Advances in Intelligent Systems Research, volume 165
International Conference on Modeling, Simulation, Optimization and Numerical Techniques (SMONT 2019)

Optimization of Seamless Steel Tube Order Planning Based on Capacity Balance

Sujian Li and Jinchao Yang
The School of Mechanical Engineering, the University of Science and Technology Beijing, 30 Xueyuan Road, Haidian District, Beijing 100083 P. R.China

Abstract--**The production process of seamless steel tube is divided into four production stages of preparation, perforation and hot rolling, cold drawing and finishing, and the order planning model is established by taking five-days as the unit of time. The mixed variable neighborhood improved genetic algorithm is designed to solve the model, which makes the order planning more effective to guide the production planning.**

Keywords--seamless steel tube; production balance; order planning; IGA-VNS

I. INTRODUCTION

At present, the market demand environment of iron and steel industry presents the characteristics of multi-variety and small batch, which is contrary to the large-scale production mode of enterprises [1]. In order to improve the competitiveness of iron and steel enterprises, it is necessary not only to meet the requirements of customers for product quality and delivery time, but also to reduce the energy consumption in the production process, reduce production costs, shorten the production cycle and ensure the balance of production capacity[2]. Order planning is the first problem to be solved by enterprises in order to achieve efficient management. The optimization results, as the basis for the subsequent production planning, are directly related to the overall effect of the enterprise production plan. Zhang Tao, Cheng Haigang [3] set up a mixed integer programming model to solve the order planning problem of the rolling mill. The goal of the model is to minimize the total delay period of the contract, and the penalty table of the delay period is introduced, but the additional cost is not taken into account when the contract is completed prematurely. Zhang Qiqi [4] [5] put forward the MTO-MTS mixed order planning management model, and proved that the MTO-MTS model is more suitable for the development trend of multi-variety and small-batch through experiments. Based on the above research, a mathematical model of order planning optimization is established for seamless steel tube manufacturing enterprises, which takes into account the production contract delivery time, unit capacity balance, production cycle and so on, and a hybrid variable neighborhood improved genetic algorithm is designed to solve it. The validity of the mathematical model and algorithm is verified by the actual data of a steel tube factory.

II. PROBLEM DESCRIPTION AND MODEL

A. Problem Description

The production contract is a production order that is determined according to the customer order information and the production process of the enterprise, that is, each production contract only corresponds to one kind of steel tube product and the corresponding production process parameters. The order planning is based on the production capacity of the production unit and the delivery date of the production contract, the overall production planning arrangement is carried out for each production contract, and the production date and completion date of each production contract in each production stage is determined.

1) Division of steel tube production stage: The division of steel tube production stage and production unit is the basis of order planning, which should be moderate according to the layout of steel tube production process equipment. According to the main process and equipment configuration of cold drawing seamless steel tube production, this paper divides it into four production stages: billet preparation, piercing and hot rolling, cold drawing and finishing, see figure 1. There are three production units in production stage 3 and three production units in production stage 4.

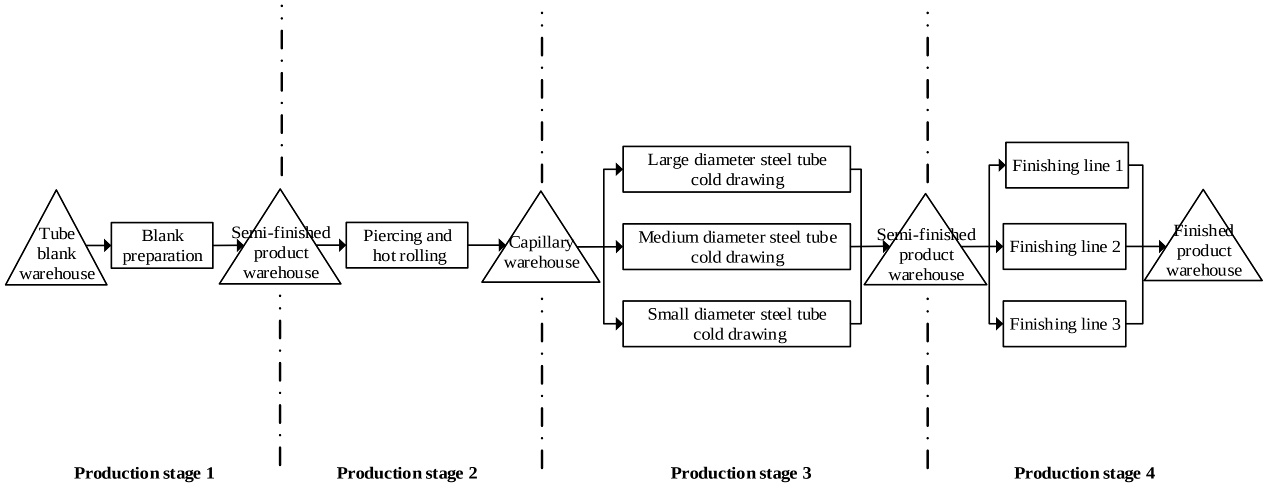


FIGURE I. DIVISION OF PRODUCTION STAGE

(2) Steel tube production logistics balance

a) Production logistics balance calculation cycle

Generally speaking, the logistics balance cycle of steel tube production includes two stages: rough balance calculation and detailed balance calculation. The calculation cycle of rough balance is generally consistent with the total production planning cycle of steel tube. In this paper, the month is taken as the planning forecast cycle. The calculation period of detailed balance is generally the same as that of steel tube production plan. The paper takes 5-days as the unit to calculate the detailed balance.

b) Material flow in each stage of production

In the actual production of steel tube, there must be a certain material loss in each production stage. For example, the waste produced by the operations such as cutting the end in the rolling process and the head in the cold drawing process will gradually reduce the material flow in each stage of production. That is, yield of good-tube.

c) Production time of each stage of production

First, production managers need to determine the standard processing time of each production stage and production unit according to the performance of production equipment, the inventory capacity of production process and the statistics of production data. Then, according to the delivery date of the production contract, the production date and the completion date of each production contract in each production stage are calculated by the way of reverse logistics sequence, that is, the whole production plan of each production contract is determined.

B. Model Building

1) Assumed condition

In this paper, according to the steel tube production technology, the problem is reasonably simplified.

a) It is considered that the WIP (or finished product) after each stage of production is qualified, but each stage of production will produce a certain loss, that is, only consider the problem of the yield of good-tube.

b) The processing capacity of each production unit in a certain period of time is known.

c) The production contract shall be divided so that the capacity requirement of the production contract on each production unit shall not be greater than the maximum capacity of the time period of the production unit.

d) Any production stage of a production contract shall not cross the time period.

2) Symbol definition

$I = \{1,2,\cdots,i,\cdots,N\}$—Contract set

$L = \{1,2,\cdots,j,\cdots,J',\cdots,J\}$—Production stage set

$T = \{1,2,\cdots,t,\cdots,T\}$—5-days set

$M = \{1,2,\cdots,k,\cdots,M_j\}$ —Production units in the production stage j

J—Number of production stages of the finished product contract

J'—Number of production stages of the semi-finished product contract

$[u_i,\ v_i]$—Delivery window of the contract i

α—Penalty coefficient for early delivery

β—Penalty coefficient for delay delivery

χ—Unbalance penalty coefficient of production unit load

γ – Penalty coefficient of inventory cost in production process

t_{ij}—Production stage j processing time of contract i

w_i—Requirement of contract i

e_{ij}—Requirement of capacity in production stage j of contract i

$\overline{E_{jt}}$ —Total production capacity of production stage j within 5-days

λ_j—Inventory cost of unit WIP (finished product)

I_{jt}—Inventory level of WIP and finished products at 5-days t in production stage i

I_{j0}—Initial inventory level in production stage j

I_j^{max}—Maximum inventory level in production stage j

$$x_{ijkt} = \begin{cases} 1 & \text{if contract } i \text{ is processed on the unit } k \text{ of the stage } j \text{ in the period } t \\ 0 & \text{else} \end{cases}$$

$$y_i = \begin{cases} 1 & \text{if contract } i \text{ is a semifinished product contract} \\ 0 & \text{else} \end{cases}$$

3) Mathematical model

a） Objective function

$$\min f_1 = \sum_{i=1}^{N}\left\{\alpha w_i \max[\sum_{t=1}^{T}\sum_{k=1}^{M_J}(u_i - t_{ij})x_{iJ_ikt}, 0]\right\} + \sum_{i=1}^{N}\{\beta w_i \max[\sum_{t=1}^{T}\sum_{k=1}^{M_J}(t_{iJ} - v_i)x_{iJ_ikt}, 0]\} \quad (1)$$

$$\min f_2 = \theta \sum_{j=1}^{J}\sum_{k=1}^{M_J}[\frac{1}{T-1}\sum_{t=1}^{T}(\frac{1}{M_j}\sum_{i=1}^{N}\sum_{k=1}^{M_J} e_{ij}x_{ijkt} - \sum_{i=1}^{N} e_{ij}x_{ijkt})^2]^{1/2} \quad (2)$$

$$\min f_3 = \gamma \sum_{j=1}^{J}\sum_{t=1}^{T}\lambda_j I_{jt} \quad (3)$$

b） Constraint condition

$$\sum_{t=1}^{T}\sum_{k=1}^{M_j} x_{ijkt} \le 1, \forall i, j, k, t \quad (4)$$

$$(1-10\%)\times \overline{E_{jt}} \le \sum_{i=1}^{N}\sum_{k=1}^{M_J} x_{ijkt}e_{ij} \le (1+10\%) \times \overline{E_{jt}}, \forall i, j, k, t \quad (5)$$

$$I_{j0} + \sum_{i=1}^{N}(\sum_{t=1}^{T}\sum_{k=1}^{M_j} e_{ij}\cdot x_{ijkt} - \sum_{t=1}^{T}\sum_{k=1}^{M_j} e_{i(j+1)}\cdot x_{i(j+1)kt}) \le I_j^{\max}, \forall i, j, k, t \qquad J = 1,2..., J-1 \quad (6)$$

$$y_i \sum_{t=1}^{T}\sum_{k=1}^{M_j} x_{ijkt} = (1-y_i)\sum_{t=1}^{T}\sum_{k=1}^{M_j} x_{i(j+1)kt}, \quad j = 1,2,\dots J-1 \quad (7)$$

$$(1-y_i)\sum_{t=1}^{T}\sum_{k=1}^{M_j} x_{ijkt} = (1-y_i)\times \sum_{t=1}^{T}\sum_{k=1}^{M_j} x_{i(j+1)kt}, J = 1,2..., J-1 \quad (8)$$

$$y_i t_{i(j-1)} \le y_i t_{ij}, \forall i, j = 2,\dots, J-1 \quad (9)$$

$$(1-y_i)t_{i(j-1)} \le (1-y_i)y_i t_{ij}, \forall i, j = 2,\cdots, J-1 \quad (10)$$

$$y_i \sum_{t=1}^{T}\sum_{k=1}^{M_j} x_{ijkt} = 0, \forall i, j = J'+1, \cdots J \quad (11)$$

$$t_{ij} = \left\{ t \,|\, \sum_{t=1}^{T}\sum_{k=1}^{M_j} x_{ijkt} = 1, t = 1,2,\cdots, T \right\}, \forall i, j, k, t \quad (12)$$

$$x_{ijkt} \in \{0,1\}, \forall i, j, k, t \quad (13)$$

$$y_i \in \{0,1\}, \forall i \quad (14)$$

Among them, the objective function (1) represents the penalty of early or delay delivery is the least; the objective function (2) represents the productivity balance at each production stage in each time period. The objective function (3) is to minimize the cost of in-process inventory; Constraint (4) represents that there is only one production unit for contract processing at each production stage; Constraint (5) represents the capacity constraint of each production stage; Constraint (6) represents that inventory at each production stage does not exceed the maximum inventory level; Constraint (7) and (8) represent the semi-finished and finished product contract once is produced, it is guaranteed to pass through its subsequent production stage; Constraint (9) and (10) represents the starting time of the production stage of the semi-finished and finished product contract is not earlier than the completion time of the previous production stage; Constraint (11) represents that the semi-finished product contract only needs to complete the pre-production stage; Expression (12) represents the production time of contract i in the production stage j; Expression (13) and (14) represents the range of values of decision variablex_{ijkt} and y_i.

III. SOLVING ALGORITHM

Through the analysis of the mathematical model, it can be seen that the order planning model is a nonlinear 0-1 integer programming model, which belongs to the NP-hard problem, so it is difficult to find the optimal solution of the problem by the optimization algorithm. Therefore, considering the characteristics of order planning, this paper proposes a hierarchical and piecewise integer coding method to encode chromosomes, and designs a hybrid variable neighborhood improved genetic algorithm based on heuristic repair strategy to solve the problem.

A. Algorithm Flow

According to the above description, the overall flowchart of the GA-VNS algorithm designed in this paper is shown in figure 2:

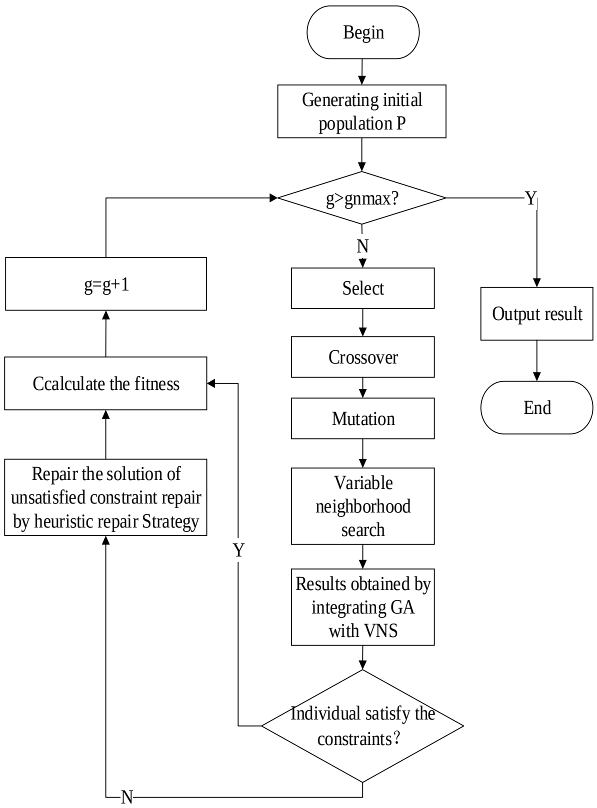


FIGURE II. IGA-VNS ALGORITHM FLOW CHART

The steps of the GA-VNS algorithm are as follows:

Step 1: Initializes the parameters in the order planning model. Initialize the planning outlook period T, population size $Popsize$, number of iterations $genmax$, crossover probability P_c, and mutation probability P_m.

Step 2: Randomly generate the initial population. Randomly generate $Popsize$ chromosomes with satisfying constraints, and let the number of iterations $g = 1$.

Step 3: Determine whether or not to satisfy the algorithm termination condition($g > gnmax$), if satisfied, go to step 10, else go to step 4.

Step 4: Selection of $Popsize$ chromosomes for crossover operation by roulette.

Step 5: According to the crossover probability P_c, determine whether the chromosome need the crossover operation.

Step 6: According to the crossover probability P_m, determine whether the chromosome need the mutation operation.

Step 7: Heuristic repair to the chromosomes that don't meet the constraints in the population.

Step 8: Calculate the fitness of the individual in the new population and record the optimal individual X in the contemporary population.

Step 9: Variable neighborhood search for the best individual X in the Contemporary population, and get a new contemporary best individual BX . Replace X with BX and integrate IT into contemporary population. And continue with step 3.

Step 10: The algorithm terminates and outputs the optimal solution.

B. Experimental Results

According to the actual problem set the experimental parameters as follows: The forecast period of the plan is one month($T = 6$); In the objective function, the penalty coefficient of early/delayed delivery $\alpha = 3$,$\beta = 5$;the penalty coefficient of unbalance of production capacity $\theta = 1$, the penalty coefficient of inventory cost $\gamma = 1$, the population size $Popsize = 30$, Iteration number $gen = 500$, the maximum crossover probability $P_{c1} = 0.9$, the minimum crossover probability $P_{c2} = 0.6$, the maximum probability of variation $P_{m1} = 0.1$, the minimum probability of variation $P_{m2} = 0.001$. The production capacity of the production units during the plan outlook period is shown in table 1:

The part of the order contract information and the partial order planning results with operating the algorithm are shown in table 2:

TABLE I. PRODUCTION CAPACITY OF PRODUCTION UNITS (T)

Production stage	Production unit	1A	1B	2A	2B	3A	3B
Production stage 1	-	583	597	589	585	564	552
Production stage 2	-	554	548	575	564	562	557
Production stage 3	1	128	120	127	129	146	137
	2	120	123	136	117	134	149
	3	121	132	124	120	137	140
Production stage 4	1	122	119	114	127	128	115
	2	116	116	123	121	122	118
	3	113	125	117	118	119	124

TABLE II. RESULTS OF ORDER PLANNING

contract ordinal	material quality	specification /mm	Order date	Delivery date	Order quantity/t	Production stage 1 production time	Production stage 2 production time	Production stage 3 production time	Production stage 4 production time
1	Q460	77.4*3.5*6000	2018.6.5	[2B,3B]	32	3B	3B	-	-
2	Q550	93.2*4.0*12000	2018.6.18	[1B,2A]	43	1A	2A	-	-
3	Q460	65.0*3.5*4000	2018.6.9	[1A,1B]	42	1A	1A	-	-
4	Q390	77.4*3.5*12000	2018.6.22	[1B,2B]	32	2A	2B	-	-
5	Q460	93.2*4.0*6000	2018.6.12	[1A,2A]	33	1A	1B	-	-
…	…	…	…	….		…	…	…	…
97	Q620	77.4*2.75*6000	2018.6.16	[2B,3A]	35	3A	3A	3A	3B
98	Q390	52.0*3.5*6000	2018.6.3	[1B,2B]	31	2A	2A	2B	2B
99	Q550	77.4*2.75*6000	2018.6.23	[3A,3B]	42	3A	3A	3B	3B
100	Q460	52.0*3.5*6000	2018.6.7	[1A,2B]	40	1B	2A	2A	2A

In order to verify whether the order planning can ensure that the production process reaches the level of logistics balance, according to the results of the order planning, the detailed analysis are as follows:

Figure 3 shows the rough capacity balance analysis chart in monthly units. Due to the existence of the semi-finished product contract, the first two stages of production have a slightly inadequate production load, but it still meets the constraint (5), that is, within the acceptable range, the overall matching condition is considered to be relatively balanced.

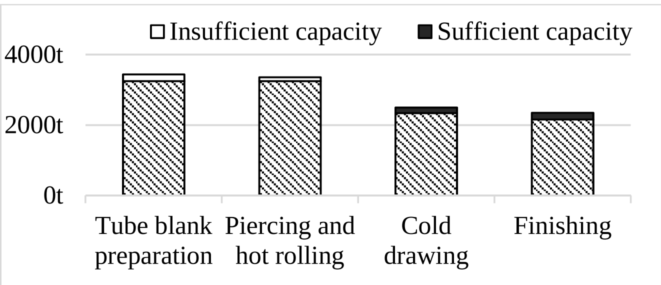


FIGURE III. PRODUCTION LOGISTICS BALANCE ANALYSIS CHART (MONTH)

In actual production, for the problem of unbalanced production load, enterprises usually use overtime or skilled workers to improve the available production capacity to solve the problem caused by insufficient production load. The problem of excess production load is usually solved by unit overhaul or insertion of new production contra

Figs.4~9 show the logistics balance in each production stage with 5-days as the unit of time. From the figures, it can be seen that the load of each production stage is basically in equilibrium state in each 5-days unit, and the unbalanced capacity in the rough capacity balance distributive into each 5-days unit, which weakens the effect of the imbalance of production capacity again. It can be seen from figure 8 and figure 9 that the load state of each unit in the production stage is balanced.

From the overall point of view, the order planning drawn up according to the example can basically realize the load balance of production units in each production stage under the precondition of ensuring the contract delivery time, and verify the validity of the mathematical model and the algorithm.

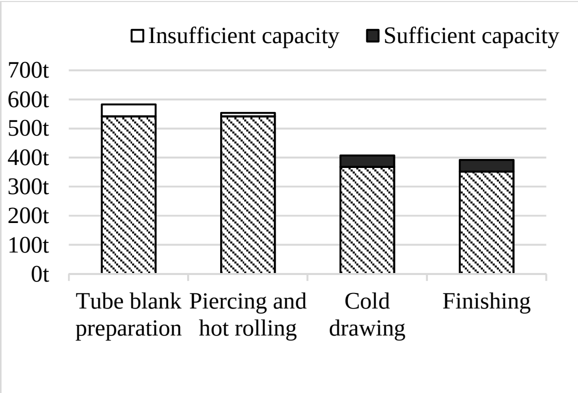


FIGURE IV. LOGISTICS BALANCE ANALYSIS CHART (1A)

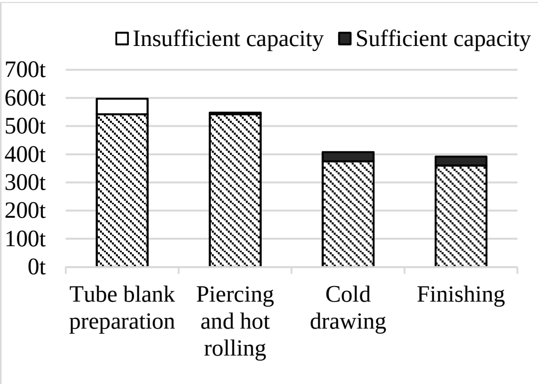


FIGURE V. LOGISTICS BALANCE ANALYSIS CHART (1B)

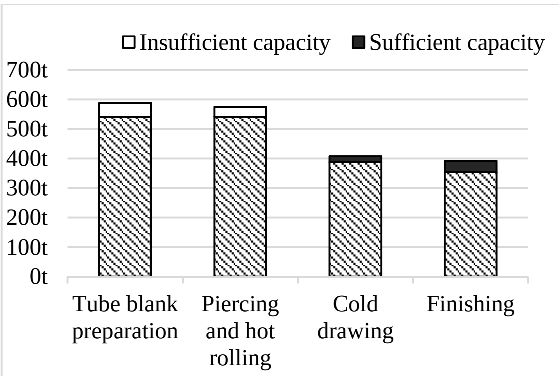


FIGURE VI. LOGISTICS BALANCE ANALYSIS CHART (2A)

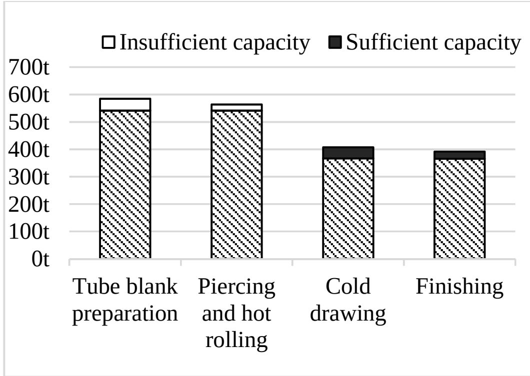


FIGURE VII. LOGISTICS BALANCE ANALYSIS CHART (2B)

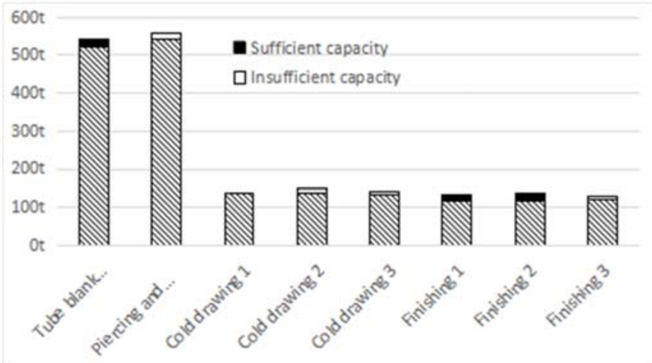
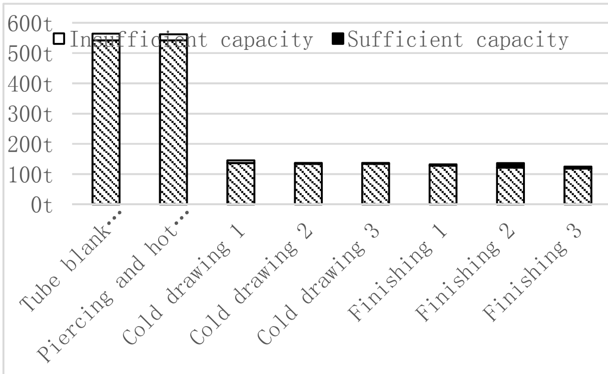


FIGURE VIII. LOGISTICS BALANCE ANALYSIS CHART (3A)



IX. LOGISTICS BALANCE ANALYSIS CHART (3B)

IV. CONCLUSION

According to the characteristics of cold drawing seamless steel tube, the production process is simplified and divided into four production stages: tube blank preparation piercing and hot rolling cold drawing finishing and then according this to draw up the follow-up order planning. A nonlinear integer programming mathematical model is established on the basis of considering factors such as contract early/delay delivery cost, production unit load balance cost and production process inventory cost. A hybrid variable neighborhood improved genetic algorithm is designed, and the three-layer chromosome coding structure is designed to solve the model according to the characteristics of the problem. The experimental results show the validity of the order planning model and the feasibility of the algorithm.

REFERENCES

[1] Lu Y, Wang L N, Chen H Z, et al. Combination optimization of order planning for iron and steel manufacturing process [J]. Journal of Southeast University (Natural Science Edition) 2012, 42(S1):168-172.

[2] Hu Z Y, Chen W W, Wang D W, et al. Combined optimization of product matching and production planning considering batch factor [J]. Journal of Systems engineering-theory methodology applications, 2004, 13(3): 199-202

[3] Zhang T, Cheng H G, Zhang Y J, et al. Order planning method of steel plant based on MTO-MTS [J]. System Engineering Theory and Practice, 2008, 11(11): 85-93.

[4] Zhang T, Chen Q, et al. Study on MTO-MTS mixed order planning management model in iron and steel enterprises [J]. Journal of Management Sciences in China 2013, 16 (06): 35-45.

[5] Zhang Q Q, Zhang T, Liu P. Modeling and optimization strategy of order planning in iron and steel enterprises based on MTO-MTS production model [J]. Journal of Industrial Engineering and Engineering Management, 2017 / 31 (03): 100-107