Abstract—The inbound and outbound operation of plate yards in shipyards lacks effective scheduling with high operation costs. Based on the analysis of steel-in and steel-out operation process, an optimization model aiming to minimize the operation cost was established. The model was formulated as a multi-level combinatorial optimization model, which is finding proper storage locations during the steel-in stage to minimize the cost during the steel-out stage. Furthermore, greedy algorithm was implemented to solve this problem. Finally, application data obtained from a shipyard was used to validate the model, and the result shows that the proposed algorithm is effective to solve the steel stockyards scheduling problem.

Index Terms—Greedy Algorithm, Plate Operation Plan, Steel Plate Yard, Scheduling

I. INTRODUCTION

In recent years, as the control on shipbuilding costs and the on-time supply of steel plates are getting stricter, the management of steel plate yards is becoming more emphasized by the shipyard. The management of steel plate yards in shipyards has the following characteristics: (1) Daily inbound amount of steel plates is large. The inbound amount of steel plates of medium and large shipyards for every month is about 57000 tons. (2) There are many types of steel plates. The specification number of steel plate for each ship type can reach up to thousands. (3) The steel plate yard is small, resulting in high stacking layers. (4) The steel plates reach intermittently. The steel plates being cut on the same date reaches in different batches from different suppliers. (5) The stockyard department has close relation with other departments like the marketing department, design department, dispatch department and manufacturing department.

That many specifications and large number of steel plates means that traditional methods are insufficient to solve the problem of steel plate optimization management for large-scale yards. The close relation with other departments means many problems with the inbound of the steel plates will directly affect the follow-up work in other departments (e.g. If the outbound of the steel plates are not on time, the steel cutting operation in manufacturing department will be delayed).

At present, the study on operational plans for steel plate yard mainly focuses on optimizing outbound operation of steel plates, such as the study on reducing shuffling workload as the main optimization objective [1], the study on making the shortest time for outbound operations as the objective [2] and the study on outbound operation plans of plates with minimizing operation costs as the objective [3]. The operation process of steel plate yards can be divided into two stages, inbound and outbound. The misplacement of steel plates for the inbound stage is the fundamental reason for causing large number of shuffling. Therefore, only considering the outbound of steel plates and only optimizing the outbound stage can’t fundamentally reduce the shuffling amount and reduce the outbound cost.

The layout and operation plan for steel plate yards is similar to the operation of container yard. The study on container yard aims to optimize the allocation of spaces and shuffling amounts [4-8]. But the difference between the operation plan of steel plate yards and container yards is that the steel plates have more specifications and demands of mixed storage. Also, as there are a much larger number of steel plates compared to containers, the stacking layer of steel plates is much more than that of containers. Therefore, while the study methods of operation plan for container yards are useful on the scheduling of steel plate yard, the methods cannot be applied directly.

The paper analyzes the inbound and outbound procedure of steel plates in shipyards, establishes the encoding mechanism which quickly and accurately describes the specific place and storage location of steel plates in the steel plate yard. And a mathematical model is built to minimize the inbound and outbound cost of steel plates and choose proper storage locations for the inbound steel plates to reduce the total shuffling amount. Furthermore, the paper uses greedy algorithm for solutions, and combines the practical data of a shipyard for an empirical test on the model. A numerical test is analyzed at last, which indicates that the greedy algorithm is more effective and provides basis for the managers.

II. PROBLEM DESCRIPTION

A. Layout of Steel Plate Yards

A typical steel plate yard usually consists of four parts; temp yard, main yard, pretreatment machine room and transferring yard. The temp yard is the temporary loading area of steel plates. The main yard consists of several bays. Each bay is divided into several storage locations, and each bay is installed with one or more cranes for transporting the steel plates. The transportation between
bays is done through the conveyor belt. The process from temp yard to the main yard is called the inbound. Formulating the inbound plan aims to determine the storage location for the inbound steel plates. After receiving the outbound plan of steel plates, the steel plate yard needs to make pretreatment on the plates. The preprocessing process includes thermal treatment, shot blasting, painting and drying. After pretreatment, the steel plates are stored in the transferring bay of transferring yard by categories for outbound.

B. Encoding Mechanism

In order to quickly and accurately describe the specific place and storage location of steel plates in the steel plate yard, the paper establishes the encoding mechanism of plate yard. The establishment of the encoding mechanism for steel plate yard needs to have a recognition function and arrangement function. In the three-dimensional steel plate yard shown in Figure 1, the encoding for steel plate yard is divided into location code and layer code.

(1) Location code: Each location in the yard is encoded and numbered according to the sequence. \( K \) represents the location number of yard, \( K = \{1,2,\ldots,K_{\text{max}}\} \), in which \( K_{\text{max}} \) means the maximum of location number in yard.

(2) Layer code: The steel plates stacked in each location are encoded, and is ordered according to the sequence from bottom to up. \( Q \) represents the number of layers in storage location. \( Q = \{1,2,\ldots,Q_{\text{max}}\} \), in which \( Q_{\text{max}} \) means the maximum of the number of layers which is determined by the height of bridge crane operation.

The above encoding mode is used, and the place of any layer for any storage location in yard can be represented by \( [K,Q] \). If there is a steel plate in the layer, the stacking status is defined as \( L_{[K,Q]} = 1 \), if there is no steel plate in the layer, the stacking status is defined as \( L_{[K,Q]} = 0 \). For example, there are plates stacking in the third layer of location in Figure 1, it can be represented as \( L_{[1,3]} = 1 \). The encoding mode makes the steel plate place and the stacking status digitalize, which is easy for computer recognition and software calculation and analysis.

![Figure 1. Diagram of yard storage location number and steel plate number](image)

C. Cost Analysis of Inbound and Outbound Process

The process of steel plates from wharf to outbound can be divided into three stages: arrival of plates, inbound of plates and outbound of plates, as shown in Figure 2. Different steel plate patterns represent different outbound date.

The operation cost of plates can be mainly divided into inbound cost and outbound cost:

(1) Inbound cost is the cost of moving plates from the temp yard to the appointed place, and it is directly proportional to the displacement distance from the temp yard to the appointed storage location and transporting unit cost, in which transporting unit cost is determined by the bridge crane transporting plates expense, manpower expense and the displacement distance, while the expense of pickup and unloading plates is determined by bridge crane expense and manpower expense.

(2) Outbound cost consists of shuffling cost and transporting cost. It is directly proportional to the shuffling quantity, the shuffling displacement distance, transporting unit cost and the expense of pickup and unloading plates. The shuffling cost is influenced by shuffling quantity, distribution of outbound date, bridge crane expense and manpower expense. For example, in the outbound of the plates in the second day in Figure 2, the outbound of plate \([2,1]\) and \([2,2]\) needs to shuffle the plate \([2,3]\), which forms the shuffling cost. The outbound transporting cost is directly proportional to the displacement distance from the storage location to the entrance of main yard, transporting unit cost and the expense of pickup and unloading plates, and it is mainly influenced by the displacement distance, bridge crane expense and manpower expense.

![Figure 2. Diagram of inbound a](image)

Objective function (1) is the minimized cost of inbound and outbound stages, which contains inbound cost and outbound cost. Constraint condition (2) ensures that the storage location chose by the plates is in the yard exists, constraint condition (3) ensures the storage location chose by the plates can’t exceed the maximum limit of each storage location, constraint condition (4) guarantees the number of the batch of plates to be warehoused can’t exceed the upper limit of the yard capacity, constraint condition (5) guarantees that the

\[
C = \min \sum_{i=1}^{p} \left( \lambda \ast d'_{i} + f \right) + \left( \lambda \ast d''_{i} + f \right) + \sum_{0<K<K_{\text{max}}} \left( \lambda \ast 2d''_{m} + f \right) \ast \min \left\{ \max \left[ \left( T_{i} - D_{i} \right), 0 \right], 1 \right\}
\]

S. T.

\[
0 < K_{i} \leq K_{\text{max}} \quad (2)
\]

\[
0 < M \leq Q_{\text{max}} \quad (3)
\]

\[
0 < i \leq i_{\text{max}} \quad (4)
\]

\[
0 < T \leq T_{\text{max}} \quad (5)
\]

\[
L_{[K_{i}, m]} \geq L_{[K_{i}, m+1]} \quad (6)
\]

\[
S_{[K_{i}, m]} \geq S_{[K_{i}, m+1]} \quad (7)
\]

\[
0 < t \leq t_{\text{max}} \quad (8)
\]

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outbound date of plates is within the constraint time, constraint condition (6) makes sure that the plates can’t be placed and suspended in air, constraint condition (7) makes sure the size of lower layer of plates in the same storage location cannot be less than the size of higher layer of plates, constraint condition (8) makes the number of outbound date types in the same storage location is positive integer.

In the actual production process of shipyard, it is not allowed to storage longer plates on shorter plates, which can cause the deformation of plates. Due to the constraint of size and outbound date, there may be the possibility that the number of plates stacking in an individual storage location is much greater than that in other storage locations in the inbound process of plates, which is not easy for the subsequent shuffling and outbound swing. In order to balance the number of plates in each storage location and accurately describe the rational degree used by storage location in yard, the standard deviation of the number of plates in storage location is used as the evaluation standard of the rational degree for storage.

\[ R = \frac{1}{K_{max}} \sum_{i=1}^{n} (x_i - \mu)^2 \]  

\( R \) is the rational degree for storage, \( K_{max} \) is the total number of storage location, \( x_i \) is the number of plates in each storage location, \( \mu \) is the mean value of \( n \) plates which can be stacked for each storage location. The smaller the value of rational degree is, the more balanced the number of plates in each storage location, and the higher the rational degree of storage and vice versa.

III. SOLVING METHODS BASED ON GREEDY ALGORITHM

Optimization on inbound and outbound operation plan of steel plates is a discrete and combinatorial optimization problem. It is on a large scale, has many constraint conditions and belongs to NP difficulty, which is difficult to figure out the optimal solution using accurate methods. For these problems, the researchers usually use heuristic algorithm to solve, such as genetic algorithm in Ref [2]. The greedy algorithm used in the paper is an efficient algorithm solving the near-optimal solution. Its basic idea is that the method of constructing the optimal solution step by step is used. In the process of construction, each step takes the optimal decision under certain greedy criterion, and once the decision is made, it can’t be modified. The characteristic is consistent with the characteristic of gradually inbound of plates. Meanwhile, the solution of greedy algorithm has less time-consumption and has unique operation result, which can provide effective decision support for the managers of plate yard. Therefore, the paper use greedy algorithm as the method of solving the inbound and outbound model of plates.

A. Greedy Algorithm

The greedy algorithm is as follows: Supposing that there are \( P \) pieces of plates arriving initially, the number of specifications for plates is \( S \), the set of outbound data for plates is \( T(1, 2, …, l_{max}) \) in which \( l_{max} \) represents the maximum of outbound date types, the number of storage location of yard is \( K_{max} \), the upper limit of the number of plates which can be stacked for each storage location is \( \mu \), and the number of plates which can be stacked for each storage layer is \( \mu \).

\[ R = \frac{1}{K_{max}} \sum_{i=1}^{n} (x_i - \mu)^2 \]

\( R \) is the total inbound and outbound cost of each piece of plate minimal. And the optimal value for the piece of plate is \( C_{i_{min}} = \min(C_{i_1}, C_{i_2}, …, C_{i_K}) \).

And the procedure of greedy algorithm solving operation plan model is as follows:

Step 1: Initializing the yard state, the amount and specification of the inbound plates, inbound sequence and outbound date.

Step 2: Plates are put in the storage in order, and chooses storage location. If the storage location is empty, the inbound of the plate can’t make stack transfer, and the next plate is put in storage. If the storage location is not empty, it needs to enter step 3.

Step 3: If the type of the plate is greater than that of the plate in the storage location, the plate needs to choose storage location again, and switches to step 2, or enters step 4.

Step 4: If the type of the plate is smaller than or equal to the plate in the storage location, and the outbound date of the plate is after that of the plate in the storage location, it wouldn’t make stack transfer. If the outbound data of the plate is prior to that of the plate in the storage location, it would make stack transfer. According to greedy criterion, the stack location with the lowest inbound and outbound cost is calculated.

Step 5: The new plates are put in storage, and enters step 2 until all plates are put in storage.

Step 6: All solution elements are combined to a feasible solution, which can get the minimal inbound and outbound cost and the storage location and the number of layer for each plate.

B. Case Study

In order to verify the effectiveness of the model and algorithm, the planned dispatching of steel plate yard for a large shipyard within a week in Shanghai China is taken as an example. The experiment includes the following input parameters: (1) Size of yard and the current applied situation. Size of yard is shown in Figure 3. The initial state of yard is empty. According to the actual production experience of the shipyard, the transporting unit cost is ¥ 1 per meter, the expense of pickup and unloading plates is ¥ 2.5 per time.

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TABLE I. INBOUND AND OUTBOUND PLANNING OF PARTIAL PLATES

<table>
<thead>
<tr>
<th>Sequence number</th>
<th>Code of plates</th>
<th>Specification(length × width)(mm)</th>
<th>Outbound date</th>
<th>Number of storage location</th>
<th>Layers</th>
<th>Shuffling amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1750</td>
<td>R01C16301</td>
<td>5100×2000</td>
<td>15</td>
<td>19</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>1786</td>
<td>R01C16102</td>
<td>7500×2700</td>
<td>15</td>
<td>19</td>
<td>41</td>
<td>0</td>
</tr>
<tr>
<td>1817</td>
<td>R01C17042</td>
<td>7500×2800</td>
<td>15</td>
<td>19</td>
<td>42</td>
<td>0</td>
</tr>
<tr>
<td>88</td>
<td>R01C13089</td>
<td>12700×2500</td>
<td>7</td>
<td>20</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>110</td>
<td>R01C13005</td>
<td>13500×3540</td>
<td>4</td>
<td>20</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>114</td>
<td>R01C13063</td>
<td>13850×2230</td>
<td>4</td>
<td>20</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>164</td>
<td>R01C17642</td>
<td>12700×2230</td>
<td>2</td>
<td>20</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>168</td>
<td>R01C18008</td>
<td>9000×2500</td>
<td>2</td>
<td>20</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>301</td>
<td>R03C14081</td>
<td>9400×2560</td>
<td>2</td>
<td>20</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>345</td>
<td>R03C14088</td>
<td>9750×2900</td>
<td>15</td>
<td>20</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>349</td>
<td>R03C14133</td>
<td>10900×3200</td>
<td>7</td>
<td>20</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>360</td>
<td>R03C14083</td>
<td>9400×2500</td>
<td>1</td>
<td>20</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>377</td>
<td>R02C19066</td>
<td>5100×2400</td>
<td>1</td>
<td>20</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>406</td>
<td>R02C19180</td>
<td>7800×2230</td>
<td>15</td>
<td>20</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>408</td>
<td>R02C19069</td>
<td>7800×2700</td>
<td>1</td>
<td>20</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>449</td>
<td>R02C19872</td>
<td>7500×2400</td>
<td>15</td>
<td>20</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>455</td>
<td>R02C19674</td>
<td>7500×2230</td>
<td>5</td>
<td>20</td>
<td>14</td>
<td>3</td>
</tr>
</tbody>
</table>

The average shuffling amount of shipyard in actual production is 4 pieces. And we can find that the operation result of the algorithm is better than the actual operation level of the shipyard.

Figure 4 is the inventory quantity of plates in each storage location after warehousing.
the average quantity gap of the plates stored in each storage location is 15.27 pieces. According to the average thickness of plates which is 25mm, we can calculate that the stacking height gap of plates is about 38cm, resulting in convenient pickup and handling plates of crane.

C. Numerical Test Analysis

(1) Algorithm Comparative Analysis
In order to compare the advantages and disadvantages in controlling the outbound cost of plates and shuffling amounts between the algorithm and other heuristic algorithms, the paper is compared with genetic algorithm in Ref. [2] in the same outbound batch.

Table II is the comparative results when the number of inbound plates is 2500. The data shows that when the inbound batch of plates is 10 pieces, the operation cost of the algorithm can be reduced by 30% compared with genetic algorithm, which indicates that the algorithm is better than genetic algorithm in the condition of smaller outbound scale. In the condition that the outbound batching scale of plates is large, the operation cost of genetic algorithm increases sharply, but the shuffling amount of the greedy algorithm increases slowly, and the corresponding operation cost increases with a small amplitude, which indicates that the planning result of the greedy algorithm is better than that of genetic algorithm, and can meet the production requirements.

(2) Sensitivity Analysis
The daily management on plate yard usually faces the problems of huge number of inbound plates, great span of outbound date for plates and restriction of size of sites. If the inbound quantity increases gradually, and the production plan is adjusted with the condition of mixed storage of plates with

TABLE II. COMPARISON OF OUTBOUND OPERATION PROGRAMS OF PLATES

<table>
<thead>
<tr>
<th>Outbound batch (piece)</th>
<th>Optimization results based on greedy algorithm</th>
<th>Optimization results based on genetic algorithm</th>
<th>Operation cost of reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shuffling amount (piece)</td>
<td>Operation cost (¥)</td>
<td>Shuffling amount (piece)</td>
</tr>
<tr>
<td>10</td>
<td>14</td>
<td>82</td>
<td>20</td>
</tr>
<tr>
<td>20</td>
<td>29</td>
<td>167</td>
<td>74</td>
</tr>
<tr>
<td>30</td>
<td>43</td>
<td>249</td>
<td>109</td>
</tr>
<tr>
<td>40</td>
<td>58</td>
<td>334</td>
<td>188</td>
</tr>
</tbody>
</table>

TABLE III. COMPARISON OF OPERATION PARAMETERS FOR PLATE YARD

<table>
<thead>
<tr>
<th>Inbound quantity (piece)</th>
<th>Total cost (yuan)</th>
<th>Rational degree of storage</th>
<th>Take-in rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15day</td>
<td>20day</td>
<td>15day</td>
</tr>
<tr>
<td>1500</td>
<td>28020</td>
<td>16.66</td>
<td>13.90</td>
</tr>
<tr>
<td>2500</td>
<td>13026</td>
<td>12.39</td>
<td>10.89</td>
</tr>
<tr>
<td>3500</td>
<td>50960</td>
<td>159015</td>
<td>19.27</td>
</tr>
<tr>
<td>4500</td>
<td>78480</td>
<td>25375</td>
<td>15.27</td>
</tr>
<tr>
<td>5500</td>
<td>113245</td>
<td>395360</td>
<td>31.23</td>
</tr>
<tr>
<td>6500</td>
<td>157040</td>
<td>590791</td>
<td>34.13</td>
</tr>
</tbody>
</table>
different specifications, the take-in rate of plates is difficult to be kept in the level of 100%. The yard managers need to face the problem of how to balance the operation cost of yard, take-in rate and rational degree of storage. So it is necessary to study the influences of inbound quantity of plates, size of yard, outbound date span of plates on average shuffling amount, rational degree of storage and take-in rate.

From the operation results in Table III, we can see that in the condition that the inbound quantity increases gradually with an unchanged outbound date span and the number of storage locations, the total cost of yard operation increases gradually, but the take-in rate of plates and rational degree of storage reduces. And in the condition that the inbound quantity and the number of storage locations are unchanged, the total operation cost of choosing 20 days as the outbound date increases greatly compared with that of choosing 15 days as the outbound date, and the take-in rate of plates reduces. For example, when the inbound quantity is 1500 pieces, the best outbound date should choose 15 days, and the best storage location should choose 38. Because the operation results indicate that the total cost, rational degree of storage and take-in rate in the condition is better than other programs, when the inbound quantity increases to 5500 pieces, if we consider from the total cost and take-in rate, the outbound date should be chosen as 15 days, and the number of storage location should be 38. However the rational degree of storage is not the best, which needs to be evaluated by the managers on making decisions. The operation results of the algorithm can provide basis for the managers.

IV. CONCLUSION

The inbound and outbound operation of plates in shipyard can be divided into several stages; determining the inbound place of plates, shuffling and outbound of plates. This is a multi-level combinational optimization problem, which belongs to NP-hard problem. The optimization based on greedy algorithm proposed in the paper can effectively solve the inbound place, the optimal inbound and the outbound cost program. The experimental results show that the optimization algorithm not only can evidently reduce the shuffling amount, but also can reduce the inbound and outbound cost, which improves the operation efficiency of steel plate yards.

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