Optimization of the raw material field layout for iron-steel enterprise

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Abstract. This paper studies a short-term layout optimization problem with the raw material field for iron-steel enterprises. The raw material field is a centralized storage place and distribution unit of various raw materials such as iron ore, which plays a significant role in the iron front logistics for iron and steel enterprises. Whether the stacking of raw materials is reasonable or not directly affects the logistics efficiency and logistics cost of raw materials for iron-steel enterprises. Based on the status and basic information of the raw materials, storage space of the field shall be made full use of to allocate the optimal position for each type of raw material. To achieve this goal, a mixed integer programming (MIP) model is developed, which is purposed to minimize the transportation cost and the loss of mixing. The solution compares favorably with the current practice in the iron-steel enterprises.

1. Introduction

The raw material field of iron-steel enterprise is the supply department for iron and steel production, and it is the preparatory stage of production. Normal smooth production of iron-steel enterprises must first rely on raw material. In the blast furnace iron-making process, the consumption of unrefined fuel accounts for more than 85% of the manufacturing cost of pig iron. Therefore, whether or not the production logistics of raw fuel bulk material is reasonable will have a direct impact on the production cost, product output and productivity of the iron-steel enterprises [1-2]. Therefore, scheduling and optimizing management of the raw fuel's circulation process is of great significance to the reduction of costs and ensuring the smooth production of the iron-steel enterprises.

The optimization of the raw material field layout for the iron-steel enterprises is premised on the inventory status of the raw material field and the basic information on the raw materials. Based on the design principle of the raw material yard layout, the optimal position is allocated for each kind of raw material in order to make full use of storage space in the raw material yard. The essence of this is to select the most appropriate storage space for each raw material and for the remaining vacancy of the raw material yard. This is a typical optimization problem. Scientific and rational layout of the raw material yard should be easy to heap, fetch and manage. Therefore, the rational allocation of raw material in the stock yard will have a direct effect on the utilization ratio of the raw material yard, thereby further affecting the production costs and economic benefits for the iron-steel enterprises.

Achieving an optimal layout of raw material fields in iron-steel enterprises needs decision to be made on where to place each type of raw material in the raw material field. Different from the daily
decision on unloading stockpile operation, it belongs to the layout optimization problem in the short and medium term [3]. Unlike the typical logistics problems such as containers, there are few studies on the optimization of raw material field layout for iron ore and other bulk materials at home and abroad. Besides, they are subjected to certain limitations. Due to the particularity of the raw material logistics in the iron-steel enterprises, other similar storage layout planning problems cannot be directly applied to optimizing the layout of the iron and steel raw material field [4-5]. The literature studies the storage and distribution problems with raw material fields in large-scale iron-steel enterprises, and constructs a nonlinear mathematical model to reduce costs and maintain the stability of raw material components as an objective function. An improved tabu search algorithm is proposed to address the problem, but no mathematical expressions are presented for the raw material neighbor relationship, specific storage locations, and distribution relationships [6]. The literature gives consideration to the impact of transportation costs and demand on the choice of the strip. However, the specific location of raw material in the strip is discounted, and the loss of mixture between adjacent materials is neglected. The mixed integer programming model is solved by using standardized software [7]. The literature has studied the raw material yard configuration process of the Masteel Harbor Materials Factory, and the process management requirements for raw material stacking are summarized [8].

This paper is purposed to study the optimal layout of different types and quantities of raw material on the raw material field of iron-steel enterprises to minimize the cost of transportation and the loss of mixed material.

2. literature review
As for the research into the layout of the raw material field in iron-steel enterprises, Japan has taken the lead. The literature [9] studied the problem of resource allocation, and established a mathematical model for the continuous resources and the discrete resource allocation problem of similar steel materials, and carried out the optimization analysis. Japanese iron-steel enterprises have also taken the lead in the development and design of expert systems for raw material logistics management. For example, the Chiba iron making plant has developed the raw material field operation plan system and production management system.

The raw material of iron-steel enterprises is transported to the raw material terminal by sea transportation, unloading and loading at the dock, and then transferred to the raw material yard. Therefore, material loading and unloading and berth arrangement are closely related to the layout of the raw material field. KAO et al. studied the optimization of berthing arrangements and unloading of raw material [10-11]. Li et al. researched the problem of continuous static berth allocation, with the problem being mathematically modeled and solved by the first matching descending meta-heuristic method [12]. Kao and Lee have studied the coordinated scheduling problem between the raw material wharf berth and raw material unloading of Sinosteel. In the initial stage, these two issues were separately decided, and the unloading time obtained by the raw material unloading problem is used as the input of the berth arrangement and re-determine the problem of unloading vessel berthing plan. Lim has studied the discrete dynamic berth allocation problem, and designed a heuristic method based on graph representation to resolve the problem [13]. Guan and Cheung performed study on the problem of continuous dynamic berth allocation where multiple ships can occupy one berth at the same time, and proposed two solutions. One is a tree search algorithm, and the other is a large-scale problem solving algorithm. A pair wise combinatorial heuristic algorithm and tree search algorithms are designed to address the problem [14]. Imai et al. studied the dynamic berth allocation problem with a zigzag distribution, and established an integer linear programming model using a genetic algorithm [15].

Xi et al. applied operational research principles to study the optimization of transportation routes for raw material yards and established a mathematical model for proportioning and transportation operation. Reasonable adjustments were made to the material yard's cargo space, as well as the rational dispatch of on-site transportation, and obvious economic benefits were achieved [16]. Li et al. constructed a non-linear mathematical model to reduce the cost and maintain the stability of raw
material components as the objective function for the distribution of raw material storage in iron-steel enterprises, and proposed improved tabu search algorithm as a solution. The results demonstrate that the proposed algorithm is a fast and effective near-optimal algorithm to solve the practical industrial problems [17]. Wang et al. learned from the business philosophy of Lingang Iron and Steel Corporation and optimized the material reception, storage, and supply processes of the integrated raw material field. Through reasonable layout of technology and perfect automation control and information system, the management level of the yard was improved and the purpose of high-efficiency and low-cost operation was achieved [18]. Zhang et al. researched the relationship between quarry sites and conservation sites based on the distribution and resource characteristics of stone sites in Shaanxi Province. The layout of the stone field is one boils down to the discrete location problem. A mixed integer programming model is established by using the Dakin branch-and-bound method. The result indicates that this model is capable of drawing a reasonable layout plan for a stone yard [19]. Lu and Wang combined the actual production of a raw material yard at the Masteel Harbor Materials Factory and conducted in-depth research into the relevant contents of the yard configuration management [8]. Ke and Zheng established a yard input configuration model in order to improve the utilization of raw material yards and reduce the cost incurred by yards. Analytic hierarchy process and mathematical optimization method are used to solve the raw material field. Finally, the results of the model are analyzed and evaluated [20]. He and Ma studied the optimization of ore allocation in Baosteel with regard to the actual situation of the raw material yard combined with the production process and the raw material yard transformation plan. The existing storage space in the yard is used to rationally allocate raw material and improve the site utilization rate. Not only does this meet the requirements for safe production raw material, it also reduces costs [21].

3. Problem description and model formulation

3.1. Problem description

The raw material field can provide strong support to the follow-up production for iron-steel enterprises. In order to stabilize production and continue, it is necessary to supply raw material of high grade, less impurity content, less powder and uniform particle size. Therefore, it is a necessity to optimize the process of raw material processing, to which the layout of the raw material field is the key. The raw material stored in the raw material yard is not only directly purchased but also has multiple varieties such as secondary crushing and blending of mineral materials. How to arrange these kinds of raw materials with different characteristics and different characteristics of suitable strips, and ensure the stability of the original material quality to minimize the loading and unloading transportation costs, is a typical optimization problem.

Fig. 1 shows a typical layout diagram of raw material field in an iron-steel enterprise. Due to the different physical and chemical properties of raw material, the raw material yard usually implements the principle of classified storage. It can be roughly divided into several categories, such as the main

Figure 1. The layout diagram of raw material yard
ore material strip, the auxiliary ore material strip, the coal material strip, the blending ore material strip and so on.

A rail-type stacker-reclaimer is arranged between the strip and can be unloaded and taken out along the strip. There are two sources of raw materials for iron-steel enterprises, one of which refers to foreign mines. By water transport, they are shipped to the raw material terminal for unloading to the dock yard, prior to being transported by a belt conveyor to the designated stockyard. The other one refers to domestic mines. In this case, they are transported to the iron-steel enterprise by railway or highway, before being stored at the designated position by the stacker-reclaimer in the raw material field. The various processing and storage facilities in the yard are primarily transported by belts and equipped with transfer stations. The yard is complete with stacker, reclaimer, screening equipment, belt conveyor and other transmission equipment, all of which are connected by a belt. The completion of a transport task from the starting point to the finish point in the yard depends on the joint operation of various equipment such as stocker, reclaimer, belt conveyor and mine dump truck. The raw material logistics process of iron-steel enterprises is presented in Fig. 2.

In order to better provide the blast furnace with raw materials of consistent quality, balanced composition and high quality, the raw material field needs to optimize the configuration and spatial layout for raw materials.

3.2. Model
The known information about the raw material field, such as the type and amount of raw materials to be stacked, raw material requirements for each production plant, etc., is factored into the mathematical model as known parameters.

Sets and Parameters

- \( I \) Set of original material variety, \( i \in I \).
- \( K \) Set of strips, \( k \in K \).
- \( P \) Set of production workshops, \( p \in P \).
- \( L \) Set of strip locations, \( l \in L \).
- \( c_{ik} \) The fixed transportation cost of raw material \( i \) from discharge point to strip \( k \).
- \( h_{kp} \) The unit transportation cost of raw material \( i \) from strip \( k \) to shop \( p \).
- \( s_{ij} \) The penalties for mixing due to mixing of raw material \( i \) and raw material \( j \) when they are stacked next to each other.
- \( E_k \) The storage capacity of strip \( k \).
- \( n_i \) The number of strips required for the safe configuration of raw material \( i \).
- \( Q_i \) The maximum amount of raw material \( i \) needs to be sent to the workshop.
- \( q_i \) The safety stock of raw material \( i \).
- \( f_i \) The lowest stock of the raw material \( i \) placed on the strip when the multi-strip safety configuration is adopted.

Figure 2. Raw material flow structure of iron-steel enterprise
The demand for raw material $i$ in workshop $p$ during the safety stock period.

The decision variables are as follows.

- $x_{ik}$: 1, if the raw material $i$ is distributed on the strip $k$; 0, otherwise.
- $y_{ik}$: The storage quantity raw material $i$ is distributed on the strip $k$.
- $z_{ikl}$: 1, if the raw material $i$ is distributed in the $l$-position stored on the strip $k$; 0, otherwise.
- $w_{ij}$: 1, if the raw material $i$ and $j$ are stacked adjacent to each other; 0, otherwise.
- $u_{ikp}$: The transportation quantity of raw material $i$ transported from the strip $k$ to the workshop $p$.

Using the above parameters and decision variables, the established mixed integer programming model is constructed as follows:

\[
\begin{align*}
\min & \sum_{i \in I} \sum_{k \in K} c_{ik} y_{ik} + \sum_{i \in I} \sum_{j > i} s_{ij} w_{ij} + \sum_{i \in I} \sum_{k \in K} \sum_{p \in P} h_{ikp} u_{ikp} \\
\text{s.t.} & \sum_{k \in K} y_{ik} = q_i & \forall i \in I \\
& \sum_{i \in I} y_{ik} \leq E_k & \forall k \in K \\
& \sum_{k \in K} x_{ik} = n_i & \forall i \in I \\
& \sum_{i \in I} z_{ikl} = x_{ik} & \forall i \in I, k \in K \\
& \sum_{i \in I} z_{ikl} \geq \sum_{i \in I} z_{ik,l+1} & \forall i \in I, k \in K \\
& w_{ij} + w_{ji} \geq 2 \cdot (z_{ikl} + z_{ik,l+1} - 1) & \forall i \in I, j \in I, k \in K, l \in L \\
& \sum_{p \in P} u_{ikp} \leq Q \cdot x_{ik} & \forall i \in I, k \in K \\
& \sum_{k \in K} u_{ikp} \geq D_{ik} & \forall i \in I, p \in P \\
& f_r x_{ik} \leq y_{ik} \leq q_i x_{ik} & \forall i \in I, k \in K \\
& x_{ik}, z_{ikl}, w_{ij} \in \{0, 1\} & \forall i \in I, j \in I, k \in K, l \in L \\
& y_{ik}, u_{ikp} \geq 0 & \forall i \in I, k \in K, p \in P
\end{align*}
\]

The objective function (1) includes the minimization of the three-part cost function, which is followed by the charge for transportation from the unloading point to the material strip, the mixture penalty cost incurred from the stacking of raw material, and the charge for transportation of each strip to each workshop. Constraint (2) ensures that each raw material is allocated to the strip in line with the configuration requirements. Constraint (3) ensures that the raw material allocated to each strip is in no excess of the storage capacity of the strip. Constraint (4) is the strip safety configuration constraint, for example, the raw material for spouting-blowing coal is 3 for safe configuration, as shown in Fig. 3.
Figure 3. Example of multi-bar security configuration constraints

Constraint (5) is a logical constraint to ensure that the logic between the variables is correct. Constraint (6) ensures that the raw material on each strip is next to each other. As shown in Fig. 4, in the main raw material yard, the spouting-blowing coal is close to the pile on the strip, and the coke powder cannot be inserted in the middle of the spouting-blowing coal.

Figure 4. Example of raw material configuration

Constraint (7) is capable of calculation of the close-to-stack relationship between the given two raw materials. It is worth noting that with two raw materials $i$ and $j$ considered, the variables $w_{ij}$ and $w_{ji}$ representing the two raw materials with close-to-stack relations correspond to two 0-1 variables respectively. The raw materials $i$ and $j$ are stacked in position $l$ and position $l+1$ on the same strip $K$ respectively. The 0-1 variable $z_{ikl}$ and $z_{jk,l+1}$ are both 1, then this formula is validated as true, as shown in Fig. 5.

Figure 5. The illustration diagram of the constraint (7)

Constraint (8) ensures that a raw material can be transported to the workshop only when it stores the raw material of a given variety for one’s strip. This constraint indicates the meaning of scale efficiency, and the raw material will only be transported after a certain amount of aggregate is gathered. As the scale increases, transportation costs will be reduced, thus increasing savings. In the mean time, economic benefits will be increased. Constraint (9) is the constraint of demand satisfaction to ensure that the material demand of each workshop is satisfied. Constraint (10) gives the upper and lower boundary requirements for the stockpile of raw material on the strip. Constraints (11) and (12) are the ranges of variables.
4. Numerical experiment
The above model fully demonstrates the characteristics of the layout problem with the raw material field in the iron-steel enterprises, and is a relatively easy-to-solve mixed integer programming linear model. Therefore, this problem is solved with the standardized solver CPLEX.

The algorithm proposed in this chapter was developed in Visual Studio 2010 under the Windows 7 environment. The test was performed on a computer with a CPU frequency of 3.1 GHz and physical memory of 4 GB, and the model was solved by the standardized solver CPLEX.

Based on the analysis of the practice adopted in the iron-steel enterprises, the site length and correlation coefficient required for storing the raw material was determined. Raw material transportation costs, fixed costs for stock yards, the penalty costs between materials, and raw material weight were all generated by a special random number generation program. The parameter distribution interval was determined under the actual conditions of iron and steel enterprises of raw material field. A total of 15 groups examples were obtained randomly. The results of the example calculations are presented in Table 1.

Table 1. Solution results

| Numerical example | Number of raw material varieties | Yard | Workshop | Objective function value | Solution time (s) |
|-------------------|---------------------------------|------|----------|--------------------------|------------------|
| 1                 | 20                              | 3    | 4        | 3.82 E+05                | 3.01             |
| 2                 | 20                              | 4    | 5        | 4.11 E+05                | 3.75             |
| 3                 | 20                              | 5    | 6        | 4.36 E+05                | 3.92             |
| 4                 | 40                              | 6    | 8        | 6.23 E+06                | 7.98             |
| 5                 | 40                              | 8    | 10       | 6.45 E+06                | 8.45             |
| 6                 | 40                              | 10   | 12       | 6.67 E+06                | 10.02            |
| 7                 | 60                              | 10   | 12       | 9.79 E+06                | 28.94            |
| 8                 | 60                              | 12   | 15       | 1.54 E+07                | 32.76            |
| 9                 | 60                              | 15   | 20       | 3.27 E+07                | 42.65            |
| 10                | 80                              | 12   | 15       | 2.63 E+08                | 135.75           |
| 11                | 80                              | 16   | 18       | 7.92 E+08                | 156.79           |
| 12                | 80                              | 20   | 25       | 9.98 E+08                | 179.42           |
| 13                | 100                             | 16   | 20       | 4.64 E+09                | 289.53           |
| 14                | 100                             | 20   | 25       | 7.12 E+09                | 311.96           |
| 15                | 100                             | 25   | 30       | 9.59 E+09                | 338.15           |

The mixed integer programming model proposed in this paper is identified as suited to solving the iron ore yard allocation problem in steel plants. By applying the same cost coefficient to the actual production data, the solution of the model is compared with the actual results of iron-steel enterprises. Table 2 reveals that there are advantages in the solutions to the layout optimization model for both the transportation charges and the cost of penalties for mixing materials (maintaining the stability of the raw material quality). The results obtained from 15 studies are averaged, which indicate that the model solution suggested in this paper saves 21.26% on average in transportation charges, 36.87% on average in the cost of penalties for mixing materials, and 24.41% in total costs.
5. Conclusion

In this paper, the layout planning problem of iron and steel raw material field is explained, and a mixed integer programming model is proposed. Based on the actual production data, the model is solved and the superiority of the optimal solution of the model solution compared with the actual production data is identified. As for the medium-term and short-term planning, the raw material storage location is reasonably solidified. Not only does this have an advantage in logistics costs, it also enables the daily input, output, and stockpiling of raw material to follow the simple rules to ensure the smooth operation. In this case temporary repetitive decisions will be avoided, thereby enhancing the logistics and management efficiency of raw material for iron-steel enterprises. This study is of certain reference value for the optimization management of raw material logistics system in iron-steel enterprises.

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