Optimization of Multi-stage Production Operations Based on Genetic Algorithm

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***Abstract*—This paper introduce a methodology, which is used to solve a multi-stage production planning problem having multiple objectives, which are conflicting in nature. The production process consists of multiple stages having one or more machines in each stage. Every processing stage produces work-in-process, semi-finished and finished items as an output, some becomes an input to the subsequent stage either fully or partially depending on the cycle times of the machines, the rest exports as products. Events of machine breakdowns and imbalances in input–output relations in one or more stages may affect both work-in-process (WIP) and final production targets. Here develop a multi stage production operation model based on genetic algorithm. Our analytic illustrate that multi stage is more complex than single stage production operation. The attributes of the cost of multi stage production include the production cost, the warehousing cost, the transportation cost, the contract penalty cost and the productivity cost of idle. The numerical results show that it can reduce overall cost, improve scheduling rationality and enhance the efficiency of production scheduling. The finding are of far-reaching importance in view of the multi stage production operation and guide the enterprise to find a quick and science way to Increase benefit.**

Keywords-multi stage; production operation schedule; genetic algorithm; cost

I. INTRODUCTION

To date, many multi stage production operation models have been established to study various complex enterprise production phenomena. The first simple production operation model was developed independently by Johnson[1] , the model can solve a question about that each of a collection of items are to be produced on two or three machines (or stages) in a restricted case.so the model was later extended to study the m machine with same type processed n spare parts[2] .However, the Johnson model and its extension cannot reproduce under the shutdown constraints to minimize approximately the sum of the holding cost and the reduction cost in shutdown times[3]].Oliver Holthausshown that for minimizing maximum flowtime, and for minimizing variance of flowtime[4]], one new rule (AT−RPT) is superior to all other rules when the models taking into account breaking of machine. To conquer unexpected machine breakdowns, A. Susanne, S. Gunterpresent an on line algorithm that constructs schedules[5] .Mahima Guptaintroduces a methodology to solve a multi-stage production planning problem having multiple objectives[6] .

Besides the models, there are many algorithm need us toresearch, M. Feldmann, D. Biskupdevelop a single-machine scheduling model for minimizing earliness and tardiness penalties by meta-heuristic approaches[7] ; M.K.ksalan,R Tadeidevelop for the single-machine total weighted tardiness scheduling problem an enhanced dynasearch neighborhood obtained by the generalized pairwise interchange (GPI) operators[8] .ChenGuang Liu develop an algorithm based on the non-dominated sorting genetic algorithm II[9] .

Production operation planning adapt to social productive forces. Y. Mikhail to find an optimal batch sequence and resource values based on linear programming formulations, with about MRP□[10] . Ma Jianhuimake model considered the processing cost of the machine and Early / delay penalty[11] , using sequential search algorithm, in the time of ERP.Two machines scheduling problemwas handled by A.A.Gladky[12] .A. Kimmspresents a genetic algorithm for the multi-level[13] , multi-machine proportional lot sizing and scheduling of PLSP model. Anwarmf, NagirIntegratedimprove an algorithm for just-in-time production of complex assemblies with finite set-up[14] . RuhulSarker[15] developeda DLSP model. W.Ipproposed a production scheduling problem for early delayed delivery based on genetic algorithm[16] . We develop a Markov Decision Process model for a two-product hybrid system to determine when to manufacture MTS and MTO products[17] .

In order to be able to research multi constraints problem in multi stage logistics system,Lawlesaresearch constraints in the production process[18] . In Jin's paper a physical model of the variables in the expression phase is presented[19] . An integrated optimization model of production operation plan for scheduling constraints to solve the problem of multi product batch production[20] . Lin Huiping present a hierarchical scheduling model based on Workflow Technology, and established an integration algorithm[21] .A multi period optimization model considering market forecast is established[22] .Sasadhar Bera attempts to develop an efficient and simplified solution approach for a typical serial multistage MRO problem[23] .

Our work has three new contributions Firstly,The complex production process of multi product specification, which is processed through multi production stage in different plant, is divided into four categories; Secondly, explicit formulae are given in our model to consider a wider range of cost factor including the production costs, warehousing costs, transportation costs, contract penalty costs and productivity costs of idle, and use genetic algorithms to solve the problem, whereas the single production stage explicit formulae for the production costs; thirdly many interesting results are established to show the effects and flexibility of this new model, in the complex manufacturing conditions.The rest of this paper is organized as follows. The classified management of multi category products is proposed in Section 2; the new model is developed in Section 3 a case study is used to study the effects of the model in Section 4; some conclusions are given in Section 5.

II. CLASSFICATION MANAGEMENT OF MULTI CATEGORY PRODUCTS

The company owns 1,500 kinds of export products, for each production of each day to make an accurate operation plan not only in technically but also in practical significance is not feasible. By related theory research, the product classification method have a strong research value.Combined with the specific circumstances of the production enterprises, the company found that although there are a large number of product specifications, but in the actual production process, the similar outer diameter specifications of the steel pipe can be classified as a class, for further analysis, try to divide specification into four categories:

1) Φ20.5mm-Φ47.5mm;
2) Φ47.5mm-Φ60.3mm;
3) C: Φ75.0mm-Φ114.0mm;
4) D: Φ140.0mm-Φ219.0mm;

A. Classification based on the following points

The production process has similarities, with the TableI, we can be found that, these four specification range are production specifications range of four pipe factory, in the actual production process, regardless of pipe, galvanized, steel, the manufacturing process of four specifications is very similar.

TABLE I. PRODUCT RANGE LIST OF EACH PRODUCTION STAGE

Pipe(mm)		**Galvanized(mm)**		**Steel(mm)**	
XingYuDa	Φ20.0-Φ47.5	ZhenXingYiChang	Φ75.0-Φ114.0	Bituo	Φ20.0-Φ219.0
LiDa	Φ47.5-Φ60.3	ZhenXingErChang	Φ75.0-Φ219.0		
HuaAo	Φ75.0-Φ114.0	LiTuo	Φ20.0-Φ114		
BinTaiShun	Φ140.0-Φ219.0				

B. The cost of storage can be unity

Four pipe production plant product four production of different specifications range, three galvanizing production plants produce combination production of four specifications rang, only one production plant produce steel, after each plant produce their finished products, finished products are put into their own warehouse, due to the production plant and the finished products are independent, storage costs in the production and inventory process can be used as total warehouse cost of the production plant;

C. Transport costs can be unity

In the pipe to galvanized, galvanized to steel Plastic allocation process, all the schedule is library to the workshop, the main affecting factors of transport costs is transport distance and weight, in construction molding process, the weight is unknown, due to the dispersion of the plant, the factory to the next link is different in the transport distance, but different specifications of unified plant can be considered as a whole;

D. Contract information can be uniformity

Demand production and delivery of export contracts have the possibility to be combined, and export contracts of the steel companies have the same punishment method, according to the number of exceeding days * the total amount of the contract * 5%, the If there is a categories production contract with three different specifications as the following TableII:

TABLE II. VIRTUAL CONTRACT

Specification	**Demand**	**DeliveryTime**
A1	T1	Q1
A2	T2	Q2
A3	T3	Q3

In the process of make operation planning, managers can merger the above-mentioned contract as a demand of (T1 + T2 + T3), by experience, delivery as Q4, where Q4 requires management baseon experience and specific information of contracts to determine;

E. According to the sales data of manufacturer

Three categories steel pipe sales priceessential stable, except a handful of special production, all of above prove the feasibility of classification method.

III. A MODEL AND GENETIC ALGORITHM FOR MUTI-STAGE PRODUCTION OPERATIONS

The main aim of this paper is to minimize the total cost of production, the total production cost include not only the cost of production, warehousing cost, transportation cost, but also include the penalty cost and idle productive fees, it can be regarded as multi-objective mathematical model.

Multi-criteria objective function can link multi-stage, multi-link, and fully and accurately described the complex production costs. Compared with only one single count, the cost is more convincing, more realistic.

A. Production cost

In the production process, depreciation of equipment and workers' production wages, which is caused by inevitable, and the costs is closely related to the production yield, the existing production cost equation can be written as follows:

$$f_{sc} = \sum_{m=1}^{M}\sum_{t=1}^{T} r_m \times x_{mt} \tag{1}$$

The notations used in the mathematical model are given, where f_{sc} is the total production cost, M and T is constant respectively represents the total production stage and work time, r_m stands the production work coefficient at stage m, x_{mt} describes the amount of production for stage m on tth day.

B. Storage costs

When the steel production is completed, the production team will pack pipe, pulled into the finished products warehouse, and then inventory costs appear, combined with the theory of inventory management and actual situation of the plant, so we for simplicity define storage cost model and some function as follows：

$$f_{ck} = \sum_{m_1=1}^{M_1}\sum_{t=1}^{T} c_{m_1} \times (k_{m_1 t} + k_{m_1 tr} - k_{m_1 tc}) \tag{2}$$

$$k_{m_1 t} = k_{m_1 0} + \sum_{t=1}^{T} k_{m_1 tr} - \sum_{t=1}^{T} k_{m_1 tc} \tag{3}$$

$$k_{m_1 tr} = x_{m_1 t} \tag{4}$$

$$k_{m_1 tc} = x_{m_1' t} \tag{5}$$

The equation (2) illustration the total cost of the company's warehouse, where c_{m_1} represents the daily inventory cost coefficientfor warehouse m1 of per day, $k_{m_1 t}$ is a function, which can reflect the start inventoryof day t in warehouse m1(here $k_{m_1 0}$ is current storage quantity of warehouse m1, $k_{m_1 tr}$ shows the input storage quantity of day tof m1 warehouse, $k_{m_1 tc}$ indicates the output storage quantity for tth day in warehouse m), $x_{m_1' t}$ is the total requirement of subsequent stage.

C. Transportation costs

The main factors affecting the transport costs is the distance and transport weight, based on the specification classification, transport route between the plant represented by the following Fig.1:

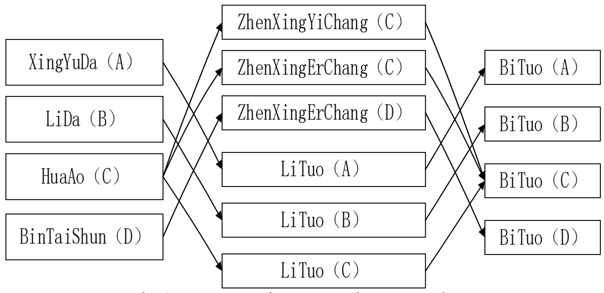

Fig.1Transportation routes between plants

By the theory of mathematical model of transportation costs, here the function is defined as follows:

$$f_{ys} = \sum_{m_2=1}^{M_2}\sum_{t=1}^{T} t_{m_2} \times d_{m_2 t} \tag{6}$$

$$d_{m_2 t} = x_{m_2' t} \tag{7}$$

Where f_{ys} introduces the total transport cost within the days of production operation planning, tm2 is the transportation cost coefficient for plant m2, without relation to the product category, as shown above, Class C and Class D product transport from ZhenXingErChang toBiTuo, although the product category is different, but for the same transport distance, the size of tm2 should also be the same, it does not rule out changes in special circumstances. $d_{m_2 t}$ represents the number of output from production plant m2 at day t, $x_{m_2' t}$ is the total requirement of subsequent stage, which describes the amount of transportation.

D. Contract penalty cost

When the export contract can't be completed on time, corporate customers will be paid a fee, compensation is calculated as follows: 5% of the total contract amount * delayed days, thus we can obtain an expression of the cost of the model, which is shown in equation (8) below:

$$f_{cf} = \sum_{m_3=1}^{M_3} \max\left\{\left(h_{m_3 l} - k_{m_3 0}\right)/s_{m_3 l} - DT_{m_3}, 0\right\} \times 5\% \times h_{m_3 j} \tag{8}$$

$$s_{m_3 l} = \sum_{t=1}^{T} x_{m_3 t} \tag{9}$$

Where f_{cf} reflects the total cost of infringing contracts (here $h_{m_3 l}$ is the total production of contract m3, $k_{m_3 0}$ introduce the current inventory of production m3, $s_{m_3 l}$ represent the finished production during the planning of contract m3, DT_{m_3} donates the deadline of contract category m3, $h_{m_3 j}$ is the total amount money of contract category m3, $x_{m_3 t}$ shows the production of contract m in day t, and the sum of $x_{m_3 t}$ is $s_{m_3 l}$.

E. Productivity idle penalty cost

If we only consider the above four factors, you will find a phenomenon, when production capacity is far less than the amount of the contract value, the best operational plan to be made with very small daily workload, which is seriously inconsistent with the reality production status, idle Productivity is a waste to the company. So we simplicity propose a model as follows:

$$f_{kx} = \sum_{m=1}^{M}\sum_{t=1}^{T} l_m \times (SD_m - x_{mt}) \tag{10}$$

Where f_{kx} donates the sum of productivity free penalty cost, l_m is the productivity idle penalty coefficient at stage m, production capacity value SD_m for the plant is different from different category, x_{mt} is the production number of stage m.

F. Muti-stage Production Operations Model and Genetic Algorithms

In summary, the operation plan model of this project is a complex multi-objective function, specifically as follows:

$$\min f = f_{sc} + f_{ck} + f_{ys} + f_{cf} + f_{kx} \tag{11}$$

Obtain the objective function and constraints are as follows:

$$x_{mn} \geq 0; m = 1,2,3...,M; n = 1,2,3...,N \tag{12}$$

$$x_{mn} \leq SD_m; m = 1,2,3...,M; n = 1,2,3...,N \tag{13}$$

$$k_{mn} + k_{mnr} - k_{mnc} \geq 0; m = 1,2,3...,M; n = 1,2,3...,N \tag{14}$$

$$k_{mn} = k_{m0} + \sum_{t=1}^{T} k_{mnr} - \sum_{t=1}^{T} k_{mnc} \tag{15}$$

$$k_{mnr} = x_{mn} \tag{16}$$

$$k_{mnc} = x_{m't} \tag{17}$$

Constraint is (12) (13) (14), and (12) shows that the results for each of the unknowns must be greater than zero, (13) shows that each stage of the production plan must be less than the value of the production capacity of the production phase, (14) represents each warehouse inventory is not less than zero, every day, in other words, the quantity of getting raw materials from workshop must be less than or equal inventories. (15) (16) (17) is the supplement of (14).

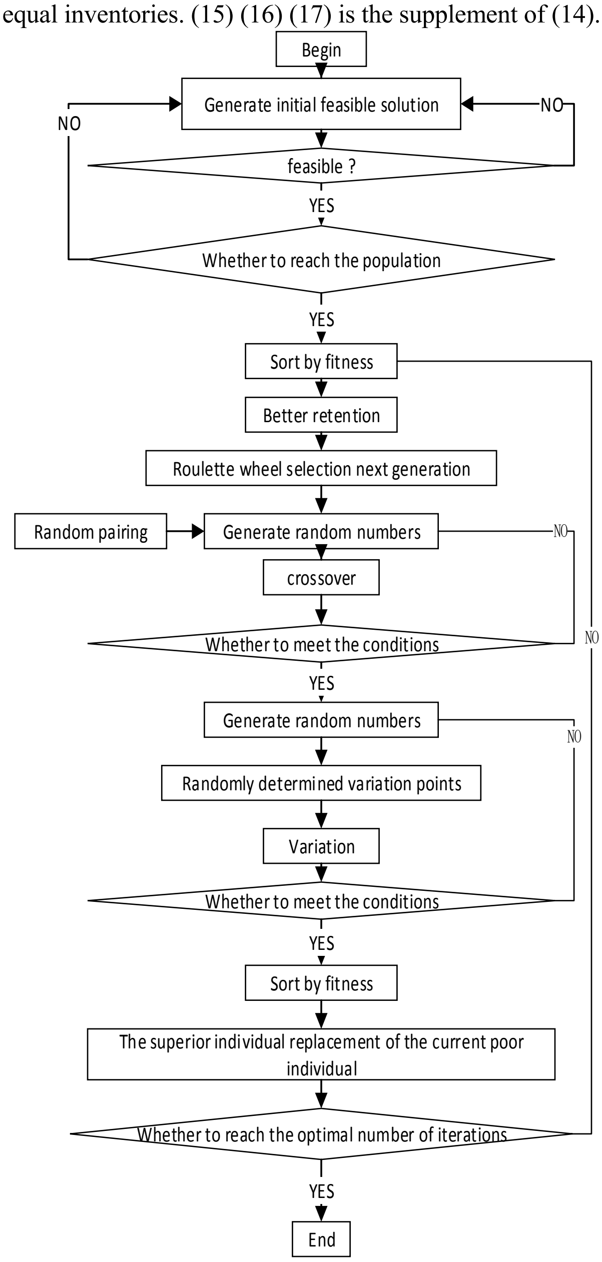

Fig.2Genetic algorithm flow chart

Based on the traditional genetic algorithm do some improvements, in this paper, by considering the characteristics of research problem, to solve our multi-

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objective optimization problem. The specific steps are as follows Fig. 2:

In order to save operating time, improve processing efficiency, extend encode real coding is the best way. In the model, xmt is set up as an unknown parameter, and the number is 16, in other words, there are 16 stage. So the length of each chromosome is 16*t, which is in the order of 16 stages, by time. Population size is 1.5 times the length, the value of genes is indexed by [0, N/Y] (here N is the capacity of production, Y is the number of the variables in this conditions).Fitness function is Fk=1/fk ,and indexed by k={1,2,3…k}.Genetic operators can follow the specific steps, firstly, choose the next generation of chromosomes by Roulette, secondly, select the same gene as the two chromosomes swap, thirdly, Randomly generating new genes in variable region at the gene position in need. Number of iterations to reach.

IV. CASE STUDY

Here to discuss combination contract by analyzing the feasibility of an instance. Assume the following information shown in Fig.3, which can be obtained by integration contract as shown Table III:

TABLE III. INTEGRATION CONTRACT INFORMATION

Name	Type	Weight（t）	Money (yuan)	T (day）
pipe	C	2006.9	8000000	11
Galvanization	A	5505.3	27500000	11
Galvanization	B	1795.59	9000000	11
Galvanization	C	7007.2	35000000	11
Galvanization	D	3009.0	15000000	11
steel	A	200.1	1200000	11
steel	B	298.61	1800000	11
steel	C	301.05	1800000	11
steel	D	300.39	1800000	11

name	size	number	weight	money	delivery date
pipe	88.0X 2.75X 6.0	57855	2006.9	8000000	2015-06-30
galvanization	20.0X 2.0 X 5.3	1170000	5505.3	27500000	2015-06-30
galvanization	88.0X 2.75X 6.0	202000	7007.2	35000000	2015-06-30
galvanization	159.0X 4.0 X 6.0	32800	3009.0	15000000	2015-06-30
steel	20.5X 2.0 X 6.0	36550	200.10	1200000	2015-06-30
steel	73.0X 2.5 X 6.0	11450	298.61	1800000	2015-06-30
steel	159.0X 4.5 X 6.0	2920	300.39	1800000	2015-06-30
galvanization	60.3X 2.2 X 6.0	50000	945.66	4725000	2015-06-30
galvanization	73.0X 2.4 X 6.0	33900	849.93	4275000	2015-06-30
steel	75.0X 2.0 X 6.0	6950	150.14	900000	2015-06-30
steel	88.0X 2.75X 6.0	4350	150.89	900000	2015-06-30

Fig.3Contract Information

The production capacity of the case with reference to the long-term accumulation of production data, weusethe productions capacity information interface to get the following results, as Fig.4shows:

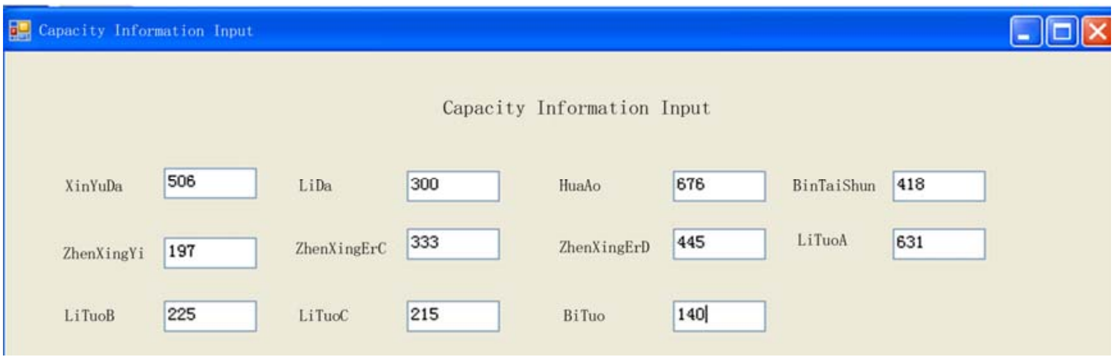

Fig.4 Cases one genetic evolution diagram

The parameter settings for each factor, such as: the production work coefficient, inventory cost coefficient, transportation cost coefficient, productivity idle penalty coefficient, is based on the business experience and data. Optimization of results, solution, and Contract completion status. This case is three days for the operating period, and the solution is obtained as follows:

Fig.5 Cases one genetic evolution diagram

Data	Xing YuDa	LiDa	HuaAo	BinTai Shun	ZhenXing YiChang	ZhenXing YiChangC	ZhenXing YiChangD	LiTuoA	LiTuoB	LiTuoC	BiTuoC ZhenXing YiChang	BiTuoC ZhenXing ErChang	BiTuoD	BiTuoA	BiTuoB	BiTuoC YuanLi Tuo
2015-12-1	449	300	655	413	163	223	410	331	223	186	91	1	13	12	9	13
2015-12-2	448	297	647	417	164	319	406	410	225	171	24	22	16	16	20	42
2015-12-3	449	300	647	418	157	324	439	607	225	214	91	4	6	4	18	17

Fig.6Case two solution

As it can be seen from Fig.5, adaptation of this model has been basically convergence stable, minimum production cost is 493,974 yuan. As it can be seen from Fig.6, the company's production capacity can be fully utilized, which illustrates that the model is reasonable, because there is no production capacity of a large number of gaps and the production of large fluctuations, the feasibility of this model is proved.

Encase to make sure whether or not the model and algorithm is flexible and effective, a new experiment is made with the phenomenon of that the production equipment need to be maintained in HuaAo welded pipe factory. The optimization results, equipment utilization ratio and contract status are as it can be seen from Fig.7 and Fig.8.

Fig.7 Cases two genetic evolution diagram

Data	Xing YuDa	LiDa	HuaAo	BinTai Shun	ZhenXing YiChang	ZhenXing YiChangC	ZhenXing YiChangD	LiTuoA	LiTuoB	LiTuoC	BiTuoC ZhenXing YiChang	BiTuoC ZhenXing ErChang	BiTuoD	BiTuoA	BiTuoB	BiTuoC YuanLi Tuo
2015-12-1	479	298	449	418	127	67	429	448	225	213	82	0	4	19	25	10
2015-12-2	496	296	447	418	128	66	386	448	222	165	28	60	8	13	15	16
2015-12-3	448	300	446	415	195	181	441	471	224	206	2	20	22	81	5	10

Fig.8 Case two solution

As it can be seen from Fig.7, adaptation of this model has been basically convergence stable, minimum production cost is 512,120 yuan, whose production costs is much higher than case one. The main reason for the decrease of production is the change of production capacity. All in all, the contract can't be finished fluently, meanwhile create tons of production costs.Fig.8shows that, the company's production amount is influenced, especially there is a zero number in some plant.

HuaAo steel pipe factory production capacity is declining, not only enable HuaAo production planning decline, but also enable the operation plan of the whole production system fluctuations, especially Huaao production of class C and products closely related plating tube class C operation plan and steel pipe class C operation plan has bigger wave motion ,but in the normal range. So it proved the flexibility of the model.

All of above, we can make sure the model is system and flexible. even in some extreme condition, at the same time, there is a closely relationship with production operation planning of the whole production system.

TABLE IV. CONTRAST RESULT CHART

Production	First day		Second day		Third day	
	Case1	Case2	Case1	Case2	Case1	Case2
XingYuDa	449	479	448	498	449	448
LiDa	300	298	297	296	300	300
HuaAo	655	449	647	447	617	446
BinTaiShun	413	418	417	418	418	415
ZhenXingYiChang	163	127	164	128	157	195
ZhenXingErChangC	223	67	319	66	321	181
ZhenXingErChangD	410	429	406	386	439	441
LiTuoA	331	448	410	448	607	471
LiTuoB	223	225	225	222	225	224
LiTuoC	186	213	171	165	214	206
BiTuoCZhenXingYiChang	91	82	24	28	91	2
BiTuoCZhenXingErChang	1	0	22	60	4	20
BiTuoD	13	4	16	8	6	22
BiTuoA	12	19	16	13	4	81
BiTuoB	9	25	20	15	18	5
BiTuoCLiTuo	13	10	42	16	17	10

V. CONCLUSIONS

Based on the research and analysis about actual production and management of enterprises in Tianjin, a steel, from inventory costs, production costs, consider the transportation costs, contract penalty costs and lost costs of idle productivity,and make the appropriate mathematical model. And use genetic algorithms to solve the model, through the application of practical examples prove the feasibility of the mathematical model and solution methods of this paper, provide a reference for the development of the multi-phase operation plan.

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