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Optimization of remanufacturing flexible job shop scheduling under uncertain environment

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ABSTRACT. *Aiming at the problem of uncertain parts processing time and delivery date in the scheduling of remanufacturing flexible job shops, triangular fuzzy numbers and trapezoidal fuzzy numbers are introduced to represent the uncertain processing time and delivery date respectively, and the maximum completion time is the minimum as the goal to establish a fuzzy model of workshop scheduling with the satisfaction constraint of the average delivery time of parts, and the model is transformed and finally solved by the MSOS coding genetic algorithm. And get: the positive or negative attitude of the decision maker will affect the decision result, the more negative the decision, the worse the result, on the contrary, the more positive the decision, the better the result; as the average delivery time satisfaction threshold gradually increases, the maximum completion time gradually extend.*

KEYWORDS: *fuzzy operation time, fuzzy delivery date, remanufacturing, flexible job shop scheduling, MSOS coding genetic algorithm*

1. Introduction

Remanufacturing is an important way to save resources and achieve sustainable development. Compared with the traditional manufacturing process, there is uncertainty in the remanufacturing process caused by many factors such as the damage degree and quality of the recycled products, and the difficulty of scheduling is significantly increased. Compared with traditional remanufacturing job shop scheduling (Job-shop Scheduling Problem, JSP), remanufacturing flexible job-shop scheduling problem (FJSP) breaks through the uniqueness of machine selection and is an extension of JSP problem. It allows multiple processing machines to choose from for a process, and the processing time on different machines may vary. It is more in line with the current situation that a single machine can process different processes at this stage. The introduction of machine flexibility can improve the execution efficiency of remanufacturing system, which is more in line with the actual situation of the flexible remanufacturing system.[1] Therefore, how to comprehensively consider various uncertain factors to reasonably schedule and

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optimize the scheduling problem of remanufacturing flexible job shop has become one of the key links for remanufacturing enterprises to improve their production management level.

In the remanufacturing/manufacturing process, there have been some results in the optimization of flexible job shop scheduling under uncertain environments. Jamrus et al.[2] used interval numbers to represent the uncertainty of the processing time in semiconductor processing operations. For processing time, a flexible job shop scheduling model that minimizes makespan was established; Xu et al.[3] used triangular fuzzy numbers to express the uncertainty of processing time, and constructed a fuzzy job time FJSP scheduling model with maximum completion time as the optimization goal; Guo Jun et al.[4] used triangular fuzzy numbers to describe the uncertainty of the job time and studied the multi-objective scheduling optimization problem of the remanufacturing shop with fuzzy job time. Through analysis, it is found that scholars mainly focus on the research of flexible job shop scheduling under the condition of uncertain processing time, and lack a comprehensive consideration of uncertain factors. In the actual remanufacturing process, the uncertain delivery date will also have a greater impact on the flexibility and flexibility of workshop scheduling. Aiming at the processing scheduling problem with uncertain delivery dates, Ishii et al.[5] aimed at the scheduling problem of two machines and the same type of machines, for the first time, they regarded the delivery date as a fuzzy number, and solved the scheduling problem based on different objective functions under the condition of fuzzy delivery date. Cheng[6] applied the concept of delivery window to the early/tardiness scheduling problem for the first time; Ma Jing et al.[7] introduced trapezoidal fuzzy numbers to represent the delivery date of parts, and studied the integrated process planning and workshop scheduling issues. Aiming at the processing scheduling problem that comprehensively considers the processing time and the uncertain delivery date, Zhou Jing[8] used random variables to describe the machine processing time, and used fuzzy variables to describe the delivery date of the workpiece, and combined the two by processing the cost-based objective function. Combining such uncertain factors, the traditional remanufacturing job shop scheduling problem under the condition of uncertain processing time and delivery date was studied; Luo Yao et al.[9] described the uncertain processing time and the delivery date by triangular fuzzy numbers and trapezoidal fuzzy numbers respectively, the traditional remanufacturing job shop scheduling problem under the uncertain condition of the part quality status, processing time and the delivery date are considered comprehensively.

Based on this, this paper draws on the existing research results, considers the flexibility of machine selection, and comprehensively considers the two uncertain factors of processing time and delivery date, and studies the remanufacturing flexibility job shop scheduling problem with fuzzy operation time and fuzzy delivery date, in order to provide theoretical guidance and practical reference for remanufacturing flexible job shop scheduling in an uncertain environment.

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2. Remanufacturing flexible job shop scheduling model in uncertain environment

2.1 Problem description

In the remanufacturing workshop, remanufactured parts are waiting for remanufacturing. After inspection, each part needs to go through multiple processes with a fixed processing sequence. Each process can be processed on any machine in the set of candidate machines. One machine can process several processes of a part, and the process set processed on different machines can be different. Remanufactured parts need to be delivered within a certain time frame. Otherwise, early delivery will cause the accumulation of parts, and delayed delivery will affect the progress of the remanufacturing system, making the system lack of flexibility and not conducive to the stability of remanufacturing. Among them, the time spent in each process is determined by the selected machine, and the remanufacturing system has a delivery date requirement for each remanufactured part, which is expressed by a trapezoidal fuzzy number $\widetilde{D}_i\left(d_i^a, d_i^b, d_i^c, d_i^d\right)$, and its membership function is:

$$U_d\left(T_i^d\right) = \begin{cases} 0, x \leq d_i^a, x \geq d_i^d \\ \dfrac{x - d_i^a}{d_i^b - d_i^a}, d_i^a < x < d_i^b \\ \dfrac{d_i^d - x}{d_i^d - d_i^c}, d_i^c < x < d_i^d \\ 1, d_i^b \leq x \leq d_i^c \end{cases}$$

Under the conditions of meeting machine constraints, process sequence constraints, and parts average delivery time satisfaction constraints, the scheduling optimization is performed to minimize the maximum completion time. It is necessary to determine the processing machine for each process of the part, and determine the processing sequence and start time of all processes on the machine. For the convenience of explaining the problem, the following assumptions are made.

(1) Each process of the parts to be processed must be processed after the previous process is completed.

(2) Each machine can only process one part at the same time, and one part can be processed on one machine at most.

(3) The parts to be processed need to go through multiple processes. Each process can select more than one machine, but it can only be processed on one of the machines. Once selected, the process cannot be interrupted.

(4) The machine will not malfunction during the remanufacturing process.

(5) The start time of the remanufacturing operation is zero, and all parts can be processed at zero time.

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(6) The priority of the parts to be processed is the same.

(7) Ignore the transportation time of the parts to be processed between machines, and include the preparation time of the parts before the start of the remanufacturing process into the processing time.

(8) Once the parts are processed, they will be delivered immediately without waiting time.

2.2 Symbol description

In order to facilitate the construction of the model, the symbols involved in the remanufacturing flexible job shop scheduling problem under uncertain environments are explained as follows.

M: a collection of m machines, $M = \{M_r\}$, r = 1, 2, . . . , m;

J: a collection of n parts, $J = J_i$, i = 1, 2, . . . , n;

$O_{i,j}$: The j-th processing procedure of the part J_i, j = 1, 2, . . . , n_i;

$H^i_{j_1,j_2}$: The processing procedure relational variable of the part J_i, if the procedure O_{i,j_1} is executed before the procedure O_{i,j_2}, $H^i_{j_1,j_2} = 1$; otherwise $H^i_{j_1,j_2} = 0$;

$V_{i,j}$: The set of optional machines for the j-th process of part J_i ,$V_{i,j} \in M$;

$ST_{i,j,r}$: The start time of the j-th process of the part J_i on the machine M_r;

$PT_{i,j,r}$: The time it takes for the j-th process of the part J_i to be processed on the machine M_r;

$CT^r_{i,j}$: The completion time of the jth process of the part J_i on the machine M_r;

T^d_i: Delivery time of the part J_i ;

$U_d(T^d_i)$: Satisfaction with the delivery time of parts J_i ;

D_i: The delivery date of the part J_i ;

φ: The threshold set for the satisfaction of the average delivery time of the parts;

$\alpha_{i,j,r}$: Decision variable, if the process $O_{i,j}$ is selected to be processed on the machine $M_r(r \in V_{i,j})$, $\alpha_{i,j,r} = 1$; otherwise $\alpha_{i,j,r} = 0$.

2.3 Model building

Through analysis, the two uncertain factors of part processing time and delivery date in the remanufacturing process are comprehensively considered, and the flexibility of the machine selection in the remanufacturing process is considered.

The goal is to minimize the maximum completion time and meet the machine constraints, process sequence constraints and the satisfaction constraints of the average delivery time of parts, the established remanufacturing flexible job shop scheduling model is as follows:

$$\min\tilde{Z}|\tilde{Z}=\max\left(\widetilde{CT}_{i,j}^{r}\right),1\leq i\leq n;1\leq j\leq n_i;1\leq r\leq m \tag{1}$$

$$\text{s.t. } \widetilde{CT}_{i,j}^{r}=\widetilde{ST}_{i,j,r}+\widetilde{PT}_{i,j,r},1\leq i\leq n;1\leq j\leq n_i;1\leq r\leq m \tag{2}$$

$$\tilde{T}_i^d=\widetilde{CT}_{i,n_i}^{r},1\leq i\leq n;1\leq r\leq m \tag{3}$$

$$\left(1-H_{j_1,j_2}^{i_1,i_2}\right)\left(\widetilde{CT}_{i_1,j_1}^{r}*\alpha_{i_1,j_1,r}-\widetilde{CT}_{i_2,j_2}^{r}*\alpha_{i_2,j_2,r}\right)\geq\left(1-H_{j_1,j_2}^{i_1,i_2}\right)*\widetilde{PT}_{i_1,j_1,r}$$

$$r\in\left(V_{i_1,j_1}\cap V_{i_2,j_2}\right) \tag{4}$$

$$\left(1-H_{j_1,j_2}^{i_1,i_1}\right)\left(\widetilde{CT}_{i_1,j_1}^{r_1}*\alpha_{i_1,j_1,r_1}-\widetilde{CT}_{i_1,j_2}^{r_2}*\alpha_{i_1,j_2,r_2}\right)\geq\left(1-H_{j_1,j_2}^{i_1,i_1}\right)*\widetilde{PT}_{i_1,j_1,r_1}$$

$$r_1\in V_{i_1,j_1},r_2\in V_{i_1,j_2} \tag{5}$$

$$\sum_{r=1}^{m}\alpha_{i,j,r}=1 \tag{6}$$

$$\frac{1}{n}\sum_{i=1}^{n}U_d\left(\tilde{T}_i^d\right)\geq\varphi,0\leq\varphi\leq1 \tag{7}$$

$$ST_{i,j,r},PT_{i,j,r},CT_{i,j}^{r},T_i^d\geq0,1\leq i\leq n;1\leq j\leq n_i;1\leq r\leq m \tag{8}$$

$$H_{j_1,j_2}^{i},\alpha_{i,j,r}\in\{0,1\},1\leq i\leq n;1\leq j\leq n_i;1\leq r\leq m \tag{9}$$

Among them, (1) is the objective function, which means that the maximum completion time of remanufactured parts is the smallest; (2) is the relationship between the start time, the time spent and the completion time of the j-th process of the part Ji on the machine.; (3) formula means that the parts Ji will be delivered immediately after the remanufacturing is completed; (4) formula means that one machine can only process one process at the same time; (5) formula means that different processes cannot be processed at the same time; (6) The formula means that the same process can only be processed on one machine; the formula (7) expresses the requirements for satisfaction with the delivery time of the parts; the formula (8) is the value range of the parameters, which means that the parameters are all non-negative numbers; (9) The formula is the value range of the parameter, which means that the parameters are all 0-1 variables.

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2.4 Model conversion

It can be seen from the formula (1) that the objective function belongs to the fuzzy programming problem, and the fuzzy programming can be transformed into a clear programming problem for solution. Since the goal is to optimize the most optimistic, most likely, and most pessimistic estimates at the same time, the original fuzzy programming model can be approximated by the multi-objective nonlinear programming determined as follows: $minZ_1 = Z^L$, $minZ_2 = Z^M$, $minZ_3 = Z^U$.

Among them, Z_1^{PIS}, Z_2^{PIS}, Z_3^{PIS} represents the optimal solution of the decision maker for the most optimistic, most likely and most pessimistic situations. The determined multi-objective nonlinear programming can be transformed into a certain single-objective nonlinear programming: $W = min[\theta_1 Z_1^{PIS} + \theta_2 Z_2^{PIS} + \theta_3 Z_3^{PIS}]$, $\theta_1 + \theta_2 + \theta_3 = 1$.

Among them, the values of the coefficients θ_1, θ_2 and θ_3 depend on the preference of the decision maker for the optimal solution obtained in the most optimistic, most likely, and most pessimistic situation. They are optimal decisions that take different situations into consideration. The values of θ_1, θ_2 and θ_3 are given by the decision maker. In order to obtain the optimal solution in the most probable situation, the value θ_2 is generally larger than the value of θ_1 and θ_3. θ_1 and θ_3 respectively indicate the degree of negative and positive of the decision-maker. The smaller the value θ_1, the larger the value θ_3, the smaller the ratio Z_1^{PIS} in the objective function and the larger the ratio Z_3^{PIS}, the more positive the decision made, and vice versa. The more negative the decisions made.

3. Algorithm for solving remanufacturing flexible job shop scheduling model in uncertain environment

In terms of solving algorithm, genetic algorithm, as a parallel search algorithm, can effectively perform global search and is very effective in solving scheduling problems. Aiming at the remanufacturing flexible job shop scheduling problem under the condition of uncertain processing time and delivery date, this paper uses MSOS coding (machine selection and operation sequence representation) genetic algorithm to solve.

Chromosome coding: Divided into two sub-chromosomes, the sequence of processes and the selection of machines. The process sequence string uses process-based coding to determine the processing sequence of all processes on the machine. Its length is the total number of processes for all parts, that is $\sum_{i=1}^{n} n_i$, where each gene represents a part number, the part number i which appears the jth time from left to right represents the j-th process of the part J_i, namely $O_{i,j}$; the machine selection string is used to represent the processing machines that can be selected for each process. The code is shown in Figure 1.

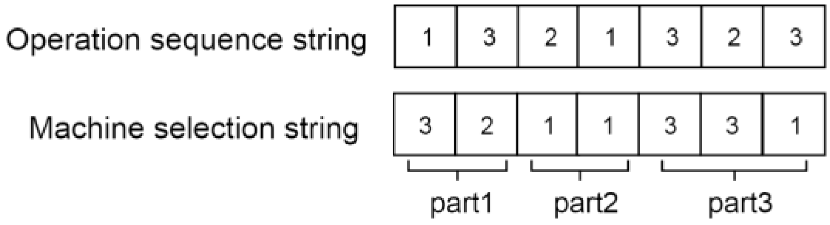

Figure 1 MSOS encoding

Calculation and evaluation of fitness: First, determine whether the delivery time satisfaction constraint (7) is satisfied. If the constraint is not met, the fitness of the chromosome is 0, and the chromosome is eliminated. For the chromosomes that meet the delivery time satisfaction constraint, the fitness function $W = min[\theta_1 Z_1^{PIS} + \theta_2 Z_2^{PIS} + \theta_3 Z_3^{PIS}]$ will be used to calculate the fitness value. The smaller the fitness value, the higher the fitness of the chromosome.

Selection operation: This article adopts the principle of combining roulette selection and elite retention strategy. The optimal individual of 0.1 in the parent population is directly copied to the next generation population without crossover and mutation; the remaining individuals pass the rounds. The gambling selects the better individual and performs cross mutation operation.

Crossover operation: ①The process sequence string is crossed by POX, and the parent chromosomes are P_1 and P_2. After the crossover, the offspring chromosomes O_1 and O_2 are generated. The operation process is: randomly divide the parts set into two non-empty sets B_1 and B_2 , copy the genes corresponding to the parts in set B_1 in P1 to the same gene position of O_1, and then fill in the remaining genes in P_2 from left to right to the empty gene position of O_1 after removing the determined genes in O_1 Above, swap the roles of P_1 and P_2 to generate O_2. The operation process is shown in Figure 2. ②The machine selection string uses single-point crossover. A crossover point is randomly selected in the chromosome, and the genes after the crossover point of the two chromosomes are exchanged to generate two new chromosomes. The specific operation is shown in Figure 3.

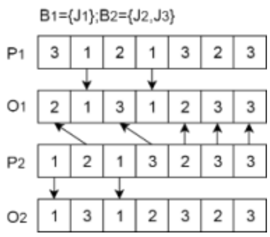

Figure 2 POX crossover operation of process sequence

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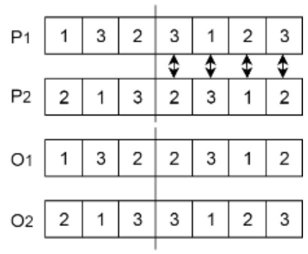

Figure 3 Single point crossover operation of machine selection string

Mutation operation: ①The process sequence string adopts exchange mutation.

Two positions are randomly selected on the chromosome, and the genes at these two positions are exchanged to generate offspring chromosomes. The operation process is shown in Figure 4. ②The machine selection string adopts random selection mutation, randomly selects k positions on the chromosome, and replaces the k positions of the machine with other machines in the optional machine set of the corresponding process. The specific operation is shown in Figure 5.

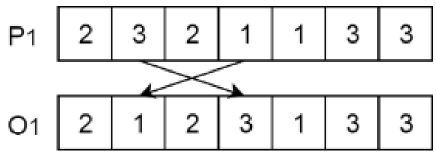

Figure 4 Exchange mutation operation of process sequence

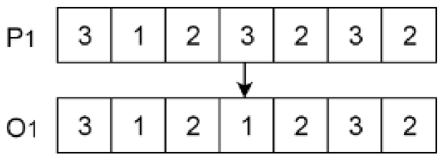

Figure 5 Random selection mutation operation of machine selection string

Termination condition judgment: take the maximum evolution algebra as the termination condition, set a suitable maximum evolution algebra in advance, when the genetic algebra is less than the maximum evolution algebra, continue to iterate; if the genetic algebra is greater than or equal to the maximum evolution algebra, the iteration stops and outputs optimal solution at the same time.

According to the above description, the genetic algorithm flow chart of the

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remanufacturing flexible job shop scheduling problem considering fuzzy operation time and fuzzy delivery date can be obtained, as shown in Figure 6.

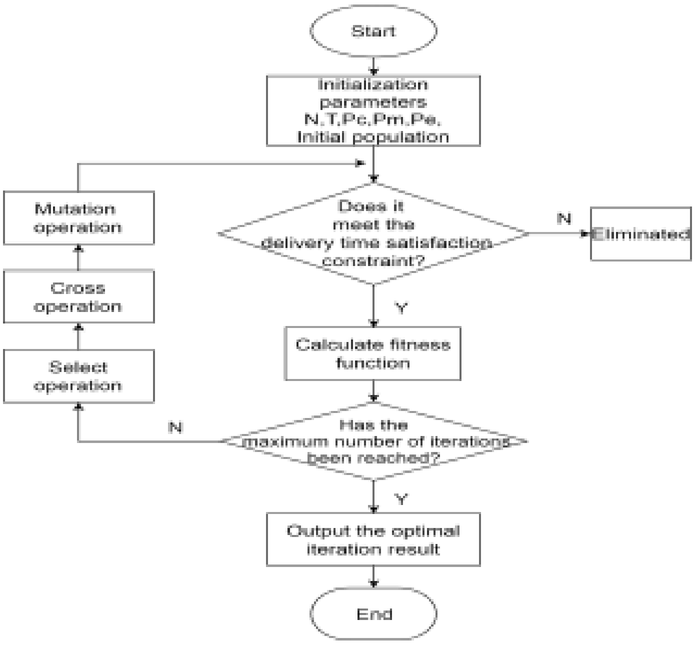

Figure 6 The genetic algorithm flow chart of the remanufacturing flexible shop scheduling problem considering fuzzy operation time and fuzzy delivery date

Where N is the population size, T is the number of iterations, P_c is the crossover probability, P_m is the mutation probability, and P_e is the elite ratio. According to the MSOS coding genetic algorithm designed in this article, it is programmed in Matlab R 2014b.

4. Example simulation

Take a remanufacturing workshop as an example. It is now preparing to process 10 remanufactured parts of the same type on 6 machines. Among them, the machines are of the same model and different in efficiency. Each machine can process several processes of the parts, and the process set processed on different machines is different. And the fuzzy processing time and fuzzy delivery date of the parts are shown in Table1.

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Table 1 Fuzzy processing time and fuzzy delivery date for remanufactured parts

Part	Process	Fuzzy processing time/min						Fuzzy delivery date
		M_1	M_2	M_3	M_4	M_5	M_6	
J1	$O_{1,1}$	(9,11,14)	—	(8,9,13)	—	(6,8,12)	—	(80,95,155,180)
	$O_{1,2}$	—	(13,16,20)	(12,16,21)	—	(10,14,18)	—	
	$O_{1,3}$	—	—	(5,9,13)	—	—	(9,13,16)	
	$O_{1,4}$	(16,19,21)	(10,12,15)	(20,23,26)	—	—	(13,15,17)	
	$O_{1,5}$	(7,8,10)	—	(13,16,21)	—	—	—	
	$O_{1,6}$	—	—	(5,9,13)	(9,11,15)	—	(14,18,22)	
J2	$O_{2,1}$	—	(15,18,22)	—	—	(20,22,25)	—	(110,130,170,210)
	$O_{2,2}$	—	—	(9,13,16)	(11,15,17)	—	—	
	$O_{2,3}$	(6,7,11)	—	(8,9,13)	—	—	—	
	$O_{2,4}$	—	(10,16,19)	—	(13,15,17)	—	—	
	$O_{2,5}$	(16,19,22)	(20,21,26)	—	—	—	(12,16,18)	
J3	$O_{3,1}$	—	(16,19,25)	—	—	(9,12,15)	—	(25,50,100,120)
	$O_{3,2}$	—	—	(6,9,12)	—	(13,15,17)	(10,12,14)	
	$O_{3,3}$	(7,10,14)	(20,23,25)	—	—	—	(13,17,21)	
	$O_{3,4}$	—	(3,6,9)	(7,9,13)	—	—	(4,7,10)	
J4	$O_{4,1}$	(16,19,24)	(19,21,26)	—	—	—	(9,10,13)	(95,105,155,185)
	$O_{4,2}$	—	(7,9,13)	—	(10,13,16)	—	—	
	$O_{4,3}$	—	—	(20,23,26)	—	(13,15,17)	—	
	$O_{4,4}$	—	(8,10,13)	(12,14,17)	—	(16,19,21)	—	
	$O_{4,5}$	—	—	(10,12,16)	—	—	(13,15,17)	
J5	$O_{5,1}$	—	(5,8,11)	(7,9,13)	—	(14,16,18)	—	(90,100,140,160)
	$O_{5,2}$	(16,19,23)	(9,13,15)	—	—	—	(11,13,14)	
	$O_{5,3}$	—	(7,9,12)	—	(9,10,14)	—	—	
	$O_{5,4}$	(17,19,22)	—	(22,24,27)	—	—	—	
	$O_{5,5}$	—	(11,12,14)	—	(13,15,16)	—	—	
J6	$O_{6,1}$	—	—	(18,21,25)	—	—	(12,13,15)	(105,115,160,220)
	$O_{6,2}$	(7,9,12)	—	(11,13,15)	—	—	—	
	$O_{6,3}$	—	(14,17,19)	(16,19,22)	—	—	(12,14,18)	
	$O_{6,4}$	—	(4,6,8)	—	(8,11,14)	—	—	
	$O_{6,5}$	(13,15,17)	(7,9,11)	—	—	—	(17,19,22)	
	$O_{6,6}$	(7,11,15)	—	—	(9,12,16)	—	—	
J7	$O_{7,1}$	—	—	—	(14,17,19)	—	(11,12,15)	(110,135,195,230)
	$O_{7,2}$	(16,19,23)	—	—	(20,22,25)	—	—	
	$O_{7,3}$	—	(12,15,18)	(17,19,22)	—	—	(23,26,28)	
	$O_{7,4}$	(7,10,11)	(13,15,17)	—	—	(14,18,21)	—	
J8	$O_{8,1}$	—	—	(13,16,19)	—	—	(14,16,18)	(100,115,160,200)
	$O_{8,2}$	—	(9,11,13)	(14,16,19)	—	—	(7,9,13)	
	$O_{8,3}$	(10,13,15)	(14,15,17)	—	—	—	(8,12,15)	
	$O_{8,4}$	—	(12,14,16)	—	(13,15,18)	—	—	
	$O_{8,5}$	—	(17,19,23)	—	(11,13,17)	—	—	
J9	$O_{9,1}$	—	—	(14,17,20)	—	—	(21,23,27)	(60,90,130,170)
	$O_{9,2}$	(13,19,21)	—	—	—	(16,18,23)	—	
	$O_{9,3}$	—	—	(9,11,14)	(7,10,13)	—	(12,14,17)	
	$O_{9,4}$	(14,17,19)	—	—	—	(18,20,23)	—	
	$O_{9,5}$	—	(17,21,24)	(11,13,15)	—	—	(23,26,29)	
	$O_{9,6}$	—	(14,17,19)	—	(18,21,24)	—	—	
J10	$O_{10,1}$	—	—	(10,13,15)	—	—	(7,11,14)	(40,60,100,120)
	$O_{10,2}$	—	(13,16,19)	(18,21,23)	—	—	(8,12,15)	
	$O_{10,3}$	—	(6,7,10)	(8,12,14)	—	(13,15,17)	—	
	$O_{10,4}$	—	—	(7,13,16)	—	—	(9,12,15)	
	$O_{10,5}$	—	(9,13,17)	—	(14,16,20)	—	—	

Substituting each parameter into the objective function and each constraint condition, using genetic algorithm to solve, among which, the specific parameters of genetic algorithm are set as: population number 120, crossover probability 0.8, mutation probability 0.2, elite ratio 0.1, maximum evolution algebra 500 times. And set up $\theta_1 = 0.25, \theta_2 = 0.5,\ \theta_3 = 0.25,\ \varphi = 0.7,$ The finally solved gantt chart of the scheduling plan is shown in Figure 7, and Figure 8 is the iterative curve of the genetic algorithm.

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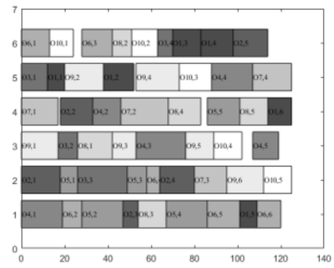

Figure 7 Gantt chart of scheduling plan

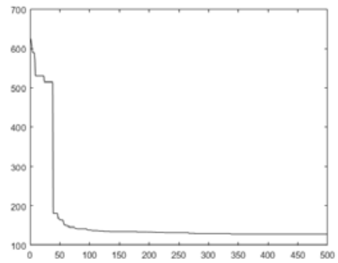

Figure 8 Iteration curve of genetic algorithm

The rectangle of the same color in the Gantt chart of the scheduling plan represents the processing sequence of different processes of the same part on the selected machine. The number before the comma in the rectangle represents the part number, and the number after the comma represents the processing process.

When $\varphi = 0.8$, gradually adjust the value of θ_1, θ_2 and θ_3 to obtain the most likely objective function value as shown in Table 2. A fixed value θ_2, it can be seen that as the value of θ_1 is gradually increased, the value of θ_3 is gradually reduced, and the value of the objective function in the most likely case gradually increases. The more negative the decision, the worse the result, on the contrary, the more positive the decision, the better the result.

Table 2 The objective function value in the most probable case corresponding to different values of θ_1, θ_2 and θ_3

θ1	0	0.1	0.2	0.3	0.4	0.5
θ2	0.5	0.5	0.5	0.5	0.5	0.5
θ3	0.5	0.4	0.3	0.2	0.1	0
The most likely objective function value	135	137	139	140	142	146

When $\theta_1 = 0.25, \theta_2 = 0.5, \theta_3 = 0.25$, gradually adjust the value of φ, and the obtained fitness function value is shown in Table 3. It can be seen that as the average delivery time satisfaction threshold φgradually increases, the fitness function value gradually increases, that is, the maximum completion time gradually increases. For different delivery time satisfaction levels, the completion time of the optimal scheduling scheme obtained is consistent with the actual workshop production law, which proves the rationality and effectiveness of the model.

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Table 3 Fitness function values corresponding to different values of φ

φ	0.5	0.6	0.7	0.8
Fitness function value	124.75	126.25	127.5	139.8

5. Conclusion

Taking into account the flexibility of the machine, this paper introduces the triangular fuzzy number to represent the processing time of the part and the trapezoidal fuzzy number to represent the delivery date of the part in order to solve the problem of the uncertainty of the operation time and the delivery date in the scheduling of the remanufacturing flexible job shop. Under the conditions of meeting machine constraints, process sequence constraints, and parts average delivery time satisfaction constraints, a fuzzy model of remanufacturing flexible job shop scheduling is established, and the model is transformed to be solved by MSOS coding genetic algorithm , and the analysis shows that: the positive or negative attitude of the decision maker will affect the decision result, the more negative the decision, the worse the result, on the contrary, the more active the decision, the better the result; as the average delivery time satisfaction threshold gradually increases, the degree of fitness function value gradually increases, and the maximum completion time gradually increases. In view of different delivery time satisfaction levels, the completion time of the optimal scheduling scheme obtained is consistent with the actual workshop production law, which once again proves the rationality and effectiveness of the model. Studying the scheduling problem of remanufacturing flexible job shop with fuzzy operation time and fuzzy delivery date is more in line with the actual status of remanufacturing scheduling, and it is expected to provide relevant reference opinions for remanufacturing enterprises to carry out reasonable workshop scheduling.

References

[1] Huang Xuewen, Chen Shaofen, Zhou Tianyu, Sun Yuting. Summary of genetic algorithms for flexible job shop scheduling [J/OL]. Computer Integrated Manufacturing System:1-26[2020-12-02].
[2] Jamrus T, Chien CF, Gen M, et al. Hybrid particle swarm optimization combined with genetic operators for flexible job-shop scheduling under uncertain processing time for semiconductor manufacturing[J]. IEEE Transactions on Semiconductor Manufacturing,2018,31(1): 32-41.
[3] Xu Y, Wang L, Wang S Y, et al. An effective teaching–learning-based optimization algorithm for the flexible job-shop scheduling problem with fuzzy processing time[J]. Neurocomputing, 2015,148:260-268.
[4] Guo Jun, Zhong Jingcheng, Du Baigang, Wu Rui, Li Yibing. Multi-objective scheduling method for remanufacturing workshops considering fuzzy operation time[J]. Control and Decision, 2020, 35(06): 1497-1504.

ISSN 2616-5767 Vol.3, Issue 8: 77-89, DOI: 10.25236/AJETS.2020.030809

[5] Hiroaki Ishii, Minoru Tada, Teruo Masuda. Two scheduling problems with fuzzy due-dates[J].Fuzzy Sets and Systems,1992,46(3):339-347.
[6] Cheng T C E. Optimal common due date with limited completion time deviation[J].Journal of the Operational Research Society,1988,15,91-96.
[7] Ma Jing, Li Yan. Research on IPPS under the condition of fuzzy delivery date[J]. Manufacturing Automation, 2019, 41(04): 24-29.
[8] Zhou Jing. Processing workshop scheduling problem based on random processing time and fuzzy delivery date [D]. Tsinghua University, 2010.
[9] Luo Yao, Gao Gengjun. Scheduling of remanufactured parts processing workshop under uncertain environment[J]. Journal of Chongqing Normal University (Natural Science Edition), 2018, 35(05): 26-32.
[10] Liu Qiong, Zhang Chaoyong, Rao Yunqing, Shao Xinyu. Improved genetic algorithm to solve flexible job shop scheduling problem[J]. Industrial Engineering and Management, 2009, 14(02): 59-66.
[11] Gao Gengjun, Luo Yao. Research on remanufacturing production scheduling under uncertain environment[J]. Operations Research and Management, 2019, 28(11): 185-190.