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Cost Control of Material Substitution in Steel Enterprise

Ya-Jun Wang*, Hui-Jie Yan, Zhang-Xuan Yin, Hao Zhang and Shi-Qi Wang

School of Mechanical Engineering of Dalian Polytechnic University, Dalian, 116034, China

Abstract: For dealing with cost control problems of material substitution in steel production process in make-to-order steel enterprise, we established the substitution rules of material substitution and built up the cost optimized controlling model for material substitution. The objective function of this model was to minimize the total cost of both stock and task lateness. We made use of Operations Research and Genetic Algorithm to solve this model. Finally, we also conducted the application research for the model and algorithm, and its promising future was revealed.

Keywords: Cost control, genetic algorithm, make to order, material substitution, steel enterprise.

1. INTRODUCTION

Material substitution occurs frequently in industrial production. Material substitution can improve the production efficiency. At the same time, it can result the frequent alteration of production plan in many production departments and increase difficulty of material management and tracing. References [1-3] proved that problem of material substitution was a NP problem and studies about it were very few. References [4, 5] broke the problem down into several independent sub-problems by Lagrangian relaxation algorithm. Reference [6] presented a heuristic algorithm for assembly sequence and multi-product production sequence to get the min-production cycle. Reference [7] proposed multi-project scheduling scheme that had availability constraints of resources and parts. MIP model was set up to minimize tardiness cost. Reference [8] studied techniques of material substitution with multi-constraint and multi-object for the complex equipment manufacturing enterprise. However, studies about material substitution of process industry were very few and almost nobody studied cost control of material substitution.

Research of material substitution cost control in MTO (make-to-order) steel enterprise production process was for the reasonable allocation of the existing materials and the materials anticipated future arrival to meet the requirements of order production and product delivery. So that it was achieved the total cost minimization, and the purpose of cost control in product production process of steel enterprise.

2. DESCRIPTION OF MATERIAL SUBSTITUTION IN PRODUCTION PROCESS

2.1. Material Substitution in Production Process of Steel Enterprises

The production process of iron & steel enterprises includes raw material processing, iron-making, steel-making rolling and other processes. It has features of long production cycle, multi processes. In order to reduce costs and meet process requirements, the majority of the materials to the next step are hot. And because of characteristics of MTO model, more variety products, small batch characteristics, material tracking is very complex [9-11], and cost control of the production process is also very difficult. In addition, the actual production process is uncertain and often affected by various random factors, such as temporary added emergency orders, temporary cancellation of the original order, the sudden damage of the equipment and so on, will result in the execution of some orders that are blocked. At this point, considering the compactness of production and lower inventory costs, it is necessary to make the materials of that order used in other orders production. In addition, in order to ensure order delivery and the quality of products, the production date of each order was arranged reasonably according to the material requirements planning to give adequate plan time to complete delivery of order products on time. Either poor or inadequate supply of raw materials or blank will disrupt the original production plan and affect subsequent processes of production plan that will lead to a contract extension and higher holding cost of semi-finished inventory. The safety stock may prevent the occurrence of these problems. But the higher inventory holding cost makes it is undesirable. Companies generally adopt the material substitution to solve such problems, namely using raw materials or blank of other order products having enough long delivery period to instead of raw materials or blank of this order product; reasonably arrange the production date of each order; and give adequate plan time to complete on time delivery of order products.

2.2. Analysis of Production Process of Steel Products

There are fixed production materials object in r processes. In a fixed period of time, the same properties material (blank or semi-finished) was manufactured. After the r processes, different process flows having different finished products were generated for the material. The nodes with non-unique successor node were called branch node, such as r node in Fig. (**1**). After the branch node, M process

*Address correspondence to this author at the School of Mechanical Engineering of Dalian Polytechnic University, Dalian, 116034, China; Tel: 13898665383; E-mail: 873959012@qq.com

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flows were generated for the material and M process routes $r_1, r_2, \cdots, r_M$ were formed. It was assumed that there were order numbers $A_1, A_2, ..., A_n$, material weights $a_1, a_2, ..., a_n$. When the process route $r_p(p \in [1, M])$ for the orders $A_1, A_2, ..., A_k$ was interrupted (by canceled order or emergency inserted order), the materials need be for the process route $r_q(q \in [1, M], q \neq p)$ at the branch node r. The materials used in orders $A_1, A_2, ..., A_k$ were used to finish the orders $A_{k+1}, A_{k+2}, ..., A_n$ or new inserted orders by material substitution.

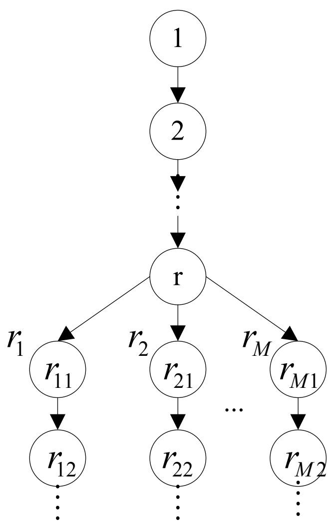

Fig. (1). Production process flow of steel products.

2.3. Material Substitution Model

There are many causes of material substitution and their forms are diverse, such as one-to-one, one-to-many, many-to-many swap, *etc*. Fig. (**2**) shows a many-to-many form of material substitution. Other forms may be considered a special form of many-to-many form. The temporary canceled order or the rush inserted order in production process can be equated to a new order and can be transformed into many-to-many form.

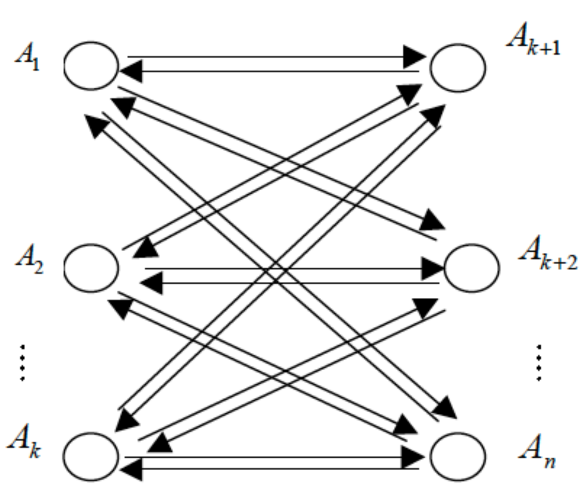

Fig. (2). Many-to-many form of material substitution.

For two batches of materials m and m', there were three substitution types:

(1) One-way substitution : m' could substitute m, m could not replace m'.

(2) Two-way substitution: m and m' could replace each other.

(3) Decision with produce: m' could substitute m in product A, could not substitute in product B.

Different material substitutions had different influences on completion period of orders. Above order deliveries supposed were $T_1^*, T_2^*, \cdots, T_n^*$, with the corresponding M process routes. The begining production time of the first process for each order was $T_b^{(1)}, T_b^{(2)}, \cdots, T_b^{(n)}$ respectively.

When the process route $r_p(p \in [1, M])$ was interrupted, materials of order $A_i(i = 1, 2, \cdots, k)$ were used in order $A_j(j = k+1, k+2, \cdots, n)$ in the process route $r_q(q \in [1, M], q \neq p)$. Its completion time was $T_e(i \to j) = T_b^{(i)} + T(j, a_{ij})$.

Here, $T(j, a_{ij})$ was production time of the material in the process route of the order A_j and was the function of material weight a_{ij}. Here, a_{ij} was the weight of the materials for order A_j supplied by order A_i, $i, j = 1, 2, \cdots, n$.

Completed early period of order A_j was

$$\Delta T(i \to j) = \\ u(T_j^* - T_e(i \to j)) \bullet (T_j^* - T_e(i \to j)) \quad (1)$$

In the formula, $u(v)$ was the threshold function, when $v \geq 0$, $u(v) = 1$, otherwise $u(v) = 0$.

Or delay of order A_j was

$$\nabla T(i \to j) = \\ u(T_e(i \to j) - T_j^*) \bullet (T_e(i \to j) - T_j^*) \quad (2)$$

Evidently, $\Delta T(i \to j) \bullet \nabla T(i \to j) = 0$.

Conversely, the material of order $A_j(j = k+1, k+2, \cdots, n)$ substituted for the material of order $A_i(i = 1, 2, \cdots, k)$. Completed early period $\Delta T(j \to i)$ and the delay $\nabla T(j \to i)$ could be obtained for $A_i(i = 1, 2, \cdots, k)$.

The various alternative schemes caused the difference of order delivery, while inventory costs, lead time costs and delays fees were not the same. Therefore, for controlling cost of material substitution in production process, the mathematical model of minimum cost of material substitution of order product in iron & steel enterprise was proposed by referring to the model proposed in reference [11, 12]. That was able to accurately describe the mathematical structure of substitution problem, and by considering and meeting the economy requirements of the product cost, the optimal alternative scheme was determined.

Supposedly, for orders $A_1, A_2, ..., A_n$, inventory cost of unit material weight and per unit time was $c_1, c_2, ..., c_n$, and tardiness cost was $d_1, d_2, ..., d_n$. The objective function was that the total cost of inventory cost and tardiness cost was minimum:

$$\min z = \sum_{i=1}^{n}\sum_{j=1}^{n}[c_j \cdot \Delta T(i \to j) + d_j \cdot \nabla T(i \to j)] \cdot a_{ij} \tag{3}$$

Determined the constraints of the objective function:

Inventory costs, delay costs for order product material were positive

$$c_i, d_i \geq 0, i = 1,...,n \tag{4}$$

Weight of substitute material for each order products was positive.

$$a_{ij} \geq 0, i = 1,...,n, j = 1,...,n \tag{5}$$

Ensured existence of feasible solution

$$0 \leq a \leq \min(a_i, a_j) \tag{6}$$

$$\sum_{j=1}^{n} a_{ij} = \sum_{j=1}^{n} a_{ji}, i = 1,...,n \tag{7}$$

$$\sum_{j=1}^{n} a_{ij} = a_i, i = 1,...,n \tag{8}$$

So, cost optimization control model for alternative material was set up according to the formulas (3)~(8):

$$s.t.\ \ c_i, d_i \geq 0, i = 1,...,n$$

$$a_{ij} \geq 0, i = 1,...,n, j = 1,...,n$$

$$0 \leq a \leq \min(a_i, a_j)$$

$$\sum_{j=1}^{n} a_{ij} = \sum_{j=1}^{n} a_{ji}, i = 1,...,n$$

$$\sum_{j=1}^{n} a_{ij} = a_i, i = 1,...,n \tag{9}$$

3. GENETIC ALGORITHM OF MATERIAL SUBSTITUTION

At present, in the production process, when the follow-up task plan could not be normally performed because of the emergency orders inserted or orders canceled, communication between technology staff of production department and design personnel was ordinarily taken for use of in production process of iron and steel enterprises, or designers and technology personnel directly made material substitution decision in production scene. Under normal circumstances, material consistent with substitution rule might have so much that design departments might not give all possible configuration schemes. Designers and technical personnel decided modification and selection of material substitution based on past experience and estimation. It was lack of scientific and reasonable selection process of material substitution.

Choice of material substitution involves a variety of factors, including certain factors and uncertain factors. To ensure the reasonable and scientific process of material selection, it had very important practical value to research the materials substitution problem in the production process of iron and steel enterprise. But the study of literature in this area was less. The selection of general parts and the general steps of substitution analysis were discussed based on grey system decision theory in reference [13]. And only two quantitative attributes, the weight and volume of part, were considered to reduce production cost. In actual production, properties of replacement parts were very complex, and most were described by language only. Combined with the actual production of iron and steel enterprises, material substitution rules were determined and then cost control problem of material substitution was solved by Genetic Algorithm through the knowledge of operations research.

3.1. Rules of Material Substitution

Although there are many forms of material substitution, yet the process of material substitution should follow the following rules:

Rule 1: In the production process, Raw materials should be used as far as possible, to minimize the change of schedule.

Rule 2: Under the premise of the provisions, requirements of products were meet, the technological rationality should be considered, the waste of raw materials should be minimized or avoided, as far as possible, the appearance of the product, assembly condition and pattern should not be changed, and process, tooling, test equipment and measuring instrument should not be changed.

Rule 3: The economy requirements of product cost should be considered and met in materials substitution. 'Gifted generation of inferior ' or 'big or small' should be avoided.

Rule 4: In principle, materials of substitution should not reduce or change their main performance and parameters, which were stipulated according to the standards or technical conditions of products and systems.

3.2. Arithmetic of Material Substitution

Material substitution was actually the issue of how to transport material from the origin to the consumer to achieve the total transportation cost minimization. Solution of the transport problem usually was the table computation method: firstly, the initial transport scheme that was determined by Vogel method, and then the test number was calculated to determine the initial transport scheme was the best. If it was not the most optimal solution, then it was adjusted using closed loop method, by determining the input and output variables and finding new basic feasible solutions. Then it was tested until the most optimal solution was obtained. There were many origins and scales to the transportation problem and table computation method was very complex. Therefore, GA was used to solve the transport problem which had advantages of high speed, and high efficiency.

GA is a global optimization algorithm inspired by biological evolution. And it is essentially a direct search method without depending on the specific problems [14, 15]. GA expresses the solution of a problem as a 'chromosome',

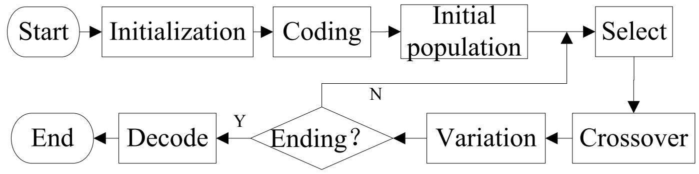

Fig. (3). Optimization process of genetic algorithm.

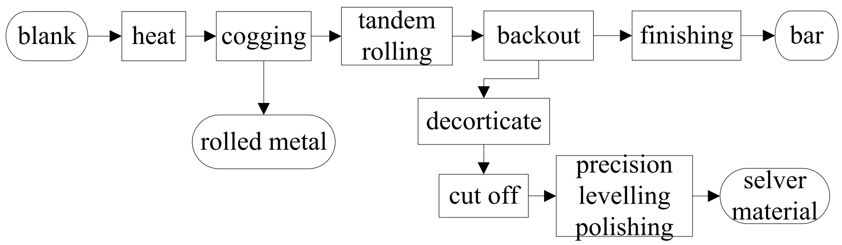

Fig. (4). The process flow of steel production.

Table 1. Start and finish time of production for orders.

Order number	Product	Weight (T)	Delivery period (H)	Inventory cost (yuan)	Tardiness cost (yuan)	Start time (h)	Finish time (h)
1	Bar	80	160.8	2.0	3.0	0	160.8
2	Silver bar	70	301.2	3.5	4.5	80	301.2
3	Mill bar	20	340.2	1.0	2.1	150	340.2
4	Mill bar	30	400.2	1.0	1.6	170	400.2
5	Mill bar	40	480.2	1.0	2.0	200	480.2
6	Mill bar	70	620.2	1.0	1.5	240	620.2
…							

represented as a binary code string in the algorithm. Before performing GA, a group of ‘chromosomes’ are given. They are assumed solutions. Then assumed solutions are placed into the ‘environment’ of problems. According to the principle of survival of the fittest, the acclimation ‘chromosomes’ are selected for copy, and then through crossover and mutation process a new generation of ‘chromosome’ group are produced that are more adapted to the environment. Such evolution is from generation to generation, which is finally converged towards the ‘chromosome’ which is best adapted to the environment. it is the optimal solution of the problem.

Operation process of GA is a typical iterative process, its basic steps are as follows:

Step 1: Initialization: Set the evolution generation counter t (initial value 0) and the maximum evolution generation T; randomly generated M individuals as the initial population P (0).

Step 2: Individual evaluation: Calculate the fitness of each individual in population P (t).

Step 3: Select operator: The selection operator acting on the population.

Step 4: Crossover operation: the crossover operator acting on the group.

Step 5: Mutation operation: the mutation operator acting on the group. Group P (t) gets the next generation group P (t +1) after selection, crossover, and variation operation.

Step 6: Analyzing the termination condition: If $t \leq T$, then $t + 1 \rightarrow t$, go to step 2. If $t > T$, the individual obtained with maximum adaptation to the evolution is outputted as the optimal solution, then terminate the computation.

Specific optimization process is shown in Fig. (**3**).

4. GA EXAMPLE

The process flow of steel products is shown in Fig. (**4**) and start time and finish time of processing for each order are shown in Table **1**. Product due date is the date of delivery. Due to the order 1 and 2 were canceled, the material of finished bar and finished bright bar in order1 and order 2 need be transferred to order of 3 to 6 (the total materials amount of the order of 3 to 6 is greater than the sum of order 1 and 2).

The optimal material substitution result was solved by GA: the initial population n = 20, the fitness function as formula (1), crossover probability = 0.8, mutation probability = 0.01. The optimal material substitution scheme is shown in Table **2**; the total cost is 143,630 yuan.

Table 2. The optimal material substitution scheme.

	Order No.1	Order No.2	Order No.3	Order No.4	Order No.5	Order No.6
Order No.1			20		20	60
Order No.2				30	40	
Order No.3		20				
Order No.4		30				
Order No.5	20	20				
Order No.6	60					10

By selection, crossover and mutation of GA under the relevant constraints, the global optimization for substitution materials was searched. Different from the traditional optimization method, GA is a parallel concurrent, gradual evolutionary optimization process, avoiding local produce optimal results. With the raise of product complexity and material substitution situation, GA superiority of solving such problems will be more fully reflected.

CONCLUSION

Material substitution is very common in MTO enterprise production. How to control the cost of material substitution has become a hot issue concerned by enterprises. Through establishing the cost optimization control model of material substitution and combining operation research and GA to solve the model, the optimal solution of material substitution was obtained under the condition meeting the order requirements. Compared with the traditional method of solving in table operation, the model has high speed, and high efficiency advantages.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] J. B. Mazzola, and A. W. Neebe, “Resource-constrained assignment scheduling,” *Operations Research*, vol. 34, no. 4, pp. 560-572, 1986.

[2] M.M. Farag, “Quantitative methods of materials substitution: Application to automotive components,” *Materials and Design,* vol. 29, pp. 374-380, 2008.

[3] J.F. Chen, and W.E. Whilhelm, “Optimizing the allocation of components to kits in small-lot, multi-echelon assembly systems,” *Naval Research Logistics*, vol. 41, pp. 229-256, 1994.

[4] J.F. Chen, and W.E. Wilhelm, “An evaluation of heuristics for allocating components to kits in small-lot, multi-echelon assembly systems,” *International Journal of Production Research*, vol. 12, pp. 31-52, 1993.

[5] W. E. Wilhem, J. F. Chen and G. R. Parija, “Cutting plane methods for kitting insmall-lot, multi-product, multi-echelon assembly systems,” *Working Paper,* pp. 253-268, 1996.

[6] H. David, B. Astghik and K. Andrew, “Scheduling manufacturing systems in an agile environment,” *Robotics and Computer-Integrated Manufacturing*, vol. 17, no. 1, pp. 87 -97, 2001.

[7] R. Kolisch, “Integrated scheduling, assembly area-and part-assignment for large- scale, make-to-order assemblies,” *International Journal of Production Economics*, vol. 64, no. 1, pp. 127-141, 2000.

[8] D. Xue, “*Research on material integration management technology for complex equipment manufacturing enterprises*,” Dalian University of Technology, Dalian, 2007.

[9] X. Liu, H. Zhang, Y. Ma, and Q. Meng, “Research on the system of material tracking management for steel enterprise,” *Computer Integrated Manufacturing System*, vol. 11, no. 10, pp. 1403-1407, 2005.

[10] S. Liu, J. Song, and J. Tang, “Iron and steel enterprise production forecast model,” *Journal of Northeastern University Natural Science*, vol. 24, no. 3, pp. 241-243, 2003.

[11] Y. X. Qi, “Iron and steel enterprise new information technology,” *Metallurgical Industry Automation*, no. 3, pp. 124, 2005.

[12] J.F. Chen, and W.E. Wilhelm. “An evaluation of heuristies for allocating components to kits in small-lot, multi-echelon assembly systems,” *International Journal of Production Research*, vol. 12, pp. 31-52, 1993.

[13] Z. Li, and X. Wan, “Grey situation decision in selection and substitution for interchangeable parts,” *Journal of Nanchang University*, vol. 24, no. 4, pp. 66-69, 2002.

[14] H. J. Holland, “*Adaptation in nature and artificial system*,” MIT Press, Cambridge, 1992.

[15] M. Zhou, and S. Sun, “*The Principle and Application of Genetic Algorithm*,” National Defense Industry Press, Beijing, 2005.

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