Research on Optimization of Rebar Cutting Process for Prefabricated Concrete Components Based on BPI

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Abstract. In view of the characteristics of the production of precast concrete components and the cutting of rebar, from a production point of view, the introduction of BPI (business process improvement) management ideas has been introduced to optimize the rebar cutting process of precast concrete components. A multi-objective prefabricated concrete component rebar cutting model is established and an improved genetic particle swarm hybrid algorithm is proposed. It is proved by examples that the model reduces the number of raw materials and the number of rebar cuts by rationally arranging the rebar cutting combination plan, and the optimization of the prefabricated concrete components rebar process can rationally use the rebar remaining material and improve the utilization rate of rebar.

1. Introduction

Traditional construction rebar cutting is based on the results of rebar cutting to formulate a rebar raw material procurement plan, and the order of the component factory is for multiple prefabricated construction projects [1]. If the order is arranged first and then the material is fed, it is easy to cause the problems of delayed delivery of orders and stuck orders. Therefore, the traditional first-discharging and then-feeding mode is no longer suitable for prefabricated construction projects, and the rebar cutting process needs to be optimized. Many scholars have conducted research around the process optimization problem. MAHA [2] and other important factors influencing the success of BPI projects based on the Taguchi method. Dragana [3] established a BPI evaluation model from the four aspects of change, process performance, process characteristics and the influence of stakeholders to improve the company’s overall performance. Dai Linpo [4] built a business process reengineering model from the business process of enterprise production and operation management based on the background of intelligent manufacturing. Zhao Yulong [5] stated that BPI (business process improvement) is derived and improved from the BPR (business process reengineering) management method, which can avoid the high failure risk of BPR. In previous studies, the existing literature on business process optimization mainly focused on the level of enterprise management, researching process analysis tools and process simulation, and there are few studies on applying business process optimization to rebar cutting production. This paper comprehensively considers the number of cutting modes of rebar cutting and the value of multi-period rebar remnants, introduces BPI to optimize the rebar cutting process, establishes a prefabricated member rebar model, and solves the joint optimization problem of prefabricated concrete components rebar cutting and inventory.
2. Rebar cutting process optimization

The core of the optimization of the rebar cutting process is to face the rebar cutting production process, and to design and optimize each link of the rebar cutting through the global optimization goal to improve the production cutting efficiency and reduce cost losses. Introducing the business process improvement (BPI) management idea to the traditional rebar cutting process, the procurement of raw materials and the management of available surplus materials, improve the utilization of rebar raw materials and surplus materials, and optimize the prefabricated rebar cutting process.

The specific steps for the optimization of the rebar cutting process are as follows: (1) Assuming that there are infinite raw materials, the reinforcement combination plan is obtained through optimization algorithm; (2) Check the number of raw materials in stock (including the rebar remaining material), first select the rebar remnant material to optimize the rebar cutting combination, and obtain a new optimal rebar combination cutting plan; if the remaining material length is less than the required rebar length, no optimization is required. If there is a lack of sufficient raw materials, a plan for purchasing raw materials for rebar should be made; (3) Rebar cutting is carried out according to the cutting list, the remaining material is registered and stored in the storehouse, and the waste is processed. The optimization of the concrete prefabricated components rebar cutting process is shown in Figure 1.

![Figure 1. Optimization of the rebar cutting process of prefabricated components](image)

3. Mathematical model of prefabricated rebar cutting

3.1. Problem description

The problem of rebar cutting of prefabricated components can be described as: There are $I$ kinds of rebar with different lengths, the lengths are $L_i (i = 1, 2, ..., I)$. The inventory quantity of each rebar is $q_i (i = 1, 2, ..., I)$. Need to cut $J$ kinds of rebar with length $l_j (j = 1, 2, ..., J)$. Respectively, and the corresponding quantity of each type of rebar is $y_j (j = 1, 2, ..., J)$. How to cut the material to minimize the number of rebar raw materials, compare the number of rebar cutting patterns, and refer to the length of the remaining rebar to determine the best cutting plan.

3.2. Mathematical model

Based on the above description, the rebar scraps that cannot be reused are treated as waste, the larger size rebar scraps are used as remnants, and the reusable rebar scraps are not treated as waste. A large number of cutting modes for rebar cutting will increase the complexity of the cutting operation, leading to increased rebar cutting costs. Therefore, when compiling the cutting plan, the goal is to minimize the raw materials and cutting methods of the rebar, and the rebar cutting model is established, as follows:
\[
\begin{align*}
\min Z_1 &= Y = \sum_{k=1}^{K} x_k^{g(s)} \\
\min Z_2 &= K
\end{align*}
\]

Among them: \(Y\) is the total number of rebar raw materials used; \(K\) is the number of cutting methods in the cutting plan; \(g(s)\) represents the raw material number corresponding to the \(k\)-th cutting method, \(g(s) \in \{1, 2, \ldots, I\}\); \(x_k^{g(s)}\) represents the \(k\)-th cutting method number in the cutting plan is the raw material quantity of \(g(s)\).

The constraints are as follows:
\[
\begin{align*}
\sum_{j=1}^{J} a_{ij} l_j &\leq L_{g(s)}, \quad k = 1, 2, \ldots, K; \quad j = 1, 2, \ldots, J \quad (3) \\
\sum_{k=1}^{K} a_{ij} x_k^{g(s)} &= y_j, \quad k = 1, 2, \ldots, K; \quad j = 1, 2, \ldots, J \quad (4) \\
\sum_{k=1}^{K} x_k^{g(s)} &\leq q_{g(s)} , \quad k = 1, 2, \ldots, K \quad (5) \\
a_{ij} &\geq 0, \quad a_{ij} \in Z \quad (6)
\end{align*}
\]

\(a_{ij}\) represents the quantity of type \(j\) rebars cut by the \(k\)-th cutting method; \(l_j\) represents the length of type \(j\) rebars; \(y_j\) represents the corresponding quantity of type \(j\) rebars; \(q_{g(s)}\) represents the number of raw material stocks of rebars with raw material number \(g(s)\).

4. Hybrid genetic particle swarm optimization design

4.1. Genetic coding and genetic manipulation

In this paper, the symbolic coding method is adopted. The total number of rebar is \(M_i\), and the number range of rebar raw materials is \([i, M_i]\). Similarly, if the total number of required rebar is \(N_i\); the number range of required rebar is \([i, N_i]\), and the value of \(N_i\) is \(\sum_{j} y_j\). The set value of \(S\) is determined according to the type of rebar raw materials and the number of rebar required, that is, there are \(I\) types of rebar raw materials, and the total number of required rebar is \(N_i\), then the value of \(M_i\) is \((I \times N_i = I \times \sum_{j} y_j\), and the total number of rebar raw materials is sufficient.

Roulette method is used to simulate unequal probability, and chromosomes with better fitness is selected; Genetic Cross-rule adopted two-point crossover; The mutation rule adopts the position mutation method. This paper uses adaptive [6] crossover probability and adaptive [6] mutation rate.

4.2. Particle update

Particle velocity updating formula, particle position updating formula and weight update formula are as follows [7]:
\[
\begin{align*}
V_{id}^{k+1} &= \omega V_{id}^{k} + c_1 \epsilon_1 (P_{id}^{g} - X_{id}^{k}) + c_2 \eta (P_{id}^{g} - X_{id}^{k}) \\
X_{id}^{k+1} &= X_{id}^{k} + V_{id}^{k+1} \\
\omega &= \omega_{\text{max}} - k (\omega_{\text{max}} - \omega_{\text{min}}) / t_{\text{max}}
\end{align*}
\]
Among them: \( V_{id}^{k+1} \) is the speed of the \( i \)-th particle in the \( d \) dimension; \( k \) is the current iteration number; \( X_{id}^{k} \) is the position of the \( k \)-th iteration of the \( d \)-th dimension of the \( i \)-th particle; \( P_{id}^{k} \) is the individual optimal position of the \( k \)-th iteration of the \( d \)-th dimension of the \( i \)-th particle; \( P_g^{k} \) is the global optimal position of the \( k \)-th iteration of the \( d \)-th dimension of the particle swarm; \( \omega \) is the inertia weight; This algorithm uses linear weight reduction method; \( t_{max} \) is the maximum number of iterations; \( \omega_{max} \) is the initial inertia weight; \( \omega_{min} \) is the inertia weight when the maximum number of iterations is reached; \( c_1 \) and \( c_2 \) are learning factors; \( \xi \) and \( \eta \) are uniform random numbers in the interval \([0,1]\).

4.3. Hybrid genetic particle swarm optimization process
The genetic particle swarm hybrid algorithm is to obtain multiple approximate optimal solutions through PSO optimization first, and then use the adaptive cross mutation of GA to improve the population, the diversity of the population is increased, and avoid falling into the local optimum to the greatest possible extent to achieve rapid global optimization [8-9]. The algorithm flowchart is shown in Figure 2.

![Algorithm Flowchart](image)

**Figure 2. Genetic particle swarm hybrid algorithm flowchart**

5. Case study
In this paper, coiled or coiled rebar are not considered, and the cutting research is carried out for straight rebar with diameters greater than 10mm. There are two types of rebar raw materials: 9000mm and 12000mm straight threaded rebar.

According to the prefabricated building project, the standard-layer prefabricated components rebar cutting length data is collected, as shown in Table 1 below, and the mathematical model and algorithm established in Section 3 are used for simulation testing. The parameter settings of the algorithm: the
population size is 50; the number of iterations is 100, and the algorithm is run on Matlab2018a, and the result is shown in Figure 3 below.

### Table 1. Reinforcement processing data of prefabricated components.

| Demand rebar number | Rebar type | Rebar diameter /mm | Rebar length /mm | Number of rebar |
|---------------------|------------|--------------------|------------------|----------------|
| 1                   | HRB        | 20                 | 3220             | 4              |
| 2                   | HRB        | 20                 | 3440             | 2              |
| 3                   | HRB        | 20                 | 4640             | 4              |
| 4                   | HRB        | 20                 | 5110             | 4              |
| 5                   | HRB        | 20                 | 5630             | 8              |
| 6                   | HRB        | 20                 | 5720             | 2              |

Figure 3. Comparison of iteration curves

It can be seen from Figure 3 that the genetic-particle swarm hybrid algorithm can effectively continuously optimize toward the optimal solution. In the later stage of the iteration, the objective function value remains basically stable, and due to the original particle swarm algorithm. The cutting table of prefabricated components rebar is shown in Table 2.

### Table 2. Rebar cutting plan.

| Number | Rebar raw material length /mm | Required rebar length /mm | Number of uses of cutting method | Remaining length of rebar/mm | Utilization % |
|--------|-------------------------------|---------------------------|---------------------------------|-----------------------------|---------------|
| 1      | 9000                          | 5720,3220                 | 2                               | 60                          | 99.33         |
| 2      | 9000                          | 3440,5110                 | 2                               | 450                         | 95            |
| 3      | 9000                          | 5630,3220                 | 2                               | 150                         | 98.33         |
| 4      | 9000                          | 4640(2)                   | 2                               | 280                         | 96.87         |
| 5      | 12000                         | 5630(2)                   | 2                               | 740                         | 91.78         |
| 6      | 12000                         | 5110,5630                 | 2                               | 1260                        | 86            |

Note: the amount of rebar in brackets.

A total of 12 raw materials are required to obtain the optimal cutting combination plan, including 8 of 9000mm and 4 of 12000mm raw material. There are 6 cutting modes for cutting, and the length of the last remaining material is 1260mm. The two rebars with a length of 1260mm can be put into the rebar inventory, waiting for priority use in the next processing. Known from inventory, the remaining stock length is 4360mm, there are 2 pieces, and the remaining material length is 7360mm, there are 2 pieces, and the optimal rebar combination plan can be adjusted, shown in Table 3.
Table 3. The optimized rebar cutting plan.

| Number | Rebar raw material length /mm | Required rebar length /mm | Number of uses of cutting method | Remaining length of rebar/mm | Utilization % |
|--------|-------------------------------|---------------------------|---------------------------------|------------------------------|---------------|
| 1      | 4360                          | 3440                      | 2                               | 920                          | -             |
| 2      | 7360                          | 5630                      | 2                               | 1730                         | -             |
| 3      | 9000                          | 5630, 3220                | 2                               | 150                          | 98.33         |
| 4      | 9000                          | 4640 (2)                  | 2                               | 280                          | 96.87         |
| 5      | 9000                          | 5720, 3220                | 2                               | 60                           | 99.33         |
| 6      | 12000                         | 5110, 5630                | 4                               | 1260                         | 86            |

Note: the amount of rebar in brackets.

From Table 3, the actual number of rebar raw materials used is 10, of which 6 are 9000mm raw materials and 4 are 12000mm raw materials. Compared with the data in Table 2, this scheme reduces the use of rebar, so the utilization rate of rebar is improved by the value of the remaining rebar.

6. Conclusion
In this paper, aiming at the problem of rebar cutting in prefabricated components, the BPI management idea is introduced to optimize the rebar cutting process, and a prefabricated member rebar cutting model is established. The optimization of the rebar cutting process based on BPI considers the value of multi-period rebar residual materials. The example verifies that the proposed model and algorithm can obtain a plan with the fewest rebar raw materials and fewer cutting patterns. Through multi-period order operation, the remaining materials in inventory can be fully utilized and the utilization rate of rebar can be improved.

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