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Study on Ladle Schedule of Steel Making Process Using Heuristic Scheduling Algorithm

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Abstract: The optimizing matching of ladle is crucial for energy conservation and consumption reduction in the process of iron and steel production. In the steel making process if there are several overhead traveling cranes, it is very difficult to obtain in practice an optimal or near optimal solution under consideration of restrictions concerning crane interference caused between them as well as many restrictions for each device in the production plant. The priorities of the ladle optimization matching are established based on the rules from the experience of the experts, and then proposed a forward heuristic algorithm to solve the crane scheduling problem. Using steel plant's actual data for a digital simulation, Results show that this software can efficiently improve the accuracy of ladle scheduling, reduce the frequency of online adjustment, and conserve more energy.

1. INTRODUCTION

During recent years, the continuous casting technology, which is developed in the 1950s, undergoes a rapid growth. Because the continuous casting technology can save more energy consumption in the production process from hot steel to slab, the main steels are produced by continuous casting. During the process of steel-making and continuous casting, most of the materials' transportations among the whole process are finished by cranes. The crane scheduling is the scheduling important branch to assist the main equipments' (steel-making, refining, continuous casting machines) scheduling, a coordinating steel-making and continuous casting system is consist of main equipments' scheduling and the assist transportation equipments' scheduling. Because a good iron and steel making scheduling system not only could realizes the reduction of the energy but also improves the production, meanwhile the steel-making and continuous casting is the bottleneck of the whole iron and steel production, the crane scheduling plays an important role in the whole process. The major problem of this paper is how to make a good crane schedule in a computationally efficient manner and effectively assist the main equipments' scheduling in order to insure the whole production in a well-organized rhythm and improve the transportation efficiency of cranes.

In this paper, the Steel-making and continuous casting process' machines include 3 blow oxygen (LD) converter; Refining stage's machines include: 3 Ruhrstahl-Hausen (RH) furnace, 1 (KIP) furnace, Ladle(LF) furnace; Casting stage's machines include: 3 (CC) continuous casting, 3 (CW) casting waiting line and many ingot casting lines. The transportation equipments include the limited cranes in each casting line. Considering the real steel-making production situation, more cranes will incur the problem of collision; fewer cranes will not satisfy the just-in-time delivery request. Based on the diversity of the main equipments scheduling requests, the limitation number of cranes' situation, except that the crane scheduling problem has the general characteristics of the hybrid flow shop problem, the crane scheduling problem has the following unique characters which lead to the crane scheduling problem is difficult to be solved:

Different manufacture factories have the different equipment (main equipment and assistant equipment) position distribution, even though in the same manufacture factory, the equipment position always changes for the reason the number of equipments' changes and the update of the equipments. In the crane scheduling problem, the carrying capacities are different; the selection of the different cranes should be based on the different production situation. Meanwhile, in the same transportation line, there are fixed sequence cranes which will finish there own tasks. Even though the cranes are in the same casting line, the possible routs of each crane are different with others. A flexible expression way should be constructed to describe the special characters of the crane scheduling problem.

The equipments' failure, the temperature change, the time disturbance could lead to the main schedule's dynamic change. Scheduler need make a reschedule immediately to satisfy the current available production status when some disturbances happened, the crane scheduling will be changed following the main scheduling. The new main equipments' schedule will be made based on the temporal available machine, the temporal available selectable process routes, the scheduled charges and the newly added charges information. In order to maintain an smooth operation and ensure the least energy consumption, the calculation time of reschedule is limited to seconds. In order to coordinate with the main equipment scheduling, how to make a quickly response to the main equipments scheduling by making a reasonable and immediately crane scheduling is our focused.

2. LITERATURE REVIEW

Crane is the major transport equipment for steel in the production process of steelmaking and continuous casting; it is responsible for shipping steel from converter to refining or continuous casting process. When crane schedule problem happens, it will increase the redundancy waiting time between processes, and affect the close convergence between refining process and continuous casting process. The plan will not be according to the original result of the scheduling. So, the crane scheduling is very important to keep production close convergence, reduce the consumption of energy and materials in steelmaking workshop. Crane scheduling is a very complex process in steelmaking workshop, not only guarantee the timeliness of the steel transport, but also considering the transport of empty ladle to dumping turntable, and from dumping turntable to baking or fast-drying. So, it is difficult to settle the crane schedule problem, mainly through artificial experience and telephone at the scene. Peng Liu and Lixin Tang (2008) studied the refining scheduling problem in which there are two or more overhead travelling cranes with non-collision constraint for handling material in the steel plant. They developed the heuristic algorithms to find the near-optimal solutions and derived two lower bounds to analyze the worst case performance of the heuristic algorithms. Tanizaki et al. (2006) present a formulation of the steelmaking process in which jobs are handled by cranes with a non-interference constraint and then proposed a heuristic algorithm to find a sub-optimal solution in a practical finite time. Research available on crane scheduling has mostly focused on port container terminals. Xie Xie and Lixin Tang (2009) studied on the problem which concerned enough two-category machines scheduled by a single crane in batch annealing process in the iron and steel manufactory. They viewed the problem as two-stage flexible flow shop with additional transportation consideration, and used heuristics to deal with this problem.

A few works in steelmaking, but there are a lot of works in container schedule. S.M. Homayouni (2009) used a hybrid genetic-Heuristic algorithm to solve the problem of automated guided vehicles (AGVs) and quay cranes in automated container terminals (ACTs). The genetic algorithm was proposed to optimize the simultaneous scheduling of AGVs and QCs. Kim et al. (2006) assumed that vehicles reserve grid blocks in advance to prevent collisions and deadlocks. They used a graphic representation method, called the "reservation graph," to express a reservation schedule in a form that the possibility of a deadlock could be easily detected. Junliang He et al. (2008) postulated a novel strategy in terms of yard crane scheduling. A hybrid algorithm which employs heuristic rule and parallel genetic algorithm is used to resolve the problem regarding the yard crane scheduling. Su Wang and Wenbin Hu (2006) gave the general model of quay crane scheduling and introduce a heuristic method Ant Colony Optimization to resolve the Quay crane scheduling problem. Using the advantages of ACO for single resource scheduling, they added virtual nodes into the scheduling graph to change the multi resource scheduling to single resource scheduling. W.C.Ng (2005) proposed the model of yard cranes scheduling and also applied B & B method to find the optimal solution. Sun Jun qing et al (2007) presented an improved model for the quay crane scheduling problem and solved this mix integer programming model by the genetic algorithm GA and the hybrid intelligent optimization algorithm GASA respectively. Kim and Park (2004) model a quay crane scheduling problem with non-interference constraints in which only single container vessel is considered as a mixed-integer program and provide a branch-and-bound algorithm and a heuristic to solve the problem.

3. THE DESCRIPTION OF LADLE SCHEDULING PROCESS

During the process of steel-making and continuous casting, based on the main equipments' scheduling and the corresponded steel ladle destination, the routes of the ladle could be divided into the following modes:

1) LD⇒no finery⇒casting mode: as shown in figure 1, after received the molten steel when the process of LD process is finished, the crane transport the motel steely by steel ladle to the casting, take the process of pre-process. And take the steel ladle to the continuous casting by crown crane.

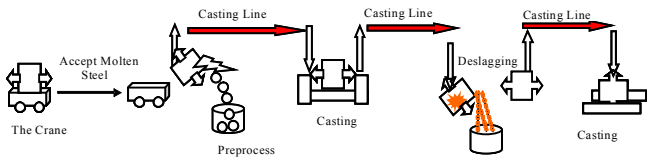

Fig. 1 Functional flow diagram of LD⇒no finery⇒casting

2) LD⇒no finery⇒IC mode: as shown in figure 2, after received the molten steel when the process of LD process is finished, the crane transport the charge to the casting line. In the casting line, the crown crane transport steel ladle to take the preprocess and transport the steel ladle by crane to another casting line, and the crown crane will take the steel ladle to the ingot casting finally.

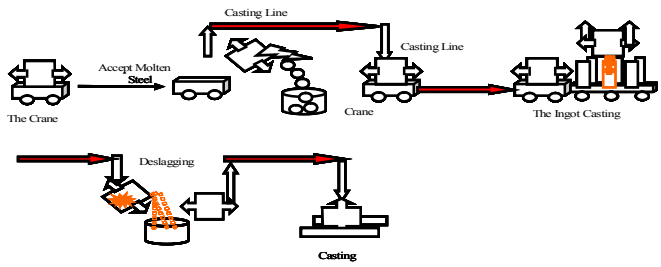

Fig. 2 Functional flow diagram of LD⇒no finery⇒IC

3) LD⇒finery⇒casting mode: as shown in figure 3, after received the molten steel when the process of LD process is finished, the charge is sent to the casting line, after the pre-process, the charge is sent to the refining stage, the crown cranes takes the action of loading and unloading, the crown crane take the charge into the casting line.

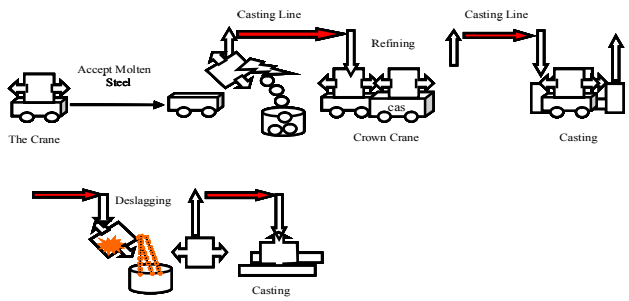

Fig. 3 Functional flow diagram of LD⇒finery⇒casting

4) LD⇒finery⇒IC mode: as shown in figure 4, after received the molten steel when the process of LD process is finished, the charge is sent to the casting line, after the preprocess, the charge is sent to the refining stage, the crown cranes takes the action of loading and unloading, the crown crane take the charge into the ingot casting line.

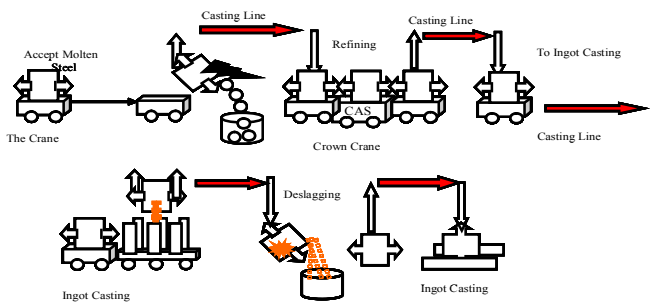

Fig. 4 Functional flow diagram of LD⇒finery⇒IC

4. THE DESCRIPTION OF LADLE SCHEDULE

There are two steps in the ladle scheduling process. The first step is ladle schedule based on the rule. The second step is crane schedule.

4.1 Ladle Schedule

It is difficult to use accurate mathematical model to describe the steelmaking and continuous casting process. The priorities of the ladle optimization matching are established based on the rules from the experience of the experts.

There are five kinds of the rule. Dephosphorization rule, quality requirement of materials rule, nozzle requirement rule, temperature rule and special rule. For example:

Dephosphorization rule

If there is online dephosphorization ladle, then choose it, else choose baking dephosphorization ladle.

Quality requirement of materials rule

If the plan can choose high-Al ladle, then can choose Mg-C ladle.

If the plan require Mg-C ladle, then can't choose high-Al ladle.

Nozzle requirement rule

If the plan can choose single-nozzle ladle, then can choose double-nozzle ladle, on the contrary can not be.

Temperature rule

Preferred choices is high temperature ladle.

Special rule

If this plan need LF refinery device, then choose the ladle that up-nozzle using time is less than 15, ladle using time is less than 100.

If this job is the fist of continuous casting, then choose baking ladle or quick baking ladle.

4.2 Crane Schedule

In order to facilitate the mathematical analysis of crane scheduling problem, several conditions are assumed.

The finishing operation order of every plan is decided.

Every plan must be only the overall production, can not be divided into multiple parts.

More of the same quality product can not be produced as a whole.

Each processing time on the device is known.

The crane position in the same rail remains the same sequence. To maintain the shortest distance δ between two adjacent cranes.

Introduce the following variables:

$U = \{J_1, J_2 ... J_i ...\}$: charging plan set, J_i is charging plan i

N_i : Manufacturing procedure set of charging plan i, $i \in U$

n_i : The number of plan i 's processes, $n_i = |N_i|$

O_{ij} : The process j of plan i, $j = 1, \mathrm{L}, n_i$

OM_{ij} : Devices collection can be used to O_{ij}

OT_{ij} : Process time of O_{ij}

ST_{ij} : Processing start time of O_{ij}

ET_{ij} : Processing end time of O_{ij}

M : Number of available crane

$CT(a,b)$: Crane running time from position a to position b

P_m : Position of device m

a_{ij} : Position of device which processes O_{ij}

d : Lifts and drops time when crane transports the ladle

δ : The shortest distance between two adjacent cranes

v : Crane speed, it is a constant.

P_k^t :Crane k′ s position on time t

x_{ij}^m : When O_{ij} works at device m, x_{ij}^m =1; otherwise x_{ij}^m =0

$X_{i_1j_1,i_2j_2}^m$: When $O_{i_2j_2}$ is operated after $O_{i_1j_1}$ at device m, $X_{i_1j_1,i_2j_2}^m$ =1; otherwise $X_{i_1j_1,i_2j_2}^m$ =0

y_{ij}^k : When crane k is assigned to a transportation job of completed O_{ij}, y_{ij}^k =1; otherwise y_{ij}^k =0

Y_{ijt}^k : When crane k is occupied to transportation job of completed O_{ij} at time t, Y_{ijt}^k =1; otherwise Y_{ijt}^k =0

G : Sufficiently large constant value.

The objective is to minimize the sum of Project completion time. The objective function is as follows:

$$Minimize \sum_{i \in U} (ET_{i,n_i} - ST_{i,1}) \tag{1}$$

ST.

$$\sum_{m \in OM_{IJ}} x_{ij}^m = 1 \tag{2}$$

$$\sum_{O_{ij}} X_{i_1 j_1, ij}^m = x_{i_1 j_1}^m \tag{3}$$

$$\sum_{O_{ij}} X_{ij, i_2 j_2}^m = x_{i_2 j_2}^m \tag{4}$$

$$ST_{i_2 j_2} \geq ET_{i_1 j_1} - G(1 - X_{i_1 j_1, i_2 j_2}^m) \quad when \quad x_{i_2 j_1}^m = x_{i_2 j_2}^m = 1 \tag{5}$$

$$ST_{i_1 j_1} \geq ET_{i_2 j_2} - GX_{i_1 j_1, i_2 j_2}^m \quad when \quad x_{i_2 j_1}^m = x_{i_2 j_2}^m = 1 \tag{6}$$

$$ET_{ij} \geq ST_{ij} + OT_{ij} + 2d \tag{7}$$

$$ST_{i,j+1} \geq ET_{ij} + CT(a_{ij}, a_{i,j+1}) \tag{8}$$

$$\sum_k y_{ij}^k = 1 \tag{9}$$

$$\sum_{O_{IJ}} Y_{ijt}^k \leq 1 \tag{10}$$

$$\sum_{t=ET_{ij}-d}^{ST_{i,j+1}+d} Y_{ijk}^t \geq ST_{i,j+1} + 2d - ET_{ij} - G(1 - y_{ij}^k) \tag{11}$$

$$a_{ij} = \sum_{m \in OM_{ij}} P_m x_{ij}^m \tag{12}$$

$$P_{kt} + v \geq P_{k,t+1} \geq P_{kt} - v \tag{13}$$

$$P_{k+1,t} \geq P_{kt} + \delta \tag{14}$$

Constraint (2) requires every O_{ij} must been Assigned to a device. Constraint (3)and(4) give a relationship between x_{ij}^m and $X_{i_1j_1,i_2j_2}^m$ .Constraint (5)and(6) mean that Pre-order job must be completed before follow-up job starting in the same device. Constraint (7) and (8) is the requirement of crane transportation. Constraint (9) ensure every O_{ij} has a crane. Constraint (10) means one crane most has a job. Constraint (11) shows that if carne k is assigned to O_{ij} , it will be occupied from $ET_{ij} - d$ to $ST_{i+1,j} + d$. Constraint (12) shows that the Processing position and the position assigned to O_{ij} is the same. Constraint (13) means the crane has its maximum speed. Constraint (14) shows the shortest distance δ between two adjacent cranes

5. SOLUTION METHODOLOGY

Several conditions are assumed:

Crane k is in the left of crane k+1;

Crane k is assigned to O_{ij}, crane k+1 is assigned to O_{mn}

There is no conflict before the crane k+1 start.

Additional notation:

$T = \{T_1, T_2 ... T_m\}$: The set of O_{ij} scrambling the same device, m is the number of devices.

$V = \{V_1, V_2 ... V_k\}$: The set of crane scheduling initial solution, k is the job number of crane

Q: The set of O_{ij} whose completed time is delayed

q : Index of crane conveyance in set V.

s_{ij} : Crane departure time at a device completing process O_{ij}

e_{ij} : Crane arrival time at a device processing the next O_{ij}

s_{ij}^* : Crane departure time at a device completing O_{ij} when crane conflict is solved.

e_{ij}^* : Crane arrival time at a device processing the next O_{ij} when crane conflict is solved.

a_{ij}^* : Start position of crane, when crane conflict is solved.

w_{ij} : Waiting time at the device until start of transportation after O_{ij} completing.

BST_i : Start time of the last procedure in plan i.

RST_{ij} : The start time of O_{ij} when crane conflict is solved

RET_{ij} : The end time of O_{ij} when crane conflict is solved

There are two methods for a crane to avoid crane conflict.

The algorithm is as follows:

Step1: Find a crane scheduling initial solution V.

Step2: Get the earliest crane schedule q, and then calculate the start time of next process $RST_{i,j+1}$.

$$RST_{i,j+1} = ET_{ij} + CT(a_{ij}, a_{i,j+1}) + w_{ij} \tag{15}$$

Step3: If $RST_{i,j+1} \neq ST_{i,j+1}$, then go to Step3.1, else go to Step 4.

Step3.1: If $RST_{i,j+1} < ST_{i,j+1}$, then change Completion time of $O_{i,j+1}$, and go to Step 4.

$$RET_{i,j+1} = RST_{i,j+1} + OT_{ij} + 2d \tag{16}$$

Step3.2: If $RST_{i,j+1} > ST_{i,j+1}$, initialize Q, set $Q \leftarrow Q + \{O_{i,j+1}\}$.

Step3.3: Arrange Q order by the completion time ascending. O_{mn} is the first element, has next process. Calculate $RST_{m,n+1}$ and $RET_{m,n+1}$, else go to Step3.5.

$$RST_{m,n+1} = RST_{m,n} + CT(a_{mn}, a_{m,n+1}) + w_{mn} \tag{17}$$

$$RET_{m,n+1} = RST_{m,n+1} + OT_{m,n+1} + 2d \tag{18}$$

Step3.4: If $RET_{m,n+1} > ET_{m,n+1}$, then set $Q \leftarrow Q + \{O_{m,n+1}\}$. Q_{uv} is the next process. If there is a conflict between $O_{m,n+1}$ and Q_{uv}. Use (24) and (25) to solve it. Set $Q \leftarrow Q + \{O_{uv}\}$.

$$RST_{uv} = RET_{m,n+1} \tag{19}$$

$$RET_{uv} = RST_{uv} + OT_{uv} + 2d \tag{20}$$

Step3.5: Set $Q \leftarrow Q - \{Q_{m,n}\}$, if $Q = \phi$, then go to Step 4, else go to Step 3.3.

Step 4: Set $V \leftarrow V - \{V_q\}$, $q \leftarrow q + 1$, if $V \neq \phi$, then go to Step 2, else go to Step 5.

Step 5 Calculate $Minimize \sum_{i \in U} (ET_{i,n_i} - ST_{i,1})$.

Step 6: If no satisfied results, then go to Step 1 and change V, else end.

6. NUMERICAL RESULTS

In this example, the method is applied into the real production situation, in order to get the confirmation of the crane scheduling, two continuous casting machines are selected, there are three charges to be process in each continuous casting machine, and the related input information of the cast plan is shown as fig 7. By using the algorithm of this paper, the new cast plan is shown as fig 8.

Finally the result is listed as the form of animation stimulation, and calculated by comprehensive evaluation.

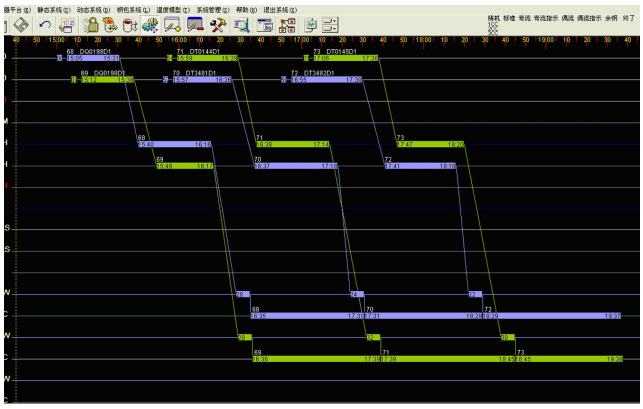

Fig. 7 Original plan shown by Gantt

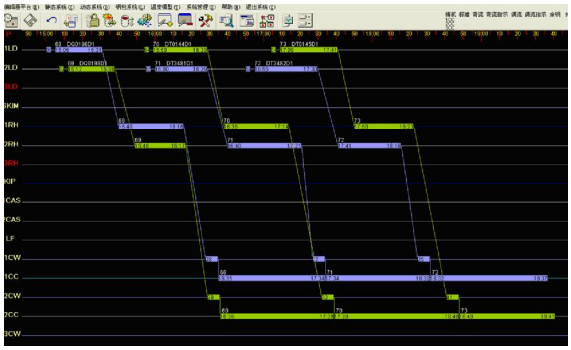

Fig.8 Finally plan result shown by Gantt

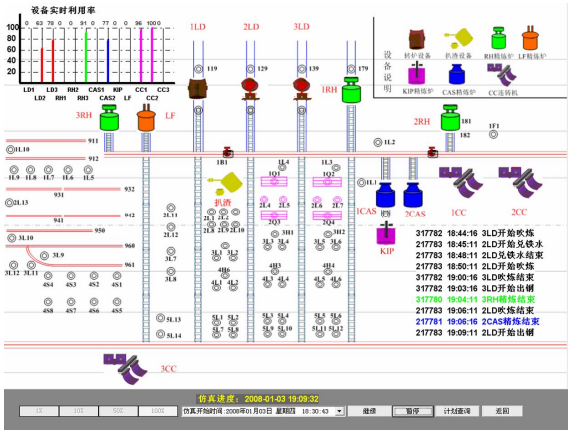

Fig.9 Plan result shown by animation stimulation

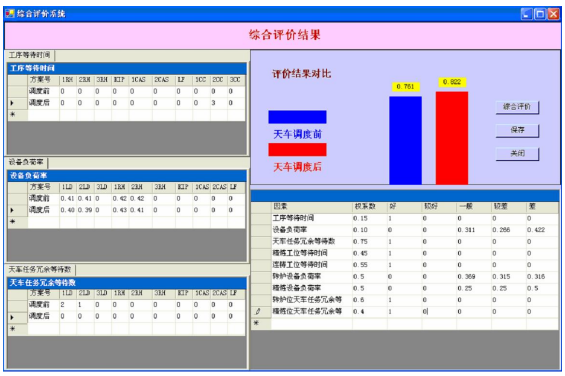

Fig.10 Result shown by comprehensive evaluation

7. CONCLUSIONS

In this paper, the heuristic approach is proposed for the crane scheduling problem. The main content of this paper is as follows:

1. Studied the method of the ladle schedule.
2. Designed ladle scheduling software system. It included scheduling subsystem; animation subsystem to direct-show the results and comprehensive evaluate subsystem.
3. Carried out an experiment to test the system using steel plant's actual data. The results of the tests carried out the analysis to prove that the validity of the scheduling system.

ACKNOWLEDGEMENT

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