

Research Article

Ordering Strategy Analysis of Prefabricated Component Manufacturer in Construction Supply Chain

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Firstly, the characteristics and present situations of the prefabricated construction supply chain are analyzed; inventory cost models for construction material of every phase order, one-off order, and fractionated order are built based on traditional EOQ model and construction supply chain theory. Next, the order decision is represented in binary numbers 0 and 1, in which 0 stands for “no order” and 1 for “order.” The analysis uses the genetic algorithm, sets the objective function, and undergoes testing and assessing the individual fitness function, encoding, decoding, crossover, mutation, and selecting parameter. Moreover, inventory cost of construction supply chain is processed and optimized in Matlab. The research establishes a research paradigm on supply chain management of component manufacturing and materials supply. This study concludes the ordering strategy on construction material, identifies the optimal order points and order batches, and provides recommendations for further research.

1. Introduction

Even though supply chain management (SCM) in the manufacturing industry has been widely studied and developed, the application of the same concepts in the construction industry reveals that the problems in construction supply chain (CSC) are extensively present and persistent. Analysis of these problems has shown that a major part originates from the interfaces between the various factors or functions and the complex nature of the construction environment [1]. The prefabricated manufacturers produce components according to the split design and deepening design of architectural drawings, then deliver the products to the construction site, and finish assembly. A large amount of construction material is purchased and transported according to the manufacturing schedule. The characteristics of building itself and the construction materials limit the procurement mode of construction materials. Transportation distance, purchasing times, and quantity have a significant impact on cost, so it

is important to make scientific and reasonable procurement strategies of construction materials to reduce costs. Because the assembly of components only takes a short time, a large number of manufactured components need temporary storage, which draws the attention of contractors to the inventory cost.

The most significant issue for the material purchasing and inventory of a CSC is how to use an optimization model to reduce cost while maintaining the whole supply chain efficiency [2]. The inventory cost under management mode of CSC is significantly less than that of traditional mode [3]. The collaborative efforts reduce total supply chain costs efficiently [4]. The construction procedure sequence and procurement strategy affect inventory [5]. Demand variation influences the safety stock and inventory cost [6]. Large quantities and low-frequency orders will directly lead to high inventory cost; on the other hand, high frequency and small batch orders will cause higher reorder cost [7]. Currently, technologies, including JIT analysis technique [8], information integration

technology on cloud platform [9], radio frequency identification (RFID) technology [10], third-party logistics [11], 4D BIM, and GIS technology [12, 13], have been applied to analyze cost, order, delivery of contractors, and components supplier. The technologies solve some practical problems of contractors and suppliers to an extent. However, they do not provide much analysis on the order and delivery time point. In the following sections, the genetic algorithm will be used to study the order and delivery time of the prefabricated components manufacturer and their material supplier. This research is expected to explain the ordering strategy from another angle in CSC.

Qiurui et al. researched how to minimize the overall costs of the CSC by CSCO proposed an integrated-operational method. However, CSCO model describes the dynamics between the project owner and the fabrication contractor [14]. Zhai et al. took into account lead time order issue in the prefabricated CSC, providing rigorous mathematical analysis of an operational hedging and coordination mechanism to mitigate the impact of production lead time uncertainty in the prefabrication construction industry [15]. The paper studied ordering and supplying problems between the component manufacturer and construction material supplier. The research assumes prefabricated components manufacturers (PCM) and their materials supplier have rich experience in production and that the construction materials supply rate and demand of each stage are known. So the lead time has no substantial influence on the inventory cost of the whole prefabricated component supply chain, which provides an alternative analysis the of the actual situation.

2. Building Inventory Cost Model of Every Phase Order about Construction Materials

The classical economic order quantity (EOQ) model is at the heart of supply chain optimization and the theory of inventories [16]. Traditional inventory models attempt to optimize material lot sizes by minimizing total annual supply chain costs [17]. Taleizadeh, Khanbaglo, and Cárdenas-Barrón introduced distance factor to study partial backordering and reparation of damaged products [18]. De and Sana developed a cost minimization model by trading off setup cost, inventory cost, backordering cost, and cost for promotional effort based on some assumptions, which includes demand rate decreases over time during a shortage period [19]. Maddah and Noueihed considered a variant of the EOQ model, which assumes that demand occurs at random times with single order of the same amount [20]. Huang and Wu built a decision model to assist a wholesaler to hand ordering batch in a replenishment cycle and the maximal backorder level to minimize the average inventory cost [21]. Most of existing literatures consider the backlogging behavior only for retailers rather than wholesalers, and some assumptions are too far from the actual situation, such as stock-out cost, lead time, and order quantities [22].

There is significant difference between industrial products and prefabricated components in construction material requirement. The construction material requirement during

the construction period consists of subperiods, each corresponding to an ordering strategy, which can refer to the EOQ model [23]. For the construction project, its structure has been determined during the design period. Thus, the quantity and type of materials, as well as project duration and material average requirement planning, become explicit. Following the simple-to-complex research procedure, assumptions are as follows.

Assumption 1. The supply chain is supplier and demander of a single construction material, and the construction material demander is core party, which is the prefabricated components manufacturer.

Assumption 2. During production period of the components, the demand for construction material is uninterrupted.

Assumption 3. There are no shortage and no shortage cost of the construction materials after setting up the safety inventory and its order strategy. Thus, the safety inventory will not have significant influence on the overall inventory cost, which means we do not need to take into consideration safety inventory cost.

Assumption 4. The order cost includes the handling cost, transportation cost, order cost, and so on, which relates only to the order times by the prefabricated components manufacturer.

Assumption 5. The communication between the demander and supplier in the CSC is barrier-free, without hiding or asymmetrical information.

Assumption 6. The inventory capacity of the demander and supplier is large enough, and the cost relates only to the unit inventory cost.

Assumption 7. The prefabricated components manufacturer can only choose whether or not to order after the production of a kind of component is completed instead of ordering when the production is going on.

The meanings of letters are as follows.

d is demand rate of the construction materials during the producing period.

k is order cost of a certain construction material during the producing period.

i is the i components completed by the manufacturer during the producing period.

hr is unit inventory holding cost of the manufacturer during the producing period.

Q is order quantity of the manufacturer during the producing period.

HC_r is total inventory cost of the manufacturer during the producing period.

T_{ij} is time j for the i components completed by the manufacturer.

p is production rate of the construction material supplier, which is greater than consumption rate.

h_s is unit inventory holding cost of the construction material supplier.

l is delivery time of material supplier that is also order time of the demander, $l = j$ for every phase order.

HCs are total inventory cost of the construction material supplier.

TC is total inventory cost of the supplier and demander in the CSC.

Total inventory cost of the supplier and demander for every phase order equals total inventory cost of the demander for every phase order adds total inventory cost of the supplier for every delivery; that is,

$$TC = HCs + HC_r \quad (1)$$

$$HC_1 = \frac{Q_1(T_{i2} - T_{i1}) + Q_2(T_{i3} - T_{i2}) + Q_3(T_{i4} - T_{i3}) + Q_4(T_{i5} - T_{i4}) + Q_5(T_{i6} - T_{i5})}{2} \times \text{hr.} \quad (2)$$

The order cost of the prefabricated components manufacturer throughout the period is as follows.

$$HC_2 = 4k. \quad (3)$$

$$HC_r = HC_1 + HC_2 = \frac{Q_1(T_{i2} - T_{i1}) + Q_2(T_{i3} - T_{i2}) + Q_3(T_{i4} - T_{i3}) + Q_4(T_{i5} - T_{i4}) + Q_5(T_{i6} - T_{i5})}{2} \times \text{hr} + 4k. \quad (4)$$

2.2. Total Inventory Cost for the Construction Materials Supplier for Every Phase Order. Based on the experience of manufacturing supply, the production rate and demand of the construction materials for the construction material supplier for each period are explicit. Taking into account lead time and Figure 1, the inventory change of the construction material supplier is shown in Figure 2.

The production rate of the construction material supplier is d , and the demand for the construction materials for each period is known. Based on the different demands, the amount of time required to produce a certain amount of the construction materials can be $Q_1/d, Q_2/d, Q_3/d, Q_4/d$, and

2.1. Total Inventory Cost for Prefabricated Components Manufacturer for Every Phase Order. Figure 1 shows the inventory changes of the prefabricated components manufacturer for every phase order.

The demand for the construction materials for each period and the average inventory in each period are as shown below.

The demand for the construction materials in the $T_{i1}-T_{i2}$ period is Q_1 , and average inventory in this period is $Q_1/(T_{i2} - T_{i1})$. Similarly, the demand in the $T_{i2}-T_{i3}$ period is Q_2 and average inventory is $Q_2/(T_{i3} - T_{i2})$, the demand in the $T_{i3}-T_{i4}$ period is Q_3 and average inventory is $Q_3/(T_{i4} - T_{i3})$, the demand in the $T_{i4}-T_{i5}$ periods is Q_4 and average inventory is $Q_4/(T_{i5} - T_{i4})$, and the demand in the $T_{i5}-T_{i6}$ period is Q_5 and average inventory is $Q_5/(T_{i6} - T_{i5})$. Then, the inventory holding cost of the prefabricated components manufacturer throughout the entire period is as follows.

The inventory cost of the prefabricated components manufacturer in the CSC is as follows.

Q_5/d , respectively. The inventory cost of the construction material supplier throughout the period is as follows.

$$H_s = \frac{(Q_1^2 + Q_2^2 + Q_3^2 + Q_4^2 + Q_5^2)}{2d} \times \text{hs.} \quad (5)$$

2.3. Total Inventory Cost of the Construction Materials for Every Phase Order. Under inventory management mode, total inventory cost of the construction materials in the CSC is as follows.

$$\begin{aligned} TC &= HC_s + HC_r \\ &= \frac{Q_1(T_{i2} - T_{i1}) + Q_2(T_{i3} - T_{i2}) + Q_3(T_{i4} - T_{i3}) + Q_4(T_{i5} - T_{i4}) + Q_5(T_{i6} - T_{i5})}{2} \times \text{hr} + 4k \\ &\quad + \frac{(Q_1^2 + Q_2^2 + Q_3^2 + Q_4^2 + Q_5^2)}{2d} \times \text{hs.} \end{aligned} \quad (6)$$

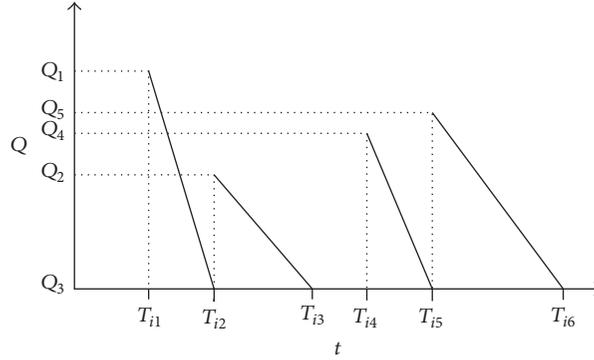


FIGURE 1: Chart of inventory changes of the prefabricated components manufacturer (every phase order).

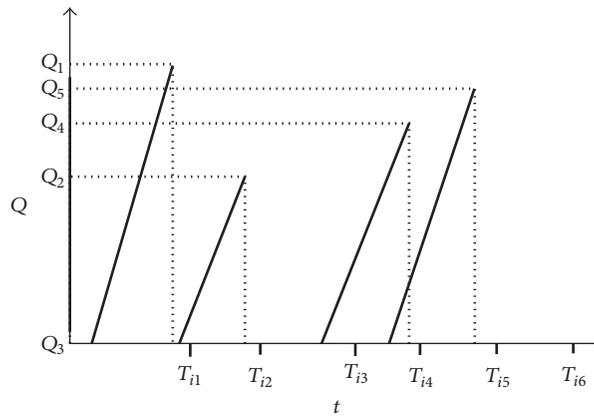


FIGURE 2: Chart of inventory changes of the construction material supplier (every phase order).

3. Building Inventory Cost Model of the Construction Materials for One-Off Order

Every phase order is an extreme situation, and one-off order is another extreme situation which we need to consider. In this situation, all construction materials are ordered only once. The inventory cost in this situation is reduced to zero and only one-off order cost needs to be considered. For the construction material supplier in the CSC, all construction materials are produced only once. Similar to every phase order mentioned before, the total demand of the construction materials for one-off order is $Q_1 + Q_2 + Q_3 + Q_4 + Q_5$. All the previous assumptions still apply but since it is one-off order strategy, $l = 1$. The term “one-off” is used to replace “every” in formula (1). Then the formula of total inventory cost of the construction material supplier and demanders for one-off order is obtained.

3.1. Total Inventory Cost for Prefabricated Components Manufacturer for One-Off Order. The characteristics of change in inventory for the prefabricated components manufacturer for one-off order are shown in Figure 3.

Then, the inventory holding cost for the prefabricated components manufacturer throughout the period is

$$\begin{aligned} HC_1 &= \frac{hr}{2} \\ &\times [(Q_1 + 2Q_2 + 2Q_3 + 2Q_4 + 2Q_5)(T_{i2} - T_{i1}) \\ &+ (Q_2 + 2Q_3 + 2Q_4 + 2Q_5)(T_{i3} - T_{i2}) \\ &+ (Q_3 + 2Q_4 + 2Q_5)(T_{i4} - T_{i3}) \\ &+ (Q_4 + 2Q_5)(T_{i5} - T_{i4}) + Q_5(T_{i6} - T_{i5})]. \end{aligned} \quad (7)$$

The order cost for the prefabricated components manufacturer throughout the period is

$$HC_2 = k. \quad (8)$$

The inventory cost for the prefabricated components manufacturer throughout the period is

$$\begin{aligned} HC_r &= HC_1 + HC_2 = \frac{hr}{2} \\ &\times [(Q_1 + 2Q_2 + 2Q_3 + 2Q_4 + 2Q_5)(T_{i2} - T_{i1}) \\ &+ (Q_2 + 2Q_3 + 2Q_4 + 2Q_5)(T_{i3} - T_{i2}) \\ &+ (Q_3 + 2Q_4 + 2Q_5)(T_{i4} - T_{i3}) \\ &+ (Q_4 + 2Q_5)(T_{i5} - T_{i4}) + Q_5(T_{i6} - T_{i5})] + k. \end{aligned} \quad (9)$$

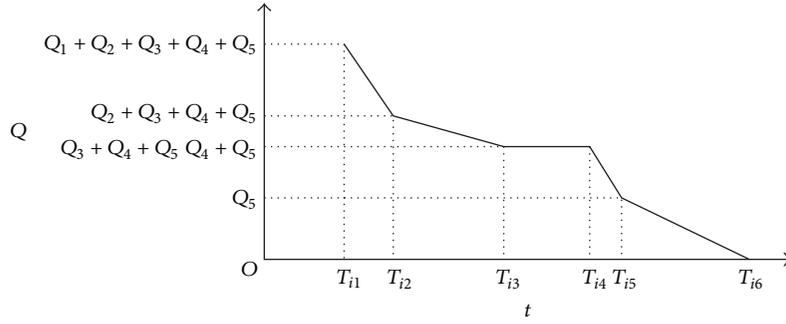


FIGURE 3: Inventory changes for the prefabricated components manufacturer (one-off order).

3.2. *Total Inventory Cost for the Construction Material Supplier for One-Off Order.* Based on production and supply experience, the production rate of the construction materials is known as d ; the demand for the construction materials for each period is also known. The lead time has no remarkable influence on the inventory cost of the whole CSC. The inventory change for the construction material supplier is shown in Figure 4.

In this order model, the construction material supplier in the CSC needs to supply only once, so the material needs to produce once. The total production of the construction materials is $Q_1+Q_2+Q_3+Q_4+Q_5$, since the production rate of the construction material supplier is d , the time for production is $(Q_1 + Q_2 + Q_3 + Q_4 + Q_5)/d$.

The inventory cost for the construction material supplier throughout the period is

$$HC_s = \frac{(Q_1 + Q_2 + Q_3 + Q_4 + Q_5)^2}{2d} \times hs. \quad (10)$$

3.3. *Total Inventory Cost of the Construction Materials for One-Off Order.* The total inventory cost of the construction materials under inventory management mode is

$$\begin{aligned} TC = HC_r + HC_s = & \frac{hr}{2} \\ & \times [(Q_1 + 2Q_2 + 2Q_3 + 2Q_4 + 2Q_5)(T_{i2} - T_{i1}) \\ & + (Q_2 + 2Q_3 + 2Q_4 + 2Q_5)(T_{i3} - T_{i2}) \\ & + (Q_3 + 2Q_4 + 2Q_5)(T_{i4} - T_{i3}) \\ & + (Q_4 + 2Q_5)(T_{i5} - T_{i4}) + Q_5(T_{i6} - T_{i5})] + k \\ & + \frac{(Q_1 + Q_2 + Q_3 + Q_4 + Q_5)^2}{2d} \times hs. \end{aligned} \quad (11)$$

4. Building Inventory Cost Model of the Construction Materials for Fractionated Order

The above two models are two extreme cases of some main construction materials with unstable demand in the CSC, namely, one-off order and every phase order strategies

throughout the period. For the inventory in the CSC, such order strategy and inventory management mode are unable to achieve the lowest-cost in most cases.

In general, the order strategy is an integrated decision considering multiple phases, which takes full advantage of the transportation, construction, and storage conditions. The fractionated order means the indentors combine several construction stages to order materials at specific time. The decision of order times and order selection mode is made based on personal experience of indentor and the inventory status of the construction materials. The assumptions of order model mentioned previously still apply, and the only differences are as follows.

l is delivery time of the construction material supplier, and it is also the order time of the prefabricated components manufacturer. Under optimal cases, l is equal to order times, which means order point is the sum of 1. By replacing “every” with “fractionated” in formula (1), we get the formula of total inventory cost for the construction material suppliers and demanders for fractionated order.

4.1. *Total Inventory Cost for the Prefabricated Components Manufacturer for Fractionated Order.* Figure 5 shows inventory change for the prefabricated components manufacturer for fractionated order.

The demand for some main construction material is different for the prefabricated components manufacturer during $T_{i1}-T_{ij}$ periods. The order point comes in the $T_{i1}-T_{ij}$ periods, and different order points have a remarkable impact on the order costs and inventory costs.

The inventory holding cost for the prefabricated components manufacturer throughout the period is

$$\begin{aligned} HC_1 = & \left[\sum_{m=2}^j Q_{m-1} (T_{im} - T_{im-1}) \right. \\ & + \sum_{n=p_1+1}^{P_2-1} Q_n (T_{in} - T_{ip1}) \\ & \left. + \sum_{n=p_2+1}^{P_3-1} Q_n (T_{in} - T_{ip2}) \cdots \sum_{n=p_{l-1}+1}^{P_l-1} Q_n (T_{in} - T_{ip_{l-1}}) \right] \\ & \times hr. \end{aligned} \quad (12)$$

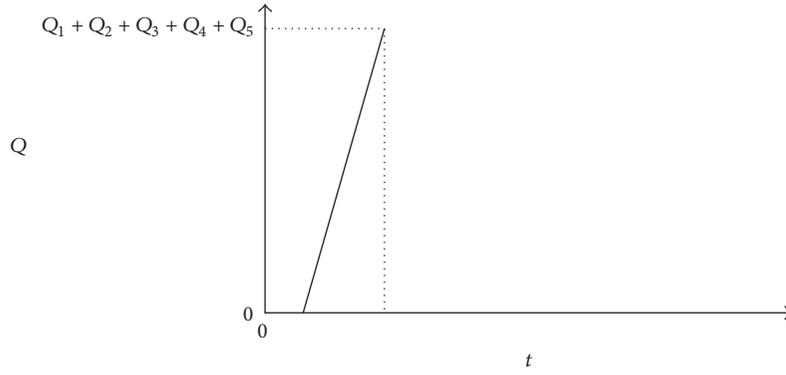


FIGURE 4: Inventory change for the construction material supplier (one-off order).

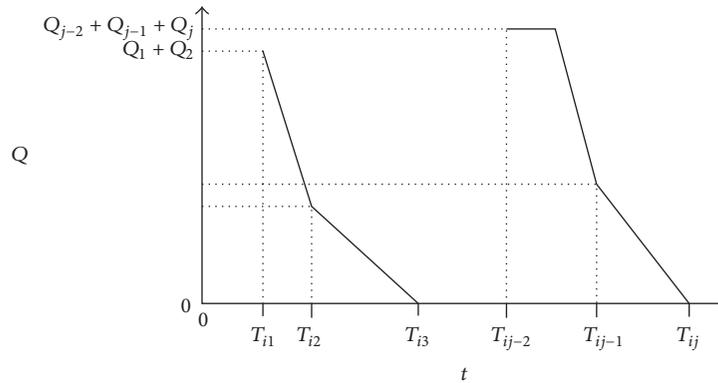


FIGURE 5: Inventory change for the prefabricated components manufacturer (fractionated order).

The order cost for the prefabricated components manufacturer throughout the period is

$$HC_2 = l \times k. \tag{13}$$

The inventory cost for the prefabricated components manufacturer throughout the period is

$$HC_r = HC_1 + HC_2 = \left[\sum_{m=2}^j Q_{m-1} (T_{im} - T_{im-1}) + \sum_{n=p_1+1}^{P_2-1} Q_n (T_{in} - T_{ip_1}) + \sum_{n=p_2+1}^{P_3-1} Q_n (T_{in} - T_{ip_2}) \dots \sum_{n=p_{l-1}+1}^{P_l-1} Q_n (T_{in} - T_{ip_{l-1}}) \right] \times hr + l \times k. \tag{14}$$

4.2. Total Inventory Cost for the Construction Material Supplier for Fractionated Order. The production rate of the construction material supplier is d , and the demand for the construction materials for each period is known. The lead time has no substantial influence on the inventory cost of the whole CSC. Figure 6 shows the material supply of the construction material supplier.

The inventory cost for the construction material supplier throughout the period is

HC_s

$$= \frac{(\sum_{n=1}^{P_2-1} Q_n)^2 + (\sum_{n=P_2}^{P_3-1} Q_n)^2 + \dots + (\sum_{n=p_{l-1}}^j Q_n)^2}{2d} \tag{15}$$

$\times Hs.$

4.3. Total Inventory Cost of the Construction Materials for Fractionated Order. Total inventory cost of the construction materials in the CSC under inventory management mode is

$$TC = HC_r + HC_s = \left[\frac{1}{2} \sum_{m=2}^j Q_{m-1} (T_m - T_{m-1}) + \sum_{n=p_1+1}^{P_2-1} Q_n (T_n - T_{p_1}) + \sum_{n=p_2+1}^{P_3-1} Q_n (T_n - T_{p_2}) \dots \sum_{n=p_{l-1}+1}^{P_l-1} Q_n (T_n - T_{p_{l-1}}) \right] \tag{16}$$

$$\times hr + l \times k$$

$$+ \frac{(\sum_{n=1}^{P_2-1} Q_n)^2 + (\sum_{n=P_2}^{P_3-1} Q_n)^2 + \dots + (\sum_{n=p_{l-1}}^{P_l-1} Q_n)^2}{2d}$$

$$\times Hs.$$

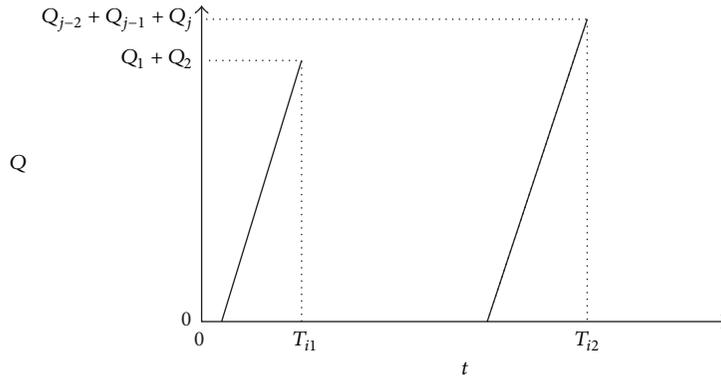


FIGURE 6: Change in inventory for the construction material supplier (fractionated order).

Thus, the inventory cost model of the construction materials in the CSC is derived, which originated from the classical EOQ model and combined with the actual situation of the construction engineering. The inventory cost model of the construction materials achieved generalization and universalization of CSC. It is a universal inventory cost model of the construction materials in the CSC and is constructed by the general-to-specific mathematical method.

5. Calculation and Program Optimization of Inventory Cost of the Construction Materials in the CSC

To make the model more suitable for the analysis of inventory cost, the demand for construction materials should be treated as uniform and continuous. Bortolini et al. choose to use the 4D model to deal with the continuity and uniformity of the construction materials demand [24]. This paper chooses to use the following methods.

5.1. Importing of Genetic Algorithm for the Inventory Cost Model of the Construction Materials. The choice of an appropriate algorithm is the core problem for the analysis of inventory cost. The genetic algorithm is a kind of multipoint searching algorithm, which is more likely to obtain a global optimal solution [25]. The genetic algorithm can be well applied to solving the problems in inventory cost model because the genetic algorithm can use binary encoding operations. At the same time, optimization of vehicle route and inventory cost and analysis of distribution region can be designed into a one-dimensional ring topology [26–30]. This transformed the original problem into the problem of (0/1). The basic premise of using the algorithm is to establish the supply chain inventory cost model [28], as built above. In the calculation of various periods, 0 represents no order and 1 represents order. Using the binary encoding mode of the genetic algorithm can solve this kind of extreme value problems. The Matlab software is used to solve inventory cost model problems on the construction materials; optimal results and order strategies are derived.

5.1.1. Setting the Objective Function. Take the order point of the construction materials as a variable. To ensure that the j period is not missing in function setting, $j + 1$ is assumed as the actual period. The whole period has J intervals; the point $j + 1$ is the termination point for calculation. The order parameter of this point is 1. Meanwhile, the expression of the function needs special explanation if the adjacent two order points are 1 in the expression process of function; namely, both need ordering. Otherwise the program will report bug. Therefore, $(P(n) + 1) < P(n + 1)$ is set in the program to ensure that the interval between the previous order point and subsequent order point is always greater than 1.

One key problem is to express the objective function using the Matlab language because it is different from C language. Most importantly, this language adopts the matrix operation, which is convenient for the programming of the objective function value and is more complex in logic compared with C language programming. Meanwhile, taking into account the actual situation, the first time point (T_1) of the first period of all periods must be order and the last time point (T_j) of the first period of all periods must be no order. At the same time, there must be a termination point in the program, which cannot be the previous order point. Therefore, T_j is assumed to be “order” and only used as a termination point and will not influence the operation of the whole model. In Matlab, the following commands are used to meet the above requirements:

`NIND = 20.`

`PRECT = 8.`

`diyilie = ones(NIND,1).`

`zuihouyilie = ones(NIND,1).`

`chrom = crtbp(NIND,PRECT).`

`Chromall = [diyilie chrom zuihouyilie].`

Among which, `chrom = crtbp(NIND,PRECT)`; (0 1) matrix of row `NIND` and column `PRECT` is randomly created.

`diyilie = ones(NIND,1)`; matrix of row `NIND` and column 1 is created.

$zuihouyilie = ones(NIND,1)$; matrix of row $NIND$ and column 1 is created.

$Chromall = [diyilie\ chrom\ zuihouyilie]$ is the required $Chromall$ by adding the column vector with values of the first column and the last column of 1 to $chrom$.

5.1.2. Detection and Evaluation of Individual Fitness Function.

Fitness function describes the quality of each individual created by the genetic algorithm. Its value is subsequently used to determine the probability that each individual will be copied to next generation (a genetic operator of the selection) [31]. The greater the fitness function value, the better the performance of the descendant individual, which is generally from the objective function of the constructing function. In the actual operation, a negative fitness function value is often encountered. Thus, appropriate transformation needs to be conducted in the calculation of fitness function to ensure the fitness function value is positive.

There are many categories of fitness function values; the size of fitness function value determines the probability of the descendant moving to the next generation. When analyzing the practical problems, the analyzer must first define the category of the objective function and then transform the objective function into the fitness function.

In method 1, the objective function $f(x)$ of the mathematical model of the practical problem is transformed into the fitness function value $Fit(f(x))$ of the genetic algorithm.

In method 2, the objective function needs to be transformed to calculate the minimum value.

$$\begin{aligned} Fit(f(x)) &= C_{\max} - f(x) \quad f(x) < C_{\max} \\ Fit(f(x)) &= 0 \quad \text{others.} \end{aligned} \quad (17)$$

C_{\max} is set and selected according to the practical situation because it is the estimate of the maximum value of $f(x)$. As it will not affect other factors, the purpose will be achieved if the value of fitness function is positive.

The selecting operator is set based on the individual fitness function value. This paper adopts the roulette method. By determining a threshold, the individuals above the threshold move into the next descendant individual for operation, and the individuals under the threshold are eliminated, and the calculated ratio of the fitness function is the threshold value. For example, if the total population size is n , and the fitness of individual i is $T(A_i)$, then $T(A_i)/(T(A_1) + T(A_2) + \dots + T(A_n))$ is the probability that individual i to be selected.

To solve the problems of minimum inventory cost of the construction materials, the fitness function is

$$\begin{aligned} Fit(f(x)) &= C_{\max} - \left[\sum_{m=2}^j Q_{m-1} (T_{im} - T_{im-1}) \right. \\ &+ \sum_{n=p_1+1}^{P_2} Q_n (T_{in} - T_{ip1}) \\ &+ \left. \sum_{n=p_2+1}^{P_3} Q_n (T_{in} - T_{ip2}) \cdots \sum_{n=p_{l-1}+1}^{P_l} Q_n (T_{in} - T_{ip_{l-1}}) \right] \end{aligned}$$

$\times hr + l \times k$

$$+ \frac{(\sum_{n=1}^{P_2-1} Q_n)^2 + (\sum_{n=P_2}^{P_3-1} Q_n)^2 + \cdots + (\sum_{n=p_{l-1}}^j Q_n)^2}{2d}$$

$\times Hs.$

(18)

When solving the model using the genetic algorithm, under conditions that the whole fitness functions are positive, as long as C_{\max} is assigned with an appropriate maximum value, there are no other restrictions. According to the data obtained from the example, 5,000,000 is temporarily assigned.

5.1.3. Encoding and Decoding

Encoding. Assuming the parameter range of the studied problem is $[A\ B]$, and the problem is solved by using the binary encoding mode and length is k . There are two kinds of different encoding modes for every bit on the length, 2^k kinds in total.

Decoding. Assume the encoding mode of the studied problem is $b_k b_{k-1} \cdots b_3 b_2 b_1$, and the binary encoding mode can be transformed into real value based on the following formula.

$$X = A + \left(\sum_{t=1}^k b_t * 2^{t-1} \right) \frac{B-A}{2^t - 1}. \quad (19)$$

Suppose the order point (01) is a function variable, implementing function calculations of binary encoding, and the decoding process is not required. The entire binary function is the function variable, and the number of the binary functions is the number of function variables.

5.1.4. Crossover and Variation

(1) *Crossover.* Binary encoding is used for operations because (01) is assumed as the function variable in the mathematical modeling period. The single-point crossover is selected as the cross operator. The function code achieved by the crossover operator is

$$recombin('xovsp', SelCh, Pm).$$

(2) *Variation.* In binary symbol coding, basic bit mutation is adopted to facilitate the solving process. The mutation operator used is

$$SelCh = mut(SelCh).$$

The processes of inheritance and variation are to change all binary numbers, so before entering the next cycle, the numbers of the first column and the last column are not 1. Transformation of 1 needs to be forced again on the first column and the last column when calculating the built-in population; namely,

$$SelCh(:,1) = []; \text{ force } SelCh \text{ to delete first column};$$

$$SelCh(:,PRECT+1) = []; \text{ force } SelCh \text{ to delete last column};$$

The first column = ones(NIND,1); generate row NIND column 1 matrix;

The last column = ones(NIND,1); generate row NIND column 1 matrix;

SelCh = [the first column SelCh the last column]; force SelCh the first column and the last column to be 1.

The probability of mutation operation in the genetic algorithm is quite low. The solving efficiency for local operation is good due to a small number of variation points. Importing mutation operator plays an important role in optimal solution convergence. Small probability value can effectively avoid the big shortcoming of genetic algorithm which is immature convergence. The crossover operation ensures the global search ability of the genetic algorithm in the entire solution region while the mutation operator ensures the search ability of the genetic algorithm in the local solution region. The two complemented each other and coordinated with each other until the mutation operator reaches the optimal value of the entire region. The two are closely related; thus the parameters need to be adjusted to make them coordinate perfectly.

5.1.5. Selection of Important Parameters of the Genetic Algorithm. Parameter selection of the genetic algorithm is key to solving the whole model correctly. There are four basic parameters in the genetic algorithm, namely, chromosome length, population size, crossover probability, and the mutation probability of the genetic algorithm [32, 33]. The selection of parameters mainly affects the accuracy and time efficiency of the genetic algorithm. To select the parameters correctly is very important because the defects of the genetic algorithm itself will also be interfered by these parameters. The accuracy of the actual situation influences the selection of the operator of the binary coding mode from chromosome length. Fixed length and variable length are the two main methods. The variable settings are 0 and 1. Encoding and decoding are not required, so the selection of chromosome length is to set the variables quantity.

The following four operating parameters of the genetic algorithm need to be preset, namely, NIND, MAXGEN, Pc, and Pm.

NIND is preset as the size of the genetic algorithm population, and the data selection range is 10–200. The operation time will increase significantly if the data selection range is too large while the operation is not universal if the data selection range is too small and the results may be limited to a small range.

MAXGEN is preset as the evolutionary operation generations of the genetic algorithm, which is the operator operation times and the range of data selection is 100–600.

Pc is preset as the crossover probability of crossover operation of the genetic algorithm; the range of data selection is 0.2–0.99.

Pm is preset as the mutation probability of mutation operation of the genetic algorithm; the range of data selection is 0.000099–0.09.

The operator is selected by the roulette method.

5.2. Optimization of Inventory Cost Program of the Construction Materials. For a prefabricated component, the reinforcement requirements are shown in Table 1. The production

speed of supplier is $d = 50$ t/w, the unit inventory cost for prefabricated components manufacturer is $hr = 35$ yuan/t/w, and the unit inventory cost for the supplier is $hs = 20$ yuan/t/w. The order cost for the prefabricated components manufacturer is $k = 100$ yuan/time. Firstly, calculation is performed for two special cases; then 20 times of cycle calculations are performed using the genetic algorithm. All the results are used as the reference for the comparison of an optimization algorithm.

5.2.1. Inventory Cost for Every Phase Order Program. The reinforcement will be supplied when they are used up in every period.

The inventory holding cost for the reinforcement demander throughout the period is $HC_1 = 34072$ yuan.

The order cost for the reinforcement demander throughout the period is $HC_2 = 24 \times k = 2400$ yuan.

The inventory cost for the reinforcement supplier throughout the period is $Hs = 1395424$ yuan.

The inventory cost of the reinforcement in the whole CSC under this order model is 1,431,896 yuan.

5.2.2. Inventory Cost for One-Off Order Program. The reinforcement will be supplied only once for all periods.

The inventory holding cost for the reinforcement demander throughout the period is $HC_1 = 793187$.

The order cost for the reinforcement demander throughout the period is $HC_2 = 200$.

The inventory cost for the reinforcement supplier throughout the period is $Hs = 169648$.

The inventory cost of the reinforcement in the whole CSC under this order model is 963,035 yuan.

5.2.3. Inventory Cost for Fractionated Order Program. The reinforcement will be supplied as fractionated for all periods.

Substitute the following data into the inventory cost model of the construction materials in the CSC; namely, $T(1) = 1; T(2) = 3; T(3) = 8; T(4) = 9; T(5) = 10; T(6) = 13; T(7) = 15; T(8) = 16; T(9) = 18; T(10) = 21; T(11) = 21; T(12) = 24; T(13) = 25; T(14) = 28; T(15) = 30; T(16) = 31; T(17) = 34;$

$T(18) = 35; T(19) = 38; T(20) = 40; T(21) = 43; T(22) = 47; T(23) = 50; T(24) = 52;$

$Q(1) = 50; Q(2) = 20; Q(3) = 60; Q(4) = 0; Q(5) = 30; Q(6) = 20; Q(7) = 70; Q(8) = 35; Q(9) = 53; Q(10) = 74; Q(11) = 59; Q(12) = 22; Q(13) = 43; Q(14) = 44; Q(15) = 24; Q(16) = 58; Q(17) = 22; Q(18) = 52; Q(19) = 37; Q(20) = 48; Q(21) = 0; Q(22) = 48; Q(23) = 52; Q(24) = 35;$

$k = 100$; order cost each time

$hr = 35$; unit inventory cost for the prefabricated components manufacturer

$hs = 20$; unit inventory cost for the reinforcement supplier

$d = 50$; production speed of the reinforcement supplier

$Pm = 0.7$; crossover probability

$MAXGEN = 200$; number of genetic generations

TABLE 1: Reinforcement demand of a prefabricated component.

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Demand (t)	50	20	60	0	30	20	70	35	53	74	59	22	43	44	24	58	22	52	37	48	0	48	52	35
Time (w)	1-3	3-4	4-8	8-9	9-10	10-13	13-15	15-16	16-18	18-21	21-24	24-25	25-28	28-30	30-31	31-34	34-35	35-38	38-40	40-43	43-44	44-47	47-50	50-52
Duration (w)	2	1	4	1	1	3	2	1	2	3	3	1	3	2	1	3	1	3	2	3	1	3	3	2

$GGAP = 1;$
 $NIND = 20;$ number of subgenerations
 $PRECT = 22;$ column number of subgenerations
 $wuqiongda = 5000000.$

Each operation involves 20 subgeneration individuals; 200 times of operations are performed. There are 4,000 times of operations in total.

From the first operation, the following conclusions are concluded:

- (1) The optimal cost obtained is 629,167 yuan.
 - (2) The corresponding binary code is 1 0 0 1 0 1 1 0 1 0 1 1 1 1 0 1 0 0 0 1 1 0 1 1;
- at this time, the subgeneration of optimal value appeared is the 605th.

The meaning of the above binary code is as follows:

The reinforcement of the 1st, 2nd, and 3rd periods is ordered before the 1st period.

The reinforcement of the 4th and 5th periods is ordered before the 4th period.

The reinforcement of the 6th period is ordered before the 6th period.

The reinforcement of the 7th and 8th periods is ordered before the 7th period.

The reinforcement of the 9th and 10th periods is ordered before the 7th period.

The reinforcement of the 11th period is ordered before the 11th period.

The reinforcement of the 12th period is ordered before the 12th period.

The reinforcement of the 13th period is ordered before the 13th period.

The reinforcement of the 14th and 15th periods is ordered before the 14th period.

The reinforcement of the 16th, 17th, 18th, and 19th periods is ordered before the 16th period.

The reinforcement of the 20th period is ordered before the 20th period.

The reinforcement of the 21st and 22nd periods is ordered before the 21st period.

The reinforcement of the 23rd period is ordered before the 23rd period.

The reinforcement of the 24th period is ordered before the 24th period.

- (3) The tracing of the genetic algorithm

The diagram of performance tracing of the genetic algorithm visually reflects the continuous optimization of the subgeneration individuals in the process of reaction software operation, and the diagram of performance tracing of the first operation is shown in Figure 7.

The solid line in the diagram shows that the minimum value appeared at the 30th generation in this operation, which is consistent with the result in 605th generation. The average

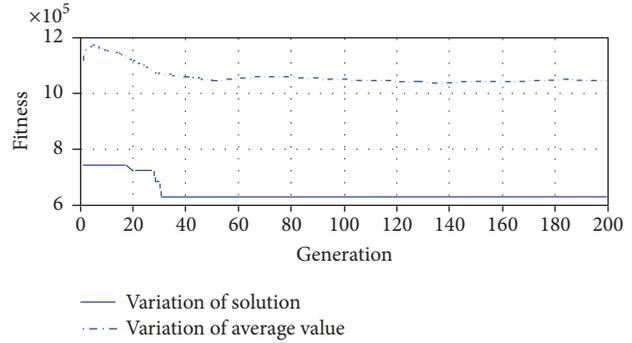


FIGURE 7: Diagram of performance tracing of the genetic algorithm.

value of the objective function in this operation is stable since the 130th generation, as shown by the dotted line.

The ability of the genetic algorithm to explore the new region is limited, and it is easy to converge to the optimal local solution. To achieve rational, objective, and scientific data, the optimal value is obtained using the simplest multiple operations. In this study, 20 repeated operations are selected, and various data of each operation are shown in Table 2. Figure 8 is the corresponding diagram of performance tracing of every operation. In the Figure 8, continuous line means variation of solution, and dash line means variation of average value, the vertical axis is fitness, and the horizontal axis is generation.

The operation results show that the genetic algorithm cannot obtain the absolute minimum or maximum value (minimum value in this paper), and only the minimum value of an operation can be obtained. By running 20 times of operations, the minimum cost can be obtained as 587,416 yuan by adopting the order strategy of 101010111110001001001111.

5.2.4. Optimization Conclusion and Program Implementation of Inventory Cost of the Construction Materials in the CSC.

The result of minimum inventory cost and order strategy for every phase order, one-off order, and fractionated order is shown in Table 3.

The results comparison shows that the optimized calculation result is significantly lower than the cost of the first two extreme cases, and the binary code calculated according to the optimal supply order strategy is 101010111110001001001111.

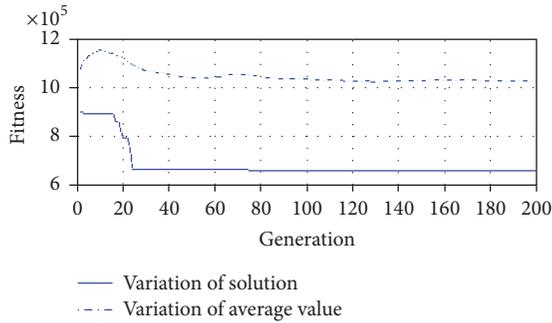
The meanings of the binary code and the corresponding order strategies are as follows:

The reinforcement of the 1st and 2nd periods is ordered before the 1st period, with an order quantity of 70t.

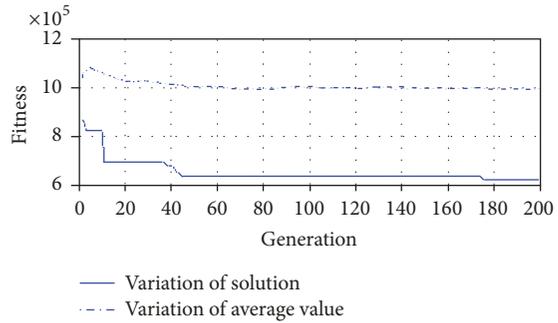
The construction materials of the 3rd and 4th periods are ordered before the 3rd period, with an order quantity of 60t.

The reinforcement of the 5th and 6th periods is ordered before the 5th period, with an order quantity of 50t.

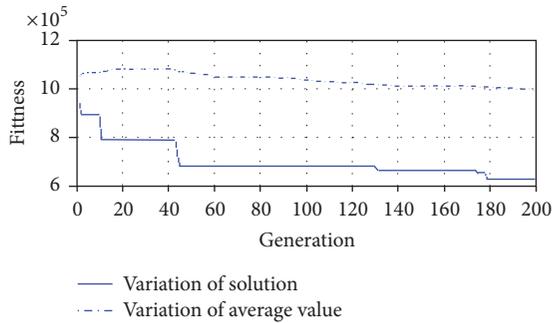
The reinforcement of the 7th period is ordered before the 7th period, with an order quantity of 70t.



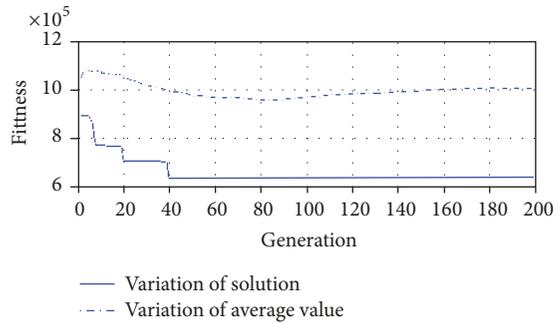
(a) Diagram of number 1 times of performance tracings of the genetic algorithm



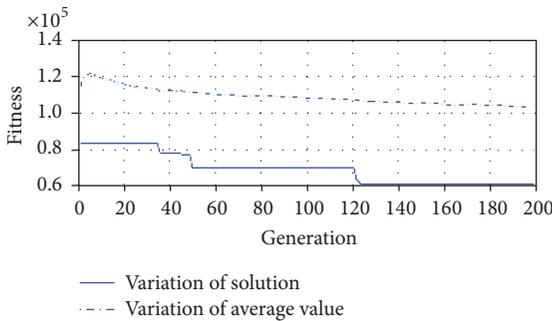
(b) Diagram of number 2 times of performance tracings of the genetic algorithm



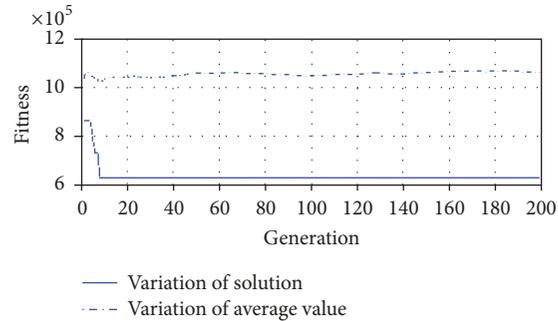
(c) Diagram of number 3 times of performance tracings of the genetic algorithm



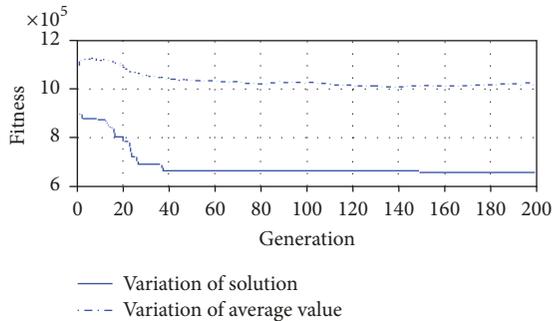
(d) Diagram of number 4 times of performance tracings of the genetic algorithm



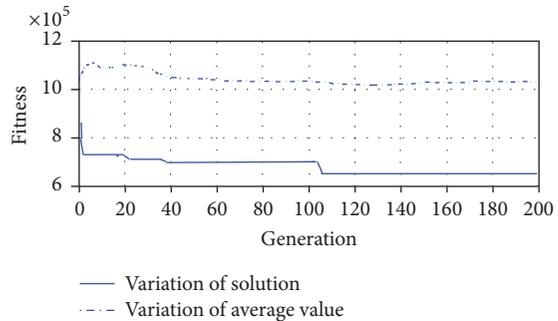
(e) Diagram of number 5 times of performance tracings of the genetic algorithm



(f) Diagram of number 6 times of performance tracings of the genetic algorithm



(g) Diagram of number 7 times of performance tracings of the genetic algorithm



(h) Diagram of number 8 times of performance tracings of the genetic algorithm

FIGURE 8: Continued.

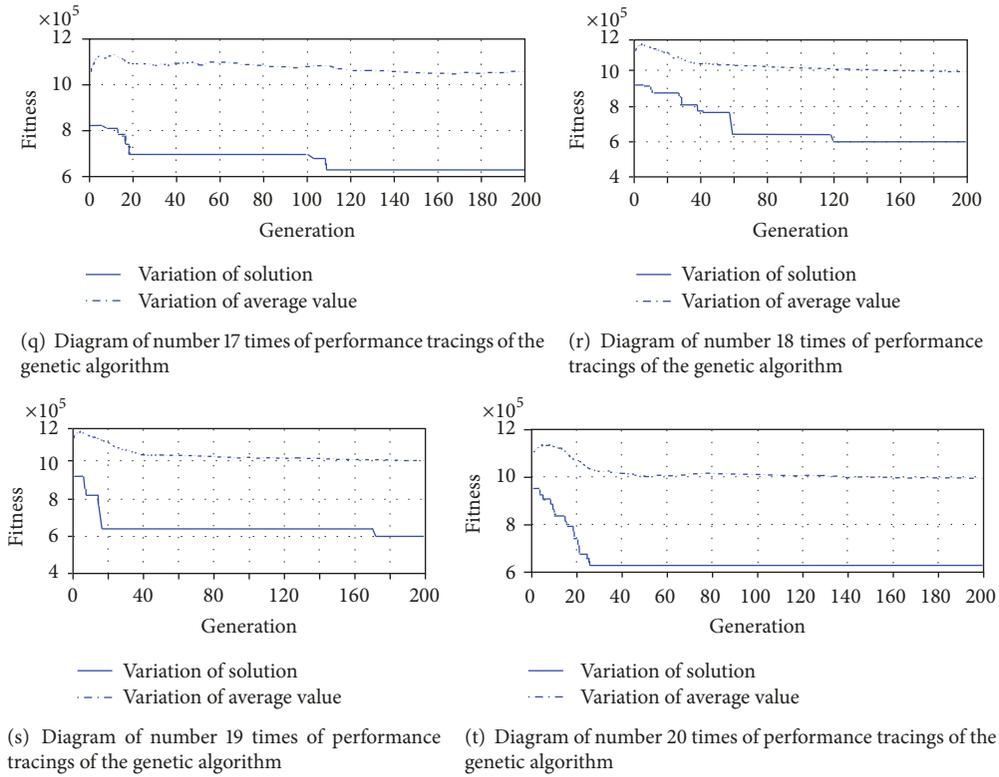


FIGURE 8

TABLE 2: Data of 20 times' operation in Matlab.

Time index	Optimal value (yuan)	Descendant generation of optimal value	Operation time (s)	Optimal binary code	Performance tracing
1	656243	1514	244.893527	10111110010000101000001	a
2	622654	3485	219.106535	111100010110110100011101	b
3	628137	3580	252.787547	111010101010110011110001	c
4	638617	784	306.611929	111100101100000100000001	d
5	611373	2472	261.379150	101100000110011010100001	e
6	626497	157	249.771833	111010100110010011100101	f
7	653815	2998	172.502950	110000000110100001011011	g
8	688007	2093	168.465815	110110101101000000010001	h
9	600608	2903	159.715251	100100101110100000100101	i
10	647640	3467	190.351622	11111000111101111110101	j
11	611642	3614	219.169720	110101011000100010101111	k
12	611642	480	242.232776	11111101100111100011111	l
13	647915	572	182.389709	110000100110000010001101	m
14	653312	3024	219.162909	101110101100100001100001	n
15	658918	2100	236.762271	100010010010000110010001	o
16	672677	2870	263.718400	111001100010011010001101	p
17	617254	2266	251.924982	111011100010101101000101	q
18	589031	2344	239.436273	111111001100001100000001	r
19	587416	3469	213.099410	101010111110001001001111	s
20	638343	532	198.166484	101001110011001110000001	t

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