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Solving multi-objective planning model for equipment manufacturing enterprises with dual uncertain demands using NSGA-II algorithm

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A B S T R A C T

In the paper we have established a multi-objective planning model. This model can solve the dual uncertainty demand problems of number and delivery time when orders are emergent or are modified for equipment manufacturing enterprises. We used scenario analysis methods to deal with our customers' urgent orders and order revisions. A fuzzy interval analysis was used to describe delivery time requirements, and a random interval analysis was used to describe the quantity of customer demand. The multi-objective production planning model proposed in this paper can solve the objectives pursued by the enterprise to meet the maximization of customer demand and minimization of costs. The NSGA-II genetic algorithm is used to solve the model. Finally, the model is solved by example simulation. Through the input of a large amount of data and the analysis of the operating results, it verified the applicability and effectiveness of the model.

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A R T I C L E   I N F O

Keywords:
Equipment manufacturing enterprises;
Dual uncertain demand;
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1. Introduction

With the continuous development of the social economy, the external competition is becoming more and more intensified. Customer requirement is changing, so product demand is becoming more and more individualized, differentiated, diversified and complicated. If the equipment manufacturers want to profit from the fierce market competition, they have to change their single variety and mass production model into a multi variety and small batch production model. The production cycle needs to be shorter and shorter. So it increases the difficulty of the production and operations management of the enterprise. Multi variety products include tangible products, service products, and the combination of tangible product and service product, etc. So the demand is not just a single uncertain demand, but also the cross of more influential and multiple demands. It is mainly manifested in the irregular order quantity of the customer at non-scheduled time and the change of the customer's demand with the passage of time and so on. It mainly includes uncertainty of variety demand, uncertainty of quantity demand, uncertainty of price demand, and uncertainty of delivery time and so on.

There searches on multi variety production plan of traditional equipment manufacturing enterprises are mainly about a specific set of plans. Soysal *et al*. proposed a multi cycle IRP (Inventory Routing Problem) model. It meets the uncertain demand level of service constraints [1].

Hasany and Shafahi mainly developed a two-stage stochastic degree for railway freight blocking problem. The fixed uncertainty of demand and supply resource index is taken into account [2]. Ji *et al*. studied the randomness of the accident and the optimal production plan of a single cycle assembly system under the uncertainty of the capacity of production [3]. Mateo *et al*. studied the production planning model of the fresh vegetable industry, and adopted the two-stage stochastic model to minimize the total purchase cost and to meet the future needs [4]. Masaru and Masahiro tested the supply plan data of a home appliance manufacturer and solved the problem of supply plan optimization under the uncertainty of demand forecast [5]. Ciarallo *et al*. considered the review cycle of uncertain length for the production plan model of a single production disk under random demand and random capacity [6]. Shi *et al*. studied the manufacturer's demand for new products and remanufactured returns for new products. The demand for all products is uncertain and the return is uncertain [7]. Kim *et al*. considered the factors of market demand uncertainty, cost and product characteristics and so on. A mathematical model and iterative algorithm were established to solve the problem of supply structure for manufacturers [8]. Modiano discussed the derivation of the original resource demand function under the uncertain economic environment, and put forward an application to expand the coal power plant to the coal demand and related capacity of the US energy sector [9]. A mathematical model and iterative algorithm were established to solve the problem of supply structure for manufacturers. Based on the stage of credibility theory, in order to minimize the cost of production. Xu *et al*. put forward multi objective decision-making methods [10-11]. Tang *et al*. established non-deterministic polynomial (NP) models [12].

But the above literature does not take into account more uncertainty and event driven production plans. In addition, the equipment manufacturing enterprises do not define the production plan. Not only research content is less, but also all these papers are on the production process of uncertainty in some aspects or in a specific application domain. They lack researches on the uncertainty of demand multiple aspects, and also did not involve more multiple uncertain demand factors.

2. Problem descriptions and hypothesis

2.1 Problem descriptions

In this paper, considering the changes in customer orders requirements and emergency order cases, it produces a series of changes in uncertain demand, including the quantity demand, delivery requirements, and so on. The requirement description of multi variety production planning arrangement in specific equipment manufacturing enterprises is shown in Fig. 1.

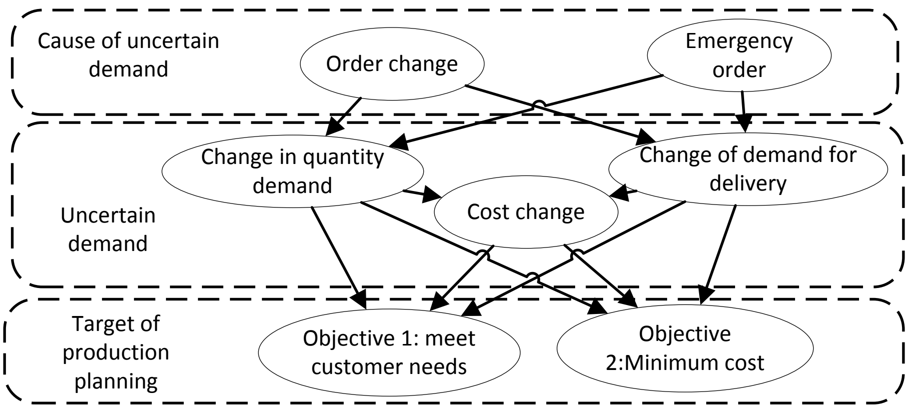

Fig. 1 Uncertain demand of equipment manufacturing enterprise production plans

2.2 Problem hypothesis

According to the requirements of the multiple uncertain requirements mentioned above, the following assumptions are made according to the needs of the model:

- We use the discrete condition of the known probability to describe the uncertainty of the order change or the emergency order of the equipment manufacturing enterprises, and establish the corresponding multi variety production planning model.
- The equipment manufacturing enterprises have the capacity constraints, including the production capacity and the limit of the level of inventory factors.
- The lead time of urgent order or order modification can't be less than the lead time of product production, that is, the product demand time should be greater than the product production plan period, so as to ensure that the demand product can be scheduled for production.

3. Multi-objective planning model for equipment manufacturing enterprises with dual uncertain demands

3.1 Scenario analysis description with dual uncertain demands

The discrete condition of known probability is used in this paper to describe the uncertainty of order change and emergency ordering in equipment manufacturing enterprises, and to establish the corresponding multi product production planning model. There are *n* kinds of products that a production manufacturer can produce, and a total of *m* resources are required.

The multiple product production of equipment manufacturing enterprises can be described with S_1 order change demand scenarios and S_2 emergency order demand scenarios respectively. p_{s1} is the probability of the occurrence of an order change demand scenario $s_1(1, 2, \dots, S_1)$. p_{s2} is the probability of the occurrence of an order change demand scenario $s_2(1, 2, \dots, S_2)$. The combination of S_1 and S_2 constitutes a S scenario. Each scenario represents a group of future equipment manufacturer's multiple production order changes or the forecast of emergency order demand. $\mathrm{p_s}$(That is, p_{s1}, p_{s2}) is the probability of the occurrence of a scenario $s(1, 2, \dots, S)$.

In scenario *s*, we represent the number of requirements for the *t* period by N_t^s. And We represent the market demand for *i* products in the *t* period by N_{it}^s.

Objective 1: The enterprise meets the customer's needs as much as possible, that is, the customer demand satisfaction rate is 100 %, that is 1. We represent the pattern as:

$$min \sum_{s=1}^{S} \sum_{t=1}^{T} p_s \cdot \delta N_1^{ts-} + min \sum_{s=1}^{S} \sum_{t=1}^{T} p_s \cdot \delta T_1^{ts-} \tag{1}$$

subject to:

$$\sum_{i=1}^{n} (N_{it}^s - ln_{it}^s) / \sum_{i=1}^{n} N_{it}^s + \delta N_1^{ts-} - \delta N_1^{ts+} = 1, \ \forall t, \ s \tag{2}$$

$$\sum_{i=1}^{n} (TN_{it}^s - lt_{it}^s) / \sum_{i=1}^{n} TN_{it}^s + \delta T_1^{ts-} - \delta T_1^{ts+} = 1, \ \forall t, \ s \tag{3}$$

where:

δN_1^{ts-} is the number of Objective 1 of the *t* period is not reached in situation *s*,

δN_1^{ts+} is the number of Objective 1 of the *t* period is excess in situation *s*,

δT_1^{ts-} is the delivery time of Objective 1 of the *t* period is not reached in situation *s*,

δT_1^{ts+} is the delivery time of Objective 1 of the period is excess in situation *s*.

In addition, the priority level of customer demand and delivery time is different. That is, the expected coefficient of satisfaction is different. The set of alpha α_{Nl}^s and α_{Tl}^s are respectively the expected coefficients of quantity and delivery time of customers *l* under scenario *s*. The target model is modified into is as follows:

$$\alpha_{Nl}^{s} \cdot min \sum_{s=1}^{S} \sum_{t=1}^{T} p_s \cdot \delta N_1^{ts-} + \alpha_{Tl}^{s} \cdot min \sum_{s=1}^{S} \sum_{t=1}^{T} p_s \cdot \delta T_1^{ts-} \tag{4}$$

At the same time, the uncertainty of the quantity of demand and the change of delivery time in the case of emergency order and order modification is considered, setting:

ΔN_{it}: It represents the change in the demand for the *i* product of the *t* cycle.

ΔTN_{it}: It represents the change in the time of customer demand for the enterprise production product *i* in the *t* cycle.

$\widehat{N}_{it}$: It represents the number of needs of the customer's *i* product in the *t* period;

$\widehat{TN}_{it}$: It represents the demand time for the *t* cycle customer to produce the product *i*.

In addition, we define a vector matrix $\gamma = [\gamma_1, \gamma_2]$, among them. Both γ_1 and γ_2 are valued at 0 or 1. It shows whether quantity and delivery time has changed.

Considering the above problems, the Eq. 1 to Eq. 3 is changed to:

$$\alpha_{Nl}^{s} \cdot min \sum_{s=1}^{S} \sum_{t=1}^{T} p_s \cdot \delta N_1^{ts-} + \alpha_{Tl}^{s} \cdot min \sum_{s=1}^{S} \sum_{t=1}^{T} p_s \cdot \delta T_1^{ts-} \tag{5}$$

subject to:

$$\sum_{i=1}^{n} (\widehat{N}_{it}^{s} - ln_{it}^{s}) / \sum_{i=1}^{n} N_{it}^{s} + \delta N_1^{ts-} - \delta N_1^{ts+} = 1, \ \forall t, \ s \tag{6}$$

$$\sum_{i=1}^{n} (\widehat{TN}_{it}^{s} - lt_{it}^{s}) / \sum_{i=1}^{n} TN_{it}^{s} + \delta T_1^{ts-} - \delta T_1^{ts+} = 1, \ \forall t, \ s \tag{7}$$

$$\widehat{N}_{it}^{s} = N_{it} + r_1 \Delta N_{it} \tag{8}$$

$$\widehat{TN}_{it}^{s} = TN_{it} + r_2 \Delta TN_{it} \tag{9}$$

<u>*Objective 2:*</u> The total production cost of the production plan is minimal. We represent the model as:

$$min\, \delta C_2^{+} \tag{10}$$

Subject to:

$$C/MC + \delta C_2^{-} - \delta C_2^{+} = 1 \tag{11}$$

$$\begin{aligned} \sum_{s=1}^{S} p_s \sum_{t=1}^{T} \Bigg\{ & \sum_{i=1}^{n} (C_{it}^{s} + RC_{it}^{s} + \sum_{j=1}^{m} C_{jt}^{\prime s} \cdot N_{ijt}^{\prime s}) \cdot \widehat{N}_{it}^{s} + \sum_{i=1}^{n} E_{it}^{s} \cdot Max(\widehat{N}_{it}^{s} - G_{it}^{s}, 0) \\ & + \sum_{i=1}^{n} F_{it}^{s} \cdot Max(G_{it}^{s} + N_{it}^{s}, 0) \Bigg\} - C \le 0 \end{aligned} \tag{12}$$

C is the actual cost of production and operation. MC is the minimum cost of production and operation. δC_2^{-} and δC_2^{+} are unreached and excess portion of Objective 2.

Combining the above two objectives, the production planning model of the equipment manufacturing enterprise is set up as follows:

$$MinPP = PP_1\left(\alpha_{Nl}^{s}\cdot min\sum_{s=1}^{S}\sum_{t=1}^{T}p_s\cdot\delta N_1^{ts-}+\alpha_{Tl}^{s}\cdot min\sum_{s=1}^{S}\sum_{t=1}^{T}p_s\cdot\delta T_1^{ts-}\right)+PP_2\delta C_2^{+} \tag{13}$$

PP_1 and PP_2 in the upper formare respectively priority factors in the production plan operation target. In the two goals, the first consideration is as far as possible to meet customer demand. On the basis of the pursuit of cost minimization, so the two priority factor meet the relationship $PP_1 \gg PP_2$. At the same time, the constraint conditions should be satisfied Eq. 2 to Eq. 10. The other constraints are as follows:

Eq. 14 indicates that the number of out of stock of product *i* of period *t* is equal to the quantity of demand subtracting this period of stock. The above described formula is defined as follows:

$$ln_{it} = N_{it} - R_{it},\ i = 1,2,\dots,n,\ \forall t,\ s \tag{14}$$

Eq. 15 indicates that the number of shortages of product *i* in period *t* is less than equal to the amount of capacity to produce *i*. The demand for *i* in period *t* is not more than the production capacity of the product *i* in the period *t*.

$$ln_{it} \le W_i,\ i = 1,2,\dots,n,\ \forall t,\ s \tag{15}$$

Eq. 16 indicates that the number of out of stock of product *i* of period *t* must not be less than the actual demand.

$$ln_{it} \le N_{it},\ i = 1,2,\dots,n,\ \forall t,\ s \tag{16}$$

Eq. 17 indicates that the demand for *j* in cycle *t* is not greater than that of the *j* product in the *t* period.

$$\sum_{i=1}^{n} N'_{ijt} - R'_{jt} \le W'_j,\ i = 1,2,\dots,n,\ j = 1,2,\dots,m,\ \forall t,\ s \tag{17}$$

Eq. 18 indicates that, in the period *t*, the stock of product *i* equals the final inventory of the product *i* plus the volume of goods for this period. That is to say, it is the demand for the product before the production cycle minus the current stock, that is, the quantity of the products in the life cycle of the product.

$$R_{i\cdot(t+1)} = R_{i\cdot t} + N_{i\cdot(t-T_i)} - R_{i\cdot(t-T_i)},\ i = 1,2,\dots,n,\ \forall t,\ s \tag{18}$$

Eq. 19 indicates that the inventory of *i* product in period *t* is less than the maximum inventory of product *i*.

$$R_{it} \le MR_i,\ R_{i\cdot(t+1)} \le MR_i,\ i = 1,2,\dots,n,\ \forall t,\ s \tag{19}$$

Eq. 20 indicates that production time should not be less than production preparation time plus production time

$$TN_{it} \ge T_{it} + ET_{it},\ i = 1,2,\dots,n,\ \forall t,\ s \tag{20}$$

Eq. 21 indicates that Production preparation time is greater than emergency production preparation time.

$$RT_{it} \ge ET_{it},\ i = 1,2,\dots,n,\ \forall t,\ s \tag{21}$$

Eq. 22 indicates that the shortage time equals the product production time plus the emergency order time minus the demand time. $lt_{it} > 0$ indicates that product *i* can not be completed according to order requirements in period *t*. and $lt_{it} \le 0$ indicates that product *i* can be complete orders according to order requirements in period *t*.

$$lt_{it} = T_{it} + ET_{it} - TN_{it} \tag{22}$$

Eq. 23 indicates the variables of nonnegative constraints.

$$N_{it}, R_{it}, W_{it}, N'_{ijt}, R'_{jt}, W'_{jt}, P_{it}, C_{it}, C'_{jt}, E_{it}, F_{it}, G_{it} \geq 0, i = 1,2,\dots,n, j = 1,2,\dots,m, \forall t, s \tag{23}$$

Among them: Eq. 14 to Eq. 17 respectively indicate production out of stock and production capacity balance; Eq. 18 and Eq. 19 respectively constraints on inventory storage capacity; Eq. 20 to Eq. 22 respectively indicate constraints on the lead time of production.

3.2 Quantity demand uncertainty analysis of the random fuzzy description

In the process of actual production operation, equipment manufacturing enterprises in the production process in accordance with the demand of N_{it} orders for production, the amount of demand is not possible to determine the value for sure. In most cases, decision makers often get a value interval of customer demand N_{it} based on order status, market research customers' needs and past data, and mark it with $M_{it} = [m_{it}^{min}, m_{it}^{max}] = \{N_{it} | m_{it}^{min} \leq N_{it} \leq m_{it}^{max}, N_{it} \in R\}$. In order to distinguish the common number, the following mark is marked by the number of requirements interval N_{it} as $\widetilde{N}_{it}$. It has no definite distribution function or membership function. If we can give the distribution function or membership function, then the interval variable can be transformed into a random variable or a fuzzy variable.

On the basis of the mathematical model established on the 3.1, the number of the product description demand uncertainty, the constraint Eq. 2 increased uncertainty description. It is expressed as:

$$s.t. \quad \sum_{i=1}^{n} (\widetilde{N}_{it}^{s} - ln_{it}^{s}) / \sum_{i=1}^{n} \widehat{N}_{it}^{s} + \delta N_{1}^{ts-} - \delta N_{1}^{ts+} = 1, \forall t, s \tag{24}$$

3.3 Fuzzy analysis description of the uncertainty of delivery demand

The requirements for the lead time of production should be greater than the sum of the emergency order and the time of production. But it is often required to calculate the minimum completion time and the latest completion time as required. And then, it determines the lead time of production. In fact, it is in an area of uncertainty within a certain range. It is expressed as:

$$TD_{it} = [td_{it}^{short}, td_{it}^{long}] = \{TD_{it} | td_{it}^{short} \leq TD_{it} \leq td_{it}^{long}, N_{it} \in R\} \tag{25}$$

The satisfactory delivery time for customers is the earliest delivery time period and the latest delivery time period. It is also a time fluctuation range. We record the delivery time of customer demand as follows:

$$TN_{it} = [tc_{it}^{earlist}, tc_{it}^{lastest}] = \{TN_{it} | tc_{it}^{earlist} \leq TN_{it} \leq tc_{it}^{lastest}, N_{it} \in R\} \tag{26}$$

So we can know that a constraint relationship between the customer's demand delivery date and the lead time of the enterprise's production is that the delivery time period of the customer demand can't be lower than the completion time of the completion request. That is:

$$td_{it}^{short} \leq tc_{it}^{earlist} \tag{27}$$

Since the customer needs is a time interval, and the customer's delivery time is fuzzy, as long as the requirements of the above Eq. 27 are satisfied. In order to distinguish ordinary numbers, we need to record the customer's delivery time requirement TN_{it} as $\widetilde{TN}_{it}$. It does not have a defined distribution function or membership function. Otherwise, the interval variable can be transformed into a random variable or a fuzzy variable.

According to the mathematical formula in Section 3.1, the uncertainty of the delivery time requirement of the enterprise product is described. For the constraint condition Eq. 3 to increase the uncertainty description, it is expressed as

$$\sum_{i=1}^{n}(\widetilde{TN}_{it}^{s}-lt_{it}^{s})/\sum_{i=1}^{n}\widetilde{TN}_{it}^{s}+\delta T_{1}^{ts-}-\delta T_{1}^{ts+}=1,\ \forall t,\ s \tag{28}$$

To sum up, the production planning model of the equipment manufacturing enterprise with uncertain demand is as follows:

- The objective function: Eq. 13,
- Constraints: Eq. 6, Eq. 7, Eq. 10, Eq. 11, Eq. 12, Eq. 14 to Eq. 24, Eq. 27, and Eq. 28,
- Nonnegative condition: Eq. 23.

The basic symbols and meanings involved in the production planning model of the equipment manufacturing enterprise with multiple uncertain demands are as follows Table 1.

Table 1 The basic symbols and meanings

Variable/ parameter	Meaning
n	The kinds of products that a production manufacturer can produce
m	A total of resources are required
N_{it}	The original planned requirement for the *i* product of the period *t* period
N'_{ijt}	The number of *j* resources needed for the *i* product of the *t* cycle
R_{it}	The inventory of the *i* product of the *t* cycle
R'_{jt}	The inventory of the *j* resource of the *t* cycle
MR_i	The largest inventory of *i* products
MR'_j	The largest inventory of *j* resources
ln_{it}	The number of out of stock of the *i* product of the *t* cycle
lt_{it}	The number of out of stock for production of *i* products in the *t* cycle
C_{it}	The production cost of the *i* product in the t cycle
RC_{it}	The production cost of the production of the *i* product in the *t* cycle
MC_{it}	The minimum cost for the *i* product of the *t* cycle
C'_{jt}	The cost of obtaining the *j* species in the *t* cycle
T_{it}	In the case of meeting the demand, the total production lead time for the production of *i* in the *t* period enterprise
RT_{it}	In the case of meeting the demand, the lead time of production preparation for production *i* in the *t* period enterprise
ET_{it}	In the case of an emergency order, the emergency order lead time of the production of *i* in the *t* period enterprise
TN_{it}	The original planned demand time for the *t* cycle customer to produce the product *i*, that is, the time of delivery
ls_i	The economic volume of the enterprise production product *i*
W_{it}	That the ability of the enterprise to produce product *i* in the t cycle is W_{it} units
MW_{it}	The largest production unit of *i* production in the enterprise's *t* period
W'_{jt}	The ability of the enterprise to produce or obtain resource *j* in the *t* cycle is W'_{jt} units
MW'_{jt}	The largest production unit of the enterprise's *t* cycle production or acquisition of resource *j*
E_{it}	The unit opportunity cost for the production of *i* products in the *t* period
F_{it}	The cost of holding stock in unit *i* product unit in the period *t*
G_{it}	The planned production of the *i* product in the *t* cycle

Among them: i = 1, 2,…,n; j = 1, 2,…,m

4. Used methods

Most of the optimization of production planning belongs to the NP-hard problem, and it is limited by the general precise algorithm. Genetic algorithm is a new global optimization search algorithm, because its principle is simple, and its versatility and robustness is strong, it is especially suitable for parallel processing. Kalyanmoy Deb's elite non dominated sorting genetic algorithm (Nondominated Sorting Genetic Algorithm II) is undoubtedly the most widely applied and the most successful one. The NSGA-II method is adopted in this paper. This method proposes accelerated non dominated sorting algorithm, which reduces the computational complexity of the algorithm from O (mN3) to O (mN2), where m is the number of objective functions and N is population size. The operation process of NSGA-II is drawn as shown in Fig. 2.

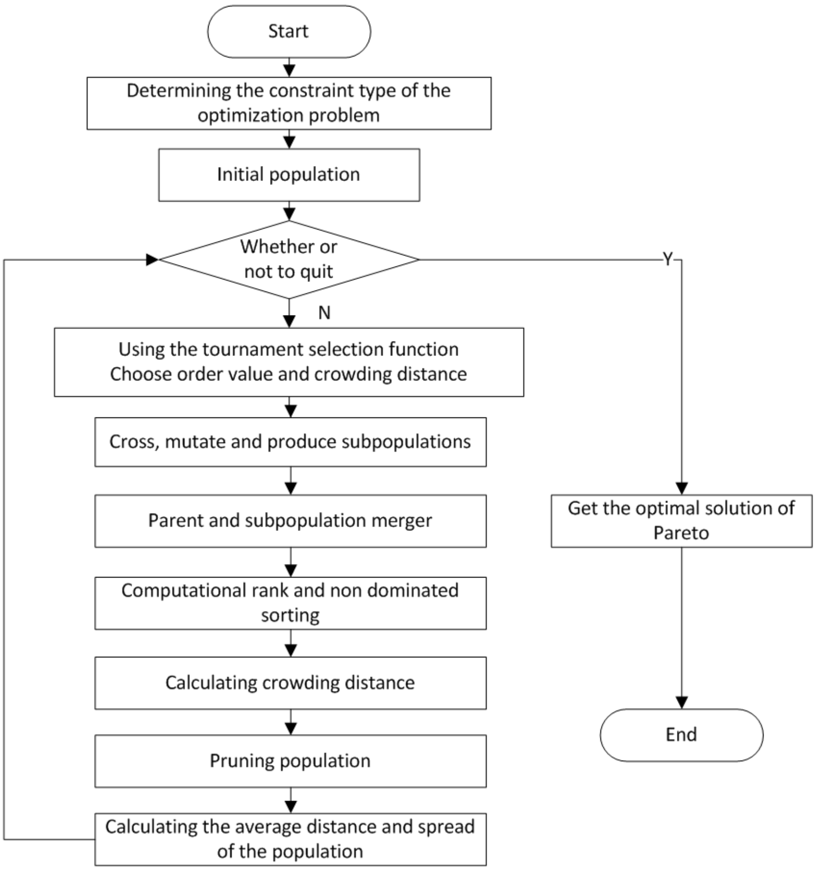

Fig. 2 Diagram: the operation process of NSGA-II

5. Results and discussion

According to the above model in Eq. 13, combined with the simulation example, the multi-objective optimization algorithm NSGA-II is based on the simulation example. The Matlab 2015b version is used to simulate and calculate the results, and the results are analyzed.

5.1 The initial data

Assuming that a production manufacturer can produce a product n = 5, a total of m = 10 resources are needed, and other parameters, as shown in Tables 2 to 11. The probability distribution of order modification and emergency order is 0.4 and 0.6.

Table 2 Product composition table

Name of the product(i) \ Number of resources (j)	$m(1)$	$m(2)$	$m(3)$	$m(4)$	$m(5)$	$m(6)$	$m(7)$	$m(8)$	$m(9)$	$m(10)$
$n(1)$	2	0	4	2	0	3	0	7	0	0
$n(2)$	1	1	0	2	5	0	4	0	0	0
$n(3)$	0	2	3	1	0	2	0	5	0	3
$n(4)$	2	0	4	0	5	0	6	0	9	0
$n(5)$	2	1	0	4	0	2	0	3	0	4

Table 3 Product or resource in t time inventory

Products or resources \ Period	t=1	t=2	t=3	t=4	t=5	Maximum stock
$n(1)$	300	1000	900	400	500	2000
$n(2)$	300	800	900	900	900	2000
$n(3)$	800	600	600	100	900	2000
$n(4)$	900	200	500	800	600	2000
$n(5)$	800	400	1000	900	300	20000
$m(1)$	8000	2000	5000	9000	10000	20000
$m(2)$	7000	10000	6000	1000	2000	20000
$m(3)$	1000	8000	2000	4000	6000	20000
$m(4)$	3000	1000	8000	10000	5000	20000
$m(5)$	2000	10000	5000	1000	5000	20000
$m(6)$	3000	9000	8000	4000	4000	20000
$m(7)$	2000	9000	10000	6000	10000	20000
$m(8)$	1000	9000	5000	4000	2000	20000
$m(9)$	7000	3000	9000	3000	10000	20000
$m(10)$	9000	10000	5000	4000	3000	20000

Table 4 t time product production capacity table

Products \ Period	t=1	t=2	t=3	t=4	t=5
$n(1)$	2000	2000	2000	2000	2000
$n(2)$	2000	2000	2000	2000	2000
$n(3)$	2000	2000	2000	2000	2000
$n(4)$	2000	2000	2000	2000	2000
$n(5)$	2000	2000	2000	2000	2000

Table 5 t = 1 time customer k demand for product production

Products \ Period	k =1	k=2	k=3	k=4	k=5	k=6	k=7	k=8	k=9	k=10	Total
$n(1)$	600	600	800	900	500	100	700	100	500	900	5700
$n(2)$	600	800	400	200	700	900	900	900	300	800	6500
$n(3)$	200	900	200	700	800	1000	100	400	200	300	4800
$n(4)$	800	400	300	1000	100	500	300	200	500	700	4800
$n(5)$	500	500	500	100	1000	500	500	800	200	100	4700

Table 6 t = 1 time requirements for the customer K

Products \ Period	k=1	k=2	k=3	k=4	k=5	k=6	k=7	k=8	k=9	k=10
$n(1)$	12	12	10	15	12	15	12	9	12	14
$n(2)$	10	8	6	10	9	10	9	6	6	11
$n(3)$	14	9	9	14	13	10	10	8	10	10
$n(4)$	14	13	16	10	14	12	11	15	15	16
$n(5)$	6	11	10	9	8	6	9	10	11	5

Table 7 t = 1 time original production plan

Products \ Period	t=1	t=2	t=3	t=4	t=5
$n(1)$	5700	5100	5300	4700	5300
$n(2)$	6500	5700	6500	4400	6000
$n(3)$	4800	4100	6300	6200	6100
$n(4)$	4800	5100	6600	7000	5600
$n(5)$	4700	4500	3600	6400	5900

Table 8 t time resource production or purchasing capacity

Resources \ Period	t=1	t=2	t=3	t=4	t=5
$m(1)$	15000	15000	15000	15000	15000
$m(2)$	15000	15000	15000	15000	15000
$m(3)$	15000	15000	15000	15000	15000
$m(4)$	15000	15000	15000	15000	15000
$m(5)$	15000	15000	15000	15000	15000
$m(6)$	15000	15000	15000	15000	15000
$m(7)$	15000	15000	15000	15000	15000
$m(8)$	15000	15000	15000	15000	15000
$m(9)$	15000	15000	15000	15000	15000
$m(10)$	15000	15000	15000	15000	15000

Table 9 The various costs of resources

Resources \ Cost	Purchasing cost	Unit Holding cost
$m(1)$	2	5
$m(2)$	3	5
$m(3)$	2	5
$m(4)$	1	5
$m(5)$	2	5
$m(6)$	3	5
$m(7)$	4	5
$m(8)$	3	5
$m(9)$	1	5
$m(10)$	2	5

Table 10 t = 1 time lead time of production plan

Products \ Period	Lead time of production	Lead time of prepares	Lead time of emergency order	Total lead time
$n(1)$	7	2	8	11
$n(2)$	5	1	5	8
$n(3)$	6	2	7	10
$n(4)$	8	2	9	12
$n(5)$	4	1	5	7

Table 11 The various costs of products

Products \ Cost	Unit production cost	Production preparation cost	Unit holding cost	Cost of stock loss
$n(1)$	20	10	5	2
$n(2)$	30	15	5	2
$n(3)$	25	12	5	2
$n(4)$	35	14	5	2
$n(5)$	40	12	5	2

5.2 The results

In matlab, the parameters of setting genetic algorithm (NSGA-II) for multi-objective optimization: the objective function is the [1,100] of the random number, production batch PL is 100, the optimal front-end individual coefficient is 0.3, the population size is 500, the largest evolution algebra is 200, the stop algebra is 200, the deviation value of the fitness function is 1e-3. The average distance between individuals and Pareto front of front individual distribution is drawn as shown in Fig. 3.

The average distance between individual shows the average distance between the points of each generation. When the number of variance decreases, the average distance between individuals and the range of fitness value decreased. These graphs reduce the number of variance and reduce the diversity of offspring.

It can be seen from the Pareto front diagram that the Pareto optimal solution of the first front end is distributed evenly. The number of Pareto optimal solutions for the return of the objective function is 150. As for the 150 objective functions 1 and the objective functions 2, and according to the objective function 1, the order of the customer satisfaction is the order. When the value of the target function is the same in objective function 1, the order is then made according to the minimum production cost. And the scatter plot of the target function is drawn as shown in Fig. 4.

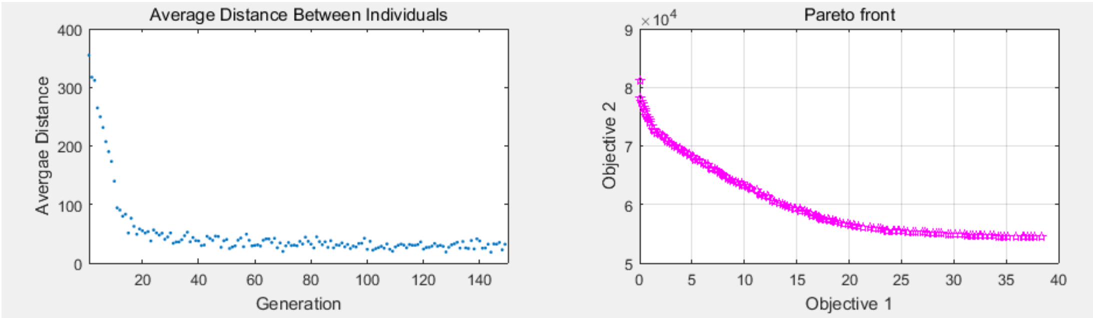

Fig. 3 The average distance between individuals and Pareto front of front individual distribution

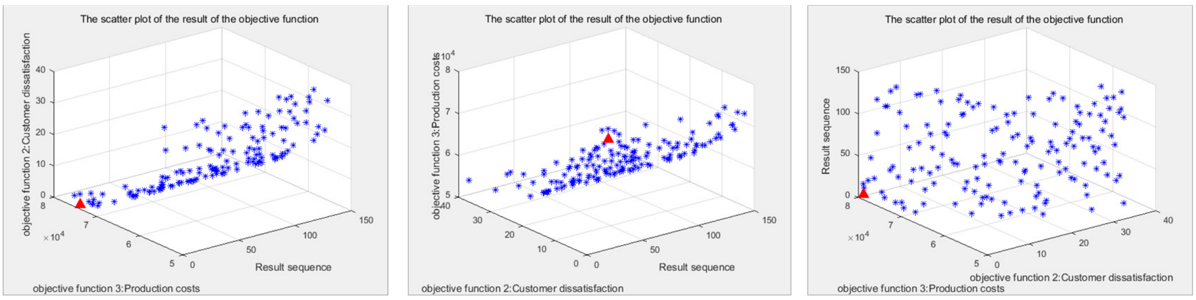

Fig. 4 Three dimensional graph of objective function scatter

From Fig. 3, Fig. 4, and Fig. 5, the program marks the point of the minimum customer dissatisfaction and the production cost center. From all angles of the three-dimensional graph of the scatter plot of the target function, 150 Pareto optimal solutions are obtained by using this model and NSGA-II. These data distribution is concentrated in a plane, which is in line with the requirements of the multi-objective programming. From these 150 sets of data, we find that the nineteenth data is to meet customer needs, that is, the minimum rate of customer order is 0, and the production cost is the smallest and the minimum production cost is 78772.4916553338. Take out the corresponding production schedule as follows Table12 and Table 13.

Table 12 $t = 1$ time product production schedule

Period / Products	k=1	k=2	k=3	k=4	k=5	k=6	k=7	k=8	k=9	k=10
$n(1)$	900	700	800	1000	600	1000	800	600	900	600
$n(2)$	700	800	800	1100	900	500	600	600	700	700
$n(3)$	800	700	600	900	500	600	500	700	800	900
$n(4)$	900	900	400	800	700	600	1000	700	600	500
$n(5)$	900	1100	800	800	1000	700	600	1000	1000	400

Although we chose the most satisfying customer orders, which does not meet the minimum rate and production plan, but the results found in the cost of production may not be minimal, so we can choose the reasonable selection of the optimal solution set, according to the actual needs of enterprises and the enterprise production.

Table 13 Product per cycle production plan

Products \ Period	t=1	t=2	t=3	t=4	t=5
$n(1)$	7900	7200	7600	8000	7000
$n(2)$	7400	5800	7900	7700	7500
$n(3)$	7000	7200	7900	7700	6600
$n(4)$	7100	6600	8100	6800	6700
$n(5)$	8300	6700	8900	8100	7600

6. Conclusion

In this paper we analyzed the customer demand issues caused by emergency orders and modified orders for equipment manufacturing enterprises. And we found that multiple uncertainties often existed in the number of customer needs and delivery time. Therefore, we use scenario analysis methods with known probabilities to formulate production plans for equipment manufacturing companies in the event of urgent orders and order modification. Random intervals and fuzzy intervals were used to distinguish between the number of customer requirements and the delivery time requirements. And we established a corresponding multi-product production planning model for equipment manufacturing enterprises. In order to maximize the satisfaction of customer needs and minimization of costs, a multi-objective production planning model was established based on the degree of customer demand for both. This model can achieve the objectives of reducing customer dissatisfaction and minimizing costs and meet the inventory constraints and production constraints of the enterprise's production. In the paper we used NSGA-II algorithm to solve the model. And it is verified that the NSGA-II algorithm can solve the model by means of a simulation example. By means of data input and simulation operations, the results of the operation meet the production needs of the enterprise. It shows that this model can solve the problem of multi-variety production planning for equipment manufacturing enterprises, and it has both operability and feasibility. The establishment of this model is conducive to equipment manufacturers to deal with complex uncertainties and the environment, but also conducive to equipment manufacturers to effectively carry out product production and scheduling.

In the future work, we need to establish more sophisticated models to deal with more rigorous customer demand uncertainties. And the model can deal with more complex production objectives. In addition, the algorithm can be extended to solve problems in multiple ways, such as particle swarm optimization and other multi-objective evolutionary computational algorithms.

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References

[1] Soysal, M., Bloemhof-Ruwaard, J.M., Haijema, R., van der Vorst, J.G.A.J. (2015). Modeling an inventory routing problem for perishable products with environmental considerations and demand uncertainty, *International Journal of Production Economics*, Vol. 164, 118-133, doi: 10.1016/j.ijpe.2015.03.008.

[2] Hasany, R.M., Shafahi, Y. (2017). Two-stage stochastic programming for the railroad blocking problem with uncertain demand and supply resources, *Computers & Industrial Engineering*, Vol. 106, 275-286, doi: 10.1016/j.cie.2017.02.014.

[3] Ji, Q., Wang, Y., Hu, X. (2016). Optimal production planning for assembly systems with uncertain capacities and random demand, *European Journal of Operational Research*, Vol. 253, No. 2, 383-391, doi: 10.1016/j.ejor.2016.02.021.

[4] Mateo, J., Pla, L.M., Solsona, F., Pagès, A. (2016). A production planning model considering uncertain demand using two-stage stochastic programming in a fresh vegetable supply chain context, *SpringerPlus*, Vol. 5, No. 1, 839, doi: 10.1186/s40064-016-2556-z.

[5] Masaru, T., Masahiro, H. (2003). Genetic algorithm for supply planning optimization under uncertain demand, In: Cantú-Paz, E. et al. (eds.), *Genetic and Evolutionary Computation – GECCO 2003, Lecture Notes in Computer Science,* Vol. 2724, Springer, Berlin, Heidelberg, Germany, 2337-2346, doi: 10.1007/3-540-45110-2_126.

[6] Ciarallo, F.W., Akella, R., Morton, T.E. (1994). A periodic review, production planning model with uncertain capacity and uncertain demand – Optimality of extended myopic policies, *Management Science,* Vol. 40, No. 3, 320-332, doi: 10.1287/mnsc.40.3.320.

[7] Shi, J., Zhang, G., Sha, J. (2011). Optimal production planning for a multi-product closed loop system with uncertain demand and return, *Computers & Operations Research*, Vol. 38, No. 3, 641-650, doi: 10.1016/j.cor.2010.08.008.

[8] Kim, B., Leung, J.M.Y., Park, K., Zhang, G., Lee, S. (2002). Configuring a manufacturing firm's supply network with multiple suppliers, *IIE Transactions,* Vol. 34, No. 8, 663-67, doi: 10.1080/07408170208928903.

[9] Modiano, E.M. (1987). Derived demand and capacity planning under uncertainty, *Operations Research,* Vol. 35, No. 2, 185-197, doi: 10.1287/opre.35.2.185.

[10] Xu, W., Liu, L., Zhang, Q., Wang, X. (2017). A multi-object decision-making method for location model of manufacturing industry under uncertain environment, *Journal of Interdisciplinary Mathematics*, Vol. 20, No. 4, 1019-1028, doi: 10.1080/09720502.2017.1358879.

[11] Xu, W., Yu, Y., Zhang, Q. (2018). A multiobjective decision-making method of service element allocation of customer behaviour, *Discrete Dynamics in Nature and Society*, Vol. 2018, Article ID 3572094, 16 pages, doi: 10.1155/2018/3572094.

[12] Tang, M., Gong, D., Liu, S., Zhang, H. (2016), Applying multi-phase particle swarm optimization to solve bulk cargo port scheduling problem, *Advances in Production Engineering & Management*, Vol. 11, No. 4, 299-310, doi: 10.14743/apem2016.4.228.