\tilde{m}=([1-(1-a_1)^\lambda,1-(1-b_1)^\lambda],[c_1^{\lambda},d_1^{\lambda}]),\lambda>0$.

Let $\tilde{M}=\{\tilde{m}_1,\tilde{m}_2,\cdots,\tilde{m}_n\}$ be a set of IVIFSs, If $IVIFWA_\omega(\tilde{M})=\sum_{i=1}^{n}\omega_i\tilde{m}_i$, then $IVIFWA$ is called a weighted averaging operator for IVIFNs**,** where $\omega=(\omega_1,\omega_2,\cdots,\omega_n)^T$ is the weight vector of $\tilde{m}_i(i=1,2,\cdots,n)$ with $\omega_i\in[0,1]$ and $\sum_{i=1}^{n}\omega_i=1$.

Definition 4. Score Function (SF) and Exact Function (EF) of IVIFNs[22,32].

SF: $S(\tilde{m})=(a-c+b-d)/2$, $S(\tilde{m})\in[-1,1]$;

EF: $\mathrm{H}(\tilde{m})=(a+c+b+d)/2$, $\mathrm{H}(\tilde{m})\in[0,1]$.

Definition 5. Comparative of IVIFNs[22,32].

If $S(\tilde{m})<S(\tilde{n})$, then $\tilde{m}<\tilde{n}$;

If $S(\tilde{m})=S(\tilde{n})$ and $\mathrm{H}(\tilde{m})<H(\tilde{n})$, then, $\tilde{m}<\tilde{n}$;

If $S(\tilde{m})=S(\tilde{n})$ and $\mathrm{H}(\tilde{m})=H(\tilde{n})$, then, $\tilde{m}=\tilde{n}$.

3.2. Problem description and assumptions

Some assumptions have been made in order to strengthen modeling ability of the proposed model, as follows.

(1) All projects are independent of each other.

(2) Resources are renewable.

(3) Once a task is started, it cannot be interrupted; the required resources are exclusive from other tasks until the end of the task.

(4) The task execution time is fuzzy and fixed. There are several different tasks' duration estimate, such as pessimistic estimate, optimistic estimate and most likely estimate. The more is the estimated duration shorter, then the greater its uncertainty. In other words, it is easy to conduct the task if its estimated duration is longer. If the estimated duration is very short, the project manager can also achieve it by working hard, but there is a big uncertainty.

(5) The fuzziness of expected duration of tasks are increased over time. It is believed that the longer the distance between the current times, the more uncertainty.

Here, FRCPSP can be expressed in the following four aspects.

(1)Projects and tasks. The project set is $P=\left\{p_1,p_2,\cdots,p_i,\cdots,p_I\right\}$, in project i ,the task set is $A=\left\{A_{i1},A_{i2},\cdots,A_{ij},\cdots,A_{iJ_i}\right\}$, task duration is expressed as d_{ij}, the uncertainty of the task duration is an IVIFN, expressed as $\tilde{F}_{d_{ij}}$, $\tilde{F}=\left\{\tilde{F}_{d_{11}},\cdots,\tilde{F}_{d_{ij}},\cdots,\tilde{F}_{d_{IJ_I}}\right\}$, here, $\tilde{F}$ is the IVIFSs set of the uncertainty of all tasks. Task start time and end time are expressed as ST_{ij} and ET_{ij}.

(2)Precedence constraints. Timing relationships exist between tasks, PC_{ij} indicates the predecessors set of A_{ij}. SC_{ij} indicates Successors set of A_{ij}.

(3)Resource constraints. Resources capacity is limited at any one time, the capacity is expressed as $R_k, k=1,2,\cdots,K$. R_k demand by A_{ij} is expressed as r_{ijk}.

(4)The targets. Under the resource constraints and precedence constraints, to achieve the minimum uncertainty and the shortest duration of the whole projects, selecting the appropriate estimated duration and allocating resources for the tasks.

3.3. Fuzzy project scheduling model

According to the description of the problem in the previous section, the model established as follows:

$$\min \sum_{i=1}^{I} \max\{0, ET_{ij}-d_i\} \quad (1)$$

$$\max IVIFWA^{\omega}(\tilde{F}) \quad (2)$$

$$ST_{ij} \ge FT_{ih}, (\forall i, j, \forall (i,h) \in PC_{ij}) \quad (3)$$

$$\sum_{i=1}^{N}\sum_{j=1}^{J} r_{ijk} \le R_k, ((i,j)\in I_t, k=1,2,\cdots,K) \quad (4)$$

$$\sum_{m=1}^{M_{ij}} F_{A_{ij},m} = 1, (\forall i, j) \quad (5)$$

Here, Equation (1) and Equation (2) are the objective function, represent the shortest project tardiness and the minimum uncertainty respectively, here, we assume all tasks have the same weight. Precedence constraints and Resource constraints are represented by Equation (3) and Equation (4). Equation (5) shows selecting one task duration from the different task's duration estimate.

4. SOLUTION APPROACH

This paper proposed a modified Pareto-GA to approximate the Pareto optimal solutions of the bi-objective FRCPSP problem. The details are illustrated as follows.

4.1. Chromosome encoding

The encoded chromosome is a formal description of genetic solution which suitable for the application of genetic operators. In this paper, a single chromosome with task sequence and schema sequence is used to represent a legal chromosome. For example, a scenario with five tasks and three manufacturing schemas for each task, a possible chromosome can be described as Figure 1, where task sequence is ranked from 1 to 5 without repeat and schema sequence is alternative from 1 to 3 for each task, such as task 3 (position 2) is manufactured with schema 3 (position 7).

4.2. Initial population

A random initial population method is used in this paper. The method is processed with two steps as follows, where *CurrentPop* is a matrix of population, i is the rowindex of matrix, T_n is the number of task, S_n is the number of schema, and *randperm* and *randint* are matlab functions.

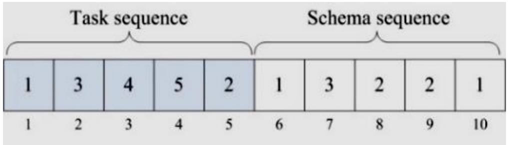

Fig. 1. Chromosome schema

Step 1: Initialing task sequence by Equation (6).

$$CurrentPop(i,1:T_n) = randperm(T_n) \quad (6)$$

Step 2: Initialing schema sequence by Equation (7).

$$CurrentPop(i,T_n+1:T_n+T_n) = randint(1,T_n,[1\ S_n]) \quad (7)$$

4.3. Fitness evaluation

To calculate fitness value, the first step is to obtain each separate objective function value, FP and FV by Equation (1) and (2). And then, the population is sorted in terms of the objective function value of each chromosome into different fronts based on the non-domination method from [33]. The non-dominated solution individuals are selected from the population and defined as rank 1 and those individuals are removed from the population. Next set of non-dominated individuals is searched and rank 2 is assigned to them. The procedure is repeated for the subsequent fronts until the entire population is sorted and non-dominantly divided to different fronts. The individual assigned the smaller rank value, represents it is the better one. Furthermore, the fitness value is evaluated by map ranked value (MRV) method with the following formula for normalization from [34].

$$f(x_i) = 1 - \frac{\sum_{r=1}^{r(x_i)} (r \times n_r)}{\sum_{r=1}^{m} (r \times n_r)} \quad (8)$$

Where $f(x_i)$ represents the fitness function value for individual x_i, m signifies the maximum rank, $r(x_i)$ denotes the grade for individual x_i, and n_r denotes the number of individuals for rank r .

4. SELECTION, CROSSOVER AND MUTATION OPERATORS

The stochastic tournament strategy [35] and elite preservation strategy [36] are applied in this study to selection operator.

The main purpose of crossover operator is to generate better offspring by combining the genetic alleles of two selected parents from the population with probability Pc. In this paper, a single point crossover operator is used, where firstly the cross point is random chosen in task sequence, and then interchange the related genetic alleles, as shown in Figure 2.

In addition, each offspring is assigned a small probability of mutation to improve the local search ability and diversity of the population with the probability P_m. With probability, randomly generate the mutation genes sequence and then select new genes from the related gene domain.

After the above operations, the individuals in the previous step become a new population.

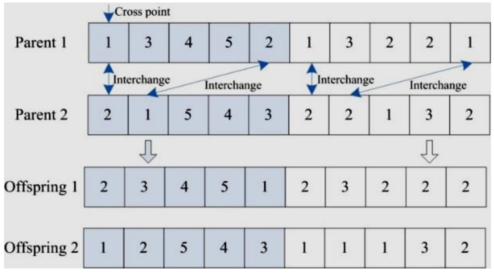

Fig. 2. Crossover operator

4.5. Pareto optimal solution

When the stopping criterion is satisfied, output the Pareto optimal solution which provides the optimal strategy for FRCPSP problem.

5. NUMERICAL EXPERIMENTS

To demonstrate the effectiveness of proposed method, the authors investigate the project scheduling problem in a manufacturing enterprise named SINOMA. The product of SINOMA is large complex cement equipment, which makes scheduling planning becomes an urgent task for project manager to be resolved with constrained resources. This paper considers project scheduling problem for 4 projects with 12 tasks. To simply the solving process, assuming each task has three kinds of selection scheme to be finished with different possibilities, as shown in Table 1 and the related parameters of projects are shown in Table 2.

The hardware and software platform parameters are listed as follows: Windows 8, Intel(R) Core(TM) i5-3230M CPU, 2.6GHz, 4G RAM and Matlab R2009b. Table 3 gives the algorithm parameters of Pareto-GA. The evolutionary process of Pareto-GA algorithms is shown in Figure 3, and Pareto solution set is shown in Figure 4. In addition, a comparison experiment has been give out with simple genetic algorithm (SGA), which evaluated the best individual with a primary objective of delay time and secondary objective of possibility. The evolutionary process of the SGA algorithms is shown in Figure 5. The results of best individual of Pareto-GA and SGA are listed in Table 4 and Table 5.

Table 1. Efficiency and particle size of microcapsule samples

Project No.	Task No.	Schema No.	IVIFN	Schedule time	Required resources
1	1	1	([0.75,0.8],[0.05,0.1])	4	10,0,3,0,5,0,0,0
		2	([0.65,0.7],[0.15,0.2])	3	10,0,3,0,5,0,0,0
		3	([0.45,0.5],[0.2,0.3])	2	10,0,3,0,5,0,0,0
	2	1	([0.7,0.85],[0.1,0.12])	5	0,0,3,6,0,5,4,8
		2	([0.5,0.75],[0.1,0.2])	4	0,0,3,6,0,5,4,8
		3	([0.3,0.5],[0.2,0.3])	3	0,0,3,6,0,5,4,8
	3	1	([0.8,0.85],[0.05,0.1])	6	0,3,0,0,7,0,3,5
		2	([0.65,0.8],[0.1,0.15])	5	0,3,0,0,7,0,3,5
		3	([0.4,0.5],[0.3,0.4])	4	0,3,0,0,7,0,3,5
2	4	1	([0.75,0.9],[0.05,0.1])	6	8,0,2,4,2,0,3,0
		2	([0.7,0.8],[0.1,0.2])	5	8,0,2,4,2,0,3,0
		3	([0.4,0.6],[0.2,0.3])	4	8,0,2,4,2,0,3,0
	5	1	([0.8,0.85],[0.05,0.1])	4	0,4,5,0,0,0,0,7
		2	([0.75,0.8],[0.15,0.2])	3	0,4,5,0,0,0,0,7
		3	([0.55,0.6],[0.2,0.3])	2	0,4,5,0,0,0,0,7
	6	1	([0.7,0.8],[0.15,0.2])	7	4,0,8,9,12,0,6,3
		2	([0.65,0.7],[0.2,0.3])	6	4,0,8,9,12,0,6,3
		3	([0.5,0.6],[0.2,0.4])	5	4,0,8,9,12,0,6,3
3	7	1	([0.8,0.85],[0.1,0.15])	3	8,3,0,2,0,6,0,0
		2	([0.6,0.7],[0.2,0.3])	2	8,3,0,2,0,6,0,0
		3	([0.3,0.4],[0.4,0.5])	1	8,3,0,2,0,6,0,0
	8	1	([0.8,0.9],[0.05,0.1])	4	0,0,2,0,6,0,5,8
		2	([0.65,0.75],[0.1,0.2])	3	0,0,2,0,6,0,5,8
		3	([0.2,0.3],[0.5,0.7])	2	0,0,2,0,6,0,5,8
	9	1	([0.7,0.8],[0.1,0.2])	7	6,4,8,4,0,0,0,0
		2	([0.5,0.6],[0.2,0.4])	6	6,4,8,4,0,0,0,0
		3	([0.4,0.5],[0.4,0.5])	5	6,4,8,4,0,0,0,0
4	10	1	([0.8,0.9],[0.05,0.1])	9	0,2,0,6,3,0,0,3
		2	([0.6,0.8],[0.1,0.2])	7	0,2,0,6,3,0,0,3
		3	([0.5,0.6],[0.2,0.3])	6	0,2,0,6,3,0,0,3
	11	1	([0.8,0.85],[0.1,0.15])	6	2,0,5,0,0,0,0,0
		2	([0.6,0.8],[0.1,0.2])	5	2,0,5,0,0,0,0,0
		3	([0.4,0.5],[0.3,0.4])	4	2,0,5,0,0,0,0,0
	12	1	([0.8,0.9],[0.05,0.1])	7	0,3,0,6,5,3,0,6
		2	([0.6,0.7],[0.2,0.3])	6	0,3,0,6,5,3,0,6
		3	([0.5,0.6],[0.2,0.4])	5	0,3,0,6,5,3,0,6

Table 2. The number of constrained resources at different times.

Time \ Resource No.	1	2	3	4	5	6	7	8	Time \ Resource No.	1	2	3	4	5	6	7	8
1	4	9	7	8	6	5	6	3	9	7	5	2	7	3	9	6	5
2	3	3	4	7	5	7	6	4	10	6	6	5	7	7	8	7	7
3	7	4	9	2	9	9	8	2	11	7	3	3	3	6	5	7	3
4	2	5	3	8	4	8	6	5	12	3	5	7	4	7	5	4	8
5	2	2	7	9	5	5	3	4	13	7	3	4	7	4	3	6	2
6	7	7	6	8	9	8	5	4	14	9	8	8	5	6	8	6	5
7	4	5	5	2	2	5	5	5	15	8	8	7	6	8	9	3	2
8	7	9	3	5	9	9	9	2	16	2	4	6	3	2	9	6	3

Table 3. The GA algorithm parameters.

PopSize	MaxGen	LeagueSize	P_c	P_m
100	400	2	0.85	0.05

Table 4. Results of Pareto-GA and SGA.

Approach	Index	Solution	Delay Time	Possibility	Elapsed time
Pareto-GA	1	12,4,11,7,10,8,5,9,1,3,2,6,3,3,1,2,2,1,1,1,1,3,3,3	6	0.5253	70.99s
	2	8,6,7,5,12,9,10,2,3,11,1,4,3,3,2,1,1,3,1,3,2,1,1,1	7	0.5622	
SGA	3	6,10,12,8,7,11,4,9,5,1,3,2,2,1,3,2,3,2,1,1,3,2,2,3	4	0.5054	39.67s

Table 5. The best individual for tasks' start time and end time of Pareto-GA and SGA.

Task No.	Schema No.	Pareto-GA 1 Start Time	Pareto-GA 1 End Time	Pareto-GA 2 Start Time	Pareto-GA 2 End Time	SGA 3 Start Time	SGA 3 End Time
1	1	0	8	0	8	0	9
2	2	0	10	0	10	0	10
3	3	0	10	0	8	0	9
4	1	0	9	0	3	0	6
5	2	0	5	0	7	0	7
6	3	1	4	0	10	1	3
7	1	0	3	0	5	0	4
8	2	1	3	0	5	0	6
9	3	0	5	0	6	0	7
10	1	0	7	0	4	0	3
11	2	0	6	0	3	0	3
12	3	0	7	1	2	0	4

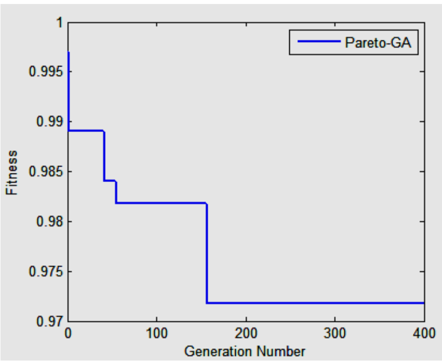

Fig. 3. Evolution process of Pareto-GA

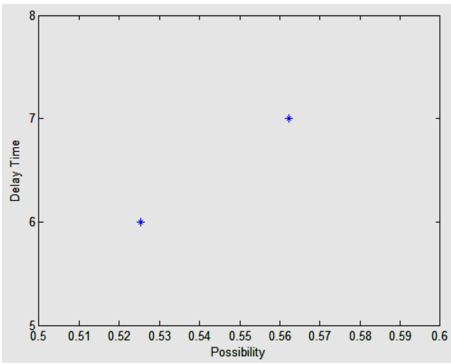

Fig. 4. Pareto solutions of Pareto-GA

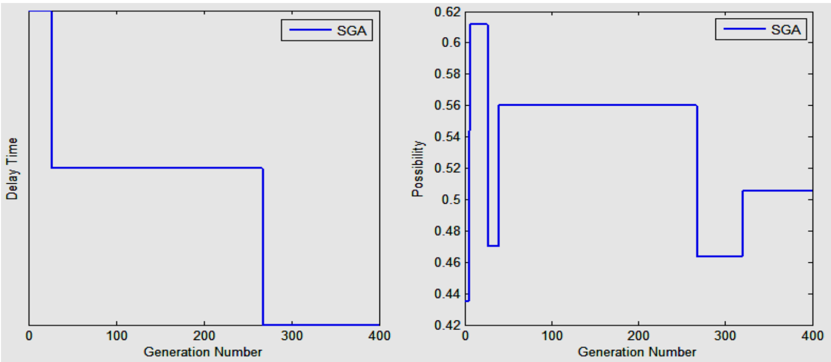

Fig. 5. Evolution process of SGA

Comparing the two evolution processes of Pareto-GA and SGA in Figure 3 and Figure 5, Pareto-GA has faster convergence speed (converged after running for about 160 generations, SGA is about 260 generations), while SGA has shorter elapsed time 39.67s comparing to Pareto-GA with 70.99s. This mainly resulted from the MRV method used in this paper, which is better for algorithm convergence with time cost. However, the time sacrifice can be expected to neglect as the FRCPSP model in this paper is not a real-time optimal scenario. Moreover, Pareto-GA is obtained with Pareto solution set, which can be provided for decision-makers to choose suitable task schema. Thus, the Pareto-GA is more effective than SGA in Pareto-optimal solution searching for the proposed FRCPSP model.

6. CONCLUSION

Many uncertainties and dynamics can affect the project scheduling and increase the complexity of project scheduling, to fill this gap, we established Resource-constrained project scheduling problem under dynamics and uncertainties model considering interval-valued intuitionistic fuzzy number, simultaneously consider the membership and hesitation of dynamics and uncertainties of activity duration and resource requirement in large complex equipment manufacturing project. The novel approach of Pareto-GA with Schedule Generation Schemes is proposed to optimize the formulated objective function. Numerical experiment shows that the proposed model and the method are effective.

Our research has certain limitations. To solve fuzzy optimization problem, it not enough to only adopt one method. Furthermore, we should compare different fuzzy project scheduling model for the real industrial case study. As a future scope of work, different fuzzy models and the solutions for the model can be used to compare the outputs and generate further insights regarding applicability of the methods for different classes of problems.

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