THE RESEARCH OF INTEGRATED PRODUCTION SCHEDULING MODEL OF IRON AND STEEL

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ABSTRACT
An integrated production scheduling model of iron and steel is established, based on the just-in-time (JIT) idea, for solving machine conflicts including steelmaking, continuous-casting, continuous-rolling procedure etc. The model is developed as a complex non-linear model based on actual production situation. An approach on Lagrangian relaxation (LR) to the integrated production scheduling model is presented. The Constraints are relaxed and the problem is turned into a two level optimization problems. The high level is the dual of the original problem, and the low level consists sub-problems. The application of the proposed method is an effective method to optimize production continuity and product delivery while eliminating machine conflicts.

KEYWORDS
LR (Lagrangian Relaxation), JIT, Integrated Management, Batch planning, Charge, Cast, Rolling unit

1 INTRODUCTION
Modern iron and steel are moving towards continuous, high-speed, and automated production process with large devices. The focus is placed on high quality, low cost, just-in-time delivery and small lot with different varieties in the market. The high challenges are facing to enterprises. The integrated scheduling technology of multi-procedure, as a key factor determining the economic benefit of enterprise, is concerned by decision-makers. And many merits are included in this technology, such as reduce energy consumption, shorten waiting time between operations, cut down production costs etc. The integrated scheduling technology of multi-procedure will be an important trend in iron and steel production management.

Recently, Many companies are developing integrated computer management system (CIMS) and computer control, based on process automation of device, which can not only make material and information flow synchronously, procedure joined closely, but also improve efficiency of devices, reduce waiting time of procedures. So the integrated scheduling technology of multi-procedure can be enabled using that (Lixin Tang 2000).

In this paper, a steelmaking-continuous casting-continuous rolling production scheduling model is established using multi working procedure integrated scheduling technology, based on integrated management and production batch plan, and a solving method lagrangian relaxation technology is applied in it effectively.

2 INTEGRATED PRODUCTION SCHEDULING MODEL
Production integration is production management of procedures, including integrated planning, integrated scheduling, integrated establishing “time-table”, which can make work flow of production continuously and efficiently.

2.1 Production Process
In the iron and steel production from iron to steel product output, there are three major manufacturing processes: Ironmaking, steelmaking, and rolling. The steelmaking process starts with the charge of crude steel and scrap iron in one of the Electronic Arc furnaces
2.2 Batch Planning

There are three kinds of planning no matter what in mechanism or steel and iron manufacturing from the functional angle, such as resources planning, batch planning and sequence/time planning etc. The batch planning of steel and iron manufacturing has relations with production working procedure greatly, and can be divided into charge, cast, rolling batch planning etc, charge batch planning is how to combine multi species, small lot production contracts that offered by ro steel-making process via a heat and determíne the casting sequences of charges, based on charge planning and life-span of Tundish (a key procedure of casting).

3) Rolling batch planning: rolling planning is to group and sequence, based on the rolling rules, into k rolling units n production slabs, in which m slabs must be placed within a certain range of a rolling unit scheduling because of strict quality demand of product and other conditions (Xiong Chen 1998).

2.3 The Structure of Integrated Production Scheduling Model

The steelmaking-continuous casting-continuous rolling production scheduling problem is handled in five steps. First, rolling sequencing is arranged. Next, cast sequencing is arranged. Sub-schedules and rough schedule are then established. Finally the steel making -continuous casting-continuous rolling production scheduling problem is formed consider ing availability of machines at all stages. A brief description for each of these steps is given below:

1) Rolling sequencing: Rolling sequences on the rolling units and charge sequence in each rolling unit are determined, based on the rolling rules. These can be considered as a single machine sequencing problems without resource constraints.

2) Cast sequencing: Cast sequences on the casters and charge sequence in each cast are determined in this step, based on their delivery times. These can be considered as a multi machines sequencing problems without resource constraints.

3) Establishment of sub-schedules: After a cast has been established, a cast job timetable called sub-schedule is formed for each cast in this step according to time progress of the operations including steelmaking, refining and continuous casting in each charge.

4) Establishment of rough schedule: In this step the sub-schedules with relative times are combined to produce a rough job schedule with physical time.

5) Elimination of machine conflicts: Because only the machine operations in rolling unit and cast are taken into account. Machine conflicts often exist in the rough schedule. Only when machine conflicts are completely eliminated can a feasible and practical schedule be established. This step is to produce an optimal schedule in which all machine conflicts are eliminated. The following discussion emphasized on the elimination of machine conflicts using an optimization model.

2.4 The Integrate Model Formulation

2.4.1 Notation

\( \Psi \) : the set of all charges, \( N \) is the total number of production charges, \( \Psi = \{1, 2, \ldots, N\} \), \( \Psi_k \) : the kth cast set of charges, \( M \) is the total number of casts, \( k \in \{1, \ldots, M\} \), \( j \neq k \); \( j, k \in \{1, \ldots, M\} \), \( \Psi_j \cap \Psi_k = \Phi \), and \( \Psi_j \cup \Psi_2 \cdots \Psi_M = \Psi \). \( \Psi_j \) : the lst rolling set of charges. \( L \) is the total of rolling unit, \( l \in \{1, \ldots, L\} \), \( j \neq i \); \( j, l \in \{1, \ldots, L\} \), \( \Psi_j \cap \Psi_i = \Phi \), and \( \Psi_j \cup \Psi_2 \cdots \Psi_L = \Psi \), for any \( \mathcal{F} \) : the set of all machines; \( \mathcal{F}_i \) : the set of all machines used for the ith charge. \( \mathcal{F} \) : the set of all
continuous casters, \( \xi \subset \pi, |\xi| = C \).

\( \omega \) : the set of all continuous rollers, \( \omega \subset \pi, |\omega| = D, D_i \) : order delivery time of charge \( i \); \( C_i \) : desired time of charge \( i \); \( Si(i, j) \) : the immediate successor charge of charge \( i \) processed on machine \( j \); \( SP(i, j) \) : the immediate successor machine of machine \( j \) for processing charge \( i \). Decision variables : \( x_{ij} \).

2.4.2 Model Description

Using the above notation, the model for the optimal scheduling problem is formulated as follows:

Objective Function:

\[
\text{Goal (Func)} = \sum_{k=1}^{N} \left[ \sum_{i \in \pi, j \in \pi, \xi \subset \pi, |\xi| = C} \left( \sum_{l=1}^{L} c_{ijl} x_{ijl} - \gamma_{ij} - T_{ijl} \right) \right]
\]

subject to:

\[
x_{ij} \geq T_{ij} \text{ for } (i \in \pi, j \in \pi, S_i(i, j) \in \pi) \quad (1)
\]

\[
x_{ij} - \gamma_{ij} \geq T_{ij} - T_{ij} \text{ for } (i \in \pi, j \in \pi, S_i(i, j) \in \pi) \quad (2)
\]

\[
x_{ij} - \gamma_{ij} \geq T_{ij} + S_{ij} \mu \text{ for } (i \in \pi, j \in \pi, S_i(i, j) \in \pi) \quad (3)
\]

\[\sum_{i \in \pi, j \in \pi, \omega \subset \pi, |\omega| = D} \delta_{ij} \leq M_c \quad (\tau = 1, 2, \ldots, \tau, i \in \pi, j \in \pi) \quad (5)
\]

\[x_{ij} \geq 0 \quad (i \in \pi, j \in \pi) \quad (6)
\]

- \( c_{ijl} \) : coefficient of cast break loss penalty for cast \( k \).
- \( r_{ijl} \) : coefficient of rolling break loss penalty for rolling \( l \).
- \( \gamma_{ij} \) : coefficient of penalty cost for the waiting time of charge \( i \) after finishing process on machine \( j \).
- \( \delta_{ij} \) : integer variable equal to one if charge \( i \) is active on machine \( j \) at time \( \tau \), else zero.
- \( M_c \) : Capacity of machine type (cast or rolling) at time \( \tau \).
- \( E_i \) : Earliness of charge \( i \), defined as: \( \min(0, x_{ij} + T_{ij} - D_j) \text{ and } j \in \pi, \omega \).
- \( T_{ij} \) : tardiness of charge \( i \), defined as: \( \max(0, x_{ij} + T_{ij} - D_j) \text{ and } j \in \pi, \omega \).

The objective function (1) for this model is to ensure continuity of the production process and just-in-time delivery of final products. This is achieved through minimizing a cost function consisting of the following terms:

- (a) Cast break loss penalties exerted to ensure that charges in the same cast are cast as continuously as possible.
- (b) Rolling break loss penalties exerted to ensure that charges in the same rolling unit are rolling unit as continuously as possible.
- (c) Molten steel temperature drop cost in terms of waiting time from operation to operation.
- (d) Earliness/tardiness penalty used to ensure that blooms or billets in each charge are delivered as punctually as possible.

The following constraints are considered in the model to guarantee that there will be no machine conflicts in the schedule generated. Constraint (2) for the two contiguous operations for the same charge, only when the preceding operation has been completed, the immediately next one can be started. Constraint (3) for two contiguous operations on the same machine, only when the preceding charge has been completed, the immediately next one can be started. Constraint (4) setup time and interval are required from cast to cast (or from rolling unit to unit) on the same cast (or rolling unit).

Constraint (5) machine capacity constraint of cast (or rolling) at time \( \tau \).

3 SOLUTION METHODOLOGY

Recently, scheduling methodologies based on Lagrangian Relaxation have proven to be computationally efficient and have provided near optimal solutions to scheduling problems. Using LR technology, the scheduling problem is decomposed into operation-level sub-problems for the selection of operation beginning times, with given multipliers and
coefficients. The multipliers and penalty coefficients are then updated at the high level. The solution forms the basis of list-scheduling algorithm that generates a feasible schedule. A procedure is also developed to evaluate the quality of this feasible schedule by generating a lower bound on the optimal cost.

Fisher (1973,1981) uses the LR lower bound to obtain a more efficient enumeration method for a class of job-shop scheduling problem. Hoitomt and Luh (1988,1989) have not only used the technology to obtain near optimal solutions (within one scheduling of parallel, identical, multiple machine types)(1993,1994), but also include generic precedence constraints, and simple routing considerations etc (1999).

3.1 Lagrangian Relaxation Approach
The capacity constraint (5) can be relaxed by using the nonnegative Lagrangian Relaxation multipliers \( \pi_{kh} \).

\[
P: \min \sum_{i \in O} \left( \sum_{k \in K_i} [\text{Goal} - \text{Func}(i)] + \sum_{k \in K_i} \pi_{kh} \sum_{t \in T_k} (b_{kt} - M_{kt}) \right)
\]

subject to (2),(3),(4),(6)

The Lagrangian Relaxation dual to problem p:

\[
\max L = \left\{ \sum_{k \in K_i} \pi_{kh} M_{kt} \right\} + \sum_{k \in K_i} \left[ \text{Goal} - \text{Func}(i) + \pi_{kh} \sum_{t \in T_k} (b_{kt} - M_{kt}) \right]
\]

subject to (2),(3),(4),(6)

The minimization operation in (7) has been brought inside the summation because the minimum of the sum is the sum of the minima when the charges are independent. This results in a minimization sub-problem for each charge:

\[
\min_{\pi_{kh}} L_i = \{ \text{Goal} - \text{Func}(i) + \sum_{k \in K_i} \pi_{kh} \}
\]

subject to (2),(3),(4),(6)

For a particular operation and a particular machine type (such as continuous casters, continuous rollers etc.), (9) can be further decomposed.

The sub-problems of operations can be solved enumeration (or dynamic programming etc.). We can obtain a near optimal schedule with quantifiable performance and within reasonable computation time.

3.2 Solving the Dual Problem
To solve the dual problem related to (7), the sub-gradient method is commonly used to solve the problem. The Lagrangian multiplier \( \pi_{kh}^* \) is updated by

\[
\pi_{kh}^{n+1} = \pi_{kh}^n + \alpha^n g(\pi_{kh}^n)
\]

Where \( \alpha^n \) is the step size at the \( n \)th iteration, \( g(\cdot) \) is the sub-gradient of the dual problem.

\[
\alpha^n = \frac{L^* - L^m}{g(\pi^n)} \quad \beta > 0
\]

\( L^* \) is an estimate of the optimal solution of (8), \( L^m \) is the value of \( L^* \) at the \( n \)th iteration. The parameter \( \beta \) and \( L^m \) are changed adaptively as the algorithm converges.

3.3 Construction of Feasible Schedule
Because of the stopping criterion used, the solution to the dual problem is associated with an infeasible schedule generally, some constraints can be violated. To construct a feasible schedule, the list-scheduling is then applied. In this list-scheduling procedure, a list is created by arranging operations in certain order. If the constraint is violated, a greedy heuristic algorithm determines which operation should begin and which should be delayed.

3.4 Evaluation of the Feasible Solution via the Approximate Duality Gap
Once a feasible schedule is obtained, the corresponding value of the objective function \( J \) is an upper bound on the optimal objective \( J^* \). The value of the dual function \( J^* \) is a lower bound on \( J \). The difference between \( J^* \) and \( J^i \) is known as the duality gap, an upper bound of the duality gap is provided by \( J^* - J^i \), which is a measure of the sub-optimality of the feasible schedule.

4 CONCLUSION
In this paper, a integrated production scheduling model of iron and steel, based on the just in time (JIT) idea is established under CIMS situation, for solving machine conflicts including steelmaking, continuous casting, continuous rolling procedure etc. An approach on Lagrangian relaxation (LR) to the integrated production scheduling model is presented. The application of the proposed method is an effective method to optimize production continuity and product delivery while eliminating machine conflicts in actual production.

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BIOGRAPHY

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