

Optimum Steelmaking Charge Plan with Unknown Charge Number Based on the Pseudo TSP Model

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Abstract: This paper presents a mathematical charge plan model of steelmaking-continuous casting (SCC) scheduling in the computer integrated manufacturing systems environment. Based on the analysis of the difficulty to solve the scheduling problem, a pseudo travel salesman problem model is presented to describe the scheduling model. By using this method, we can solve the optimum charge problem even without known the charge number, while other methods must know the charge number previously. To solve the problem, an improved discrete particle swarm optimization (DPSO) is presented. A new crossover probability is introduced into the DPSO algorithm, which is differed to that of the GA.. Simulations have been carried and the results show that the pseudo travel salesman problem is very fit for describe the model. The computation with practical data shows that the model and the solving method are very effective.

1. INTRODUCTION

IRON and steel industrial is an essential and sizable sector for industrialized economies. China, the largest steelmaking country in the world, produces about 489 million tons in 2007, which is about 36.4% of the world's total output. It is well known that the steel industrial is high energy consumptive. It is very important to reduce the energy cost, especially at present when we face to the skyrocket of the energy price. To reduce the cost, modern iron and steel corporations 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 (JIT) delivery and small lot with different varieties. To improve productivity of large devices, shorten waiting-time between operations, reduce material and energy consumption, and cut down production costs, production scheduling is a key component. Its task is to determine the starting times and the ending times of jobs on the machines so that a chosen measure of performance is optimized.

Steelmaking-continuous casting (SCC) production scheduling problems are to determine in what sequence, at what time and on which device molten steel should be arranged at various production stages from steelmaking to continuous casting. Unlike general production scheduling in machinery industry, SCC production scheduling problems have to meet special

requirements of steel production process. In the SCC process, the products being processed are handled at high temperature and converted from liquid (molten steel) into solid (drawn billets). There are extremely strict requirements on material continuity and low time (including processing time on various devices and transportation and waiting time between operations).

The study of this paper is investigating the SCC production scheduling problem and aims at developing a computerized scheduling system for generating optimal schedules. The project uses a huge iron and steel complex as the study background.

2. THE MATHEMATICAL MODEL OF CHARGE PLAN WITH UNKNOW CHARGE NUMBER

In the iron and steel production from iron ore input to steel product process, there are three major manufacturing processes: iron making, steelmaking, and rolling. Steelmaking refines pig iron into steel and casts it into slabs, blooms, or billets. The SCC production process is illustrated in Fig. 1. The steelmaking process starts with the charge of crude steel and scrap iron in one of the EAFs. Liquid iron, tapped from BF, will be transported to the steelmaking shop where BOFs and/or EAFs are located. BOF and EAF burn out the excessive carbon, sulphur, silicon, and other

impurities from liquid iron and refine it to steel with desired contents. The filling of one furnace is called a charge ((heat) and already contains the main alloying elements. The melted steel is poured into ladles that are transported by a LF. If the proceeding heat has a long processing time in the LF, the current heat must wait. The next step is a heat treatment in the LF, where the fine alloying takes place. The duration is usually about the same as the melting. Then, special treatment may be performed in the Ladle-refining equipment (VOD or VD) to eliminate impurities from molten steel or add alloy ingredients to the molten steel in ladles to make high-grade steel. Finally, a continuous caster casts molten steel continuously into slabs, blooms, or billets. If the casting format needs to be altered, a set-up time must be considered.

The modern integrated process of steelmaking, continuous casting and hot rolling directly connects the steelmaking furnace, the continuous caster and the hot rolling mill with hot metal flow and makes a synchronized production. For steel making process, the main work is to arrange the charge plan and cast plan. The basic unit of steelmaking is the charge. To make the charge plan, the following conditions are needed:

- (1) Steel grades must be the same,
- (2) Steel thickness of the charges must be equal.
- (3) The slab widths must be near
- (4) The consignment date must be near,
- (5) Total weight in each charge must great than or equal to the 90% furnace capacity and less than or equal to the 100% furnace capacity.

To obtain the mathematical model, the following assumptions are made:

- (1) The requirement of each slab is less than the furnace capacity and cannot be decomposed.

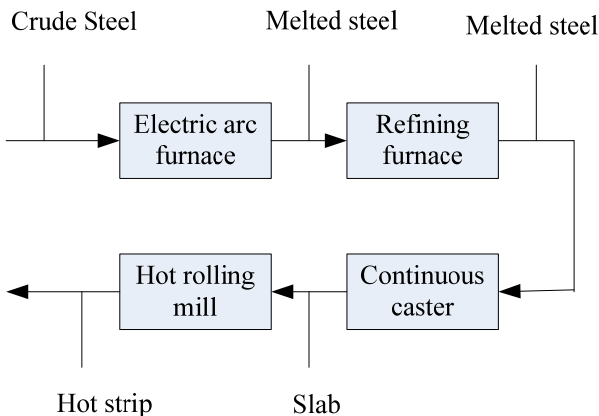


Fig.1 The SCC production process

- (2) The furnace capacity is constant.

Usually, the charge number is known previously. In this paper we present a novel method to deal this problem with unknown charge number. The mathematical model of the optimum charge plan is as follows (Tang, 1996,p.440; Xue, 2004, p.1979):

$$\min.Z = \sum_{i=1}^N \sum_{j=1}^N (c_{ij}^1 + c_{ij}^2 + c_{ij}^3)X_{ij} + \sum_{j=1}^N p_j * Y_j + \sum_{j=1}^N (1 - X_{ij})h_j \quad (1)$$

$$\text{s.t.} \sum_{j=1}^N X_{ij} \leq 1, i = 1, \dots, N \quad (2)$$

$$\sum_{j=1}^N X_{ij} = P \quad (3)$$

$$\sum_{j=1}^N g_i * X_{ij} + Y_j = T * X_{ij}, j = 1, \dots, N \quad (4)$$

$$X_{ij} \leq X_{jj}, i = 1, \dots, N, j = 1, \dots, N \quad (5)$$

$$Y_j \geq 0, j = 1, \dots, N \quad (6)$$

$$X_{ij} \in \{0,1\}, i = 1, \dots, N, j = 1, \dots, N \quad (7)$$

Where:

X —slab store matrix, if slab i and j are arranged into the same charge, $x_{ij}=1$ else $x_{ij}=0$.

P —charge number which is unknown previously.

N —the slab number to be arranged.

W_i —width of the i th slab.

T —furnace capacity.

p_j —annexed cost coefficient of residual slab of the j th charge number.

g_j —the weight of the j th slabs.

h_j —annexed cost coefficient of the j th slab not be chosen.

Y_j —the open order of the j th charge.

C_{ij}^1 —annexed steel grade cost coefficient of slab i combined to slab j and:

$$C_{ij}^2 = \begin{cases} 0 & W_i = W_j \\ F_2 * |W_i - W_j| & 0 < |W_i - W_j| \leq E \\ \infty & |W_i - W_j| > E \end{cases} \quad (9)$$

$$C_{ij}^1 = \begin{cases} 0 & \text{Steelgrades of slab } i \text{ \& } j \text{ are equal} \\ F_1(ST_i - sT_j) & \text{slab } i \text{ \& } j \text{ belong to the same steelgrade serial and the requirement of slab } i \text{ is lower than slab } j \\ +\infty & \text{slab } i \text{ \& } j \text{ belong to the same steelgrade serial and the requirement of slab } i \text{ is higher than contract } j \\ +\infty & \text{charge } i \text{ \& } j \text{ donot belong to the same steelgrade serial} \end{cases} \quad (8)$$

C_{ij}^3 —annexed date cost coefficient of slab i combined to slab j and:

$$C_{ij}^3 = \begin{cases} F_3(d_i - d_j) & d_i - d_j \geq 0 \\ F_4(d_j - d_i) & d_j - d_i < 0 \end{cases} \quad (10)$$

d_i —slab date of charge i .

Objective function (1) assures the difference cost to be smallest in steel grades, widths and consignment dates among each charges. Constraint (2) ensures that every slab can only be arranged to one charge. Constraint (3) ensures that the total charge number is P . Constraint (4) ensures the total weight of every charge cannot surpass the furnace capacity. Constraint (5) ensures the open order not be negative.

3. PSEUDO TSP MODEL FOR CHARGE PLAN

According to the charge plan model, it is natural to solve the problem by arranging the slab into an array and the array store the charge number (see Fig.2). This is effective if the slab amount is small. If the slab number is very big, the search algorithm will not be able to solve the problem effectively (Xue,2004,p.1279). Moreover, the charge number must be known previously. If the charge number is unknown previously, it will not take functions. In this paper, the travel salesman problem(TSP) solution method is used to solve the charge plan model with unknown charge number.

Slab number	N	N-1	...	4	3	2	1	0
Charge number	2	m	...	0	1	2	1	0

Fig.2 Array description of charge plan model

3.1 The general description of TSP

Given N cities and a salesman, the TSP in discussion may be stated as follows. The salesmen set out from the same fixed city and finally come back to the starting city to minimize total travelling distance. It is required that each city should be visited by exactly one salesman and each salesman should visit at least one city.

3.2 The difference between TSP and the charge plan problem

Although the charge plan scheduling problem may be reduced to TSP, there is obvious difference between the charge plan problem and the general TSP.

A feasible tour of the salesman for TSP is a closed route. This means that for the salesman, if he starts from point i , then he must finally returns to point i . Thus, the feasible tour of TSP is a closed route. However, a schedule of a turn in the actual charge plan scheduling problem is an open path, that is, each production slab is arranged exactly once.

3.3 Conversion of the charge plan scheduling problem into a normal TSP

To convert the charge plan scheduling problem into a TSP, assume that N slabs are to be arranged into M charges and M is unknown previously. These N slabs may be viewed as N nodes and a salesman may be regarded as the tour. Fig.3 shows the Pseudo TSP with 8 nodes. The first 4 slabs are arranged in the same charge and the second 3 are arranged in the same charge. The last slab cannot be arranged into any charge. The dashed line represents that the two adjacent nodes cannot be arranged in the same charge.

It must indicate out that the distance with reasonable tour route is the sum for all the nodes can be arranged in the same charge. And the distance in the same charge can be calculate as follows:

$$w = \sum_{j=1}^m w_j, \quad j=1,2,\dots,m \quad (11)$$

$$C = \sum_{i=1}^m \sum_{\substack{j=1 \\ i \neq j}}^m (c_{ij}^1 + c_{ij}^2 + c_{ij}^3), \quad j=1,2,\dots,m \quad (12)$$

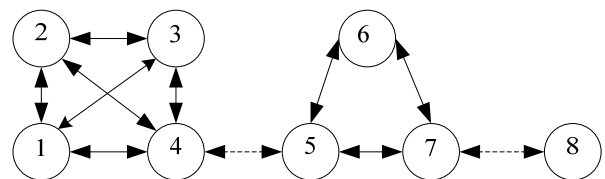


Fig.3 Pseudo TSP model with 8 nodes

How do we decide that the slab can be arranged in the same charge?

Assume that the m slabs have been arranged in the same charge. W and C are calculated with (11) and (12). And the $(m+1)$ slab is to be arranged in the same charge. If:

$$w + w_{m+1} \leq T \quad (13)$$

and:

$$C + \sum_{j=1}^m (C_{j,m+1}^1 + C_{j,m+1}^2 + C_{j,m+1}^3) < Valve \quad (14)$$

Then the $(m+1)$ th slab will be arranged in the same charge, otherwise, the charge will only arrange m slabs. In (14), the $Valve$ is a big number which can not be reached when the slabs can be arranged in the same charge.

After all the slabs have been arranged, we must decide which charges are necessary and which charges may be cancelled. If the total cost in one charge is greater than or equal to the cost that all the slabs in this charge are not arranged, then this charge is cancelled.

4. AN IMPROVED DISCRETE PARTICLE SWARM OPTIMIZATION

Particle swarm optimization is a population-based evolutionary computation technique developed by Kennedy and Eberhart in 1995 (Kennedy, 1995, p.1942). It has been widely used in PSO can define search direction and search scopes only based on the fitness function converted from the object function and doesn't need to know the differential of object function and other auxiliary information. PSO is initialized with a population of random solutions of the objective function.

TABLE 1.
BASIC PARAMETERS OF THE MODEL

Slab number	Steel grade serial	Steel grade	Width	Consignment date	Slab weight	Penal coefficient	
						P/Yuan	H/Yuan
1,31	11	DT5427A1	1050	4	25	20	100
2,32	11	DT5427A1	1050	5	25	20	100
3,33	11	DT5427A1	1050	6	25	20	100
4,34	11	DT5427A1	1050	7	25	20	100
5,35	11	DT5427A1	1050	5	25	20	100
6,36	12	DT5427A2	1100	6	28	20	100
7,37	12	DT5427A2	1100	7	28	20	100
8,38	12	DT5427A2	1100	8	28	20	100
9,39	12	DT5427A2	1100	4	28	20	100
10,40	12	DT5427A2	1100	4	8	20	100
11,41	12	DT5427A2	1100	5	8	20	100
12,42	11	DT5427A1	1200	6	26	20	100
13,43	11	DT5427A1	1200	7	26	20	100
14,44	11	DT5427A1	1200	5	26	20	100
15,45	14	DT5427A4	1150	6	23	20	100
16,46	14	DT5427A4	1150	7	23	20	100
17,47	14	DT5427A4	1150	6	23	20	100
18,48	14	DT5427A4	1150	5	23	20	100
19,49	14	DT5427A4	1150	4	23	20	100
20,50	14	DT5427A4	1150	5	23	20	100
21,51	23	AR5158E3	1150	5	23	20	100
22,52	23	AR5158E3	1150	6	23	20	100
23,53	23	AR5158E1	1000	5	24	20	100
24,54	21	AR5158E1	1000	4	24	20	100
25,55	21	AR5158E1	1000	7	24	20	100
26,56	21	AR5158E1	1000	4	24	20	100
27,57	21	AR5158E1	1250	5	20	20	100
28,58	22	AR5158E2	1250	6	20	20	100
29,59	32	DR5158E2	1250	7	10	20	1000
30,60	32	DR5158E2	1250	5	10	20	1000
		T=100	E=100	F1=4	F2=5	F3=20	F4=20

Travelling Salesman Problem (TSP) is a well-known NP-hard combinatorial optimization problem. By now, TSP has been well studied by many meta-heuristic approaches, such as nearest neighborhood search, simulated annealing, tabu search, neural networks, ant colony system (Huang,2003), and genetic algorithm. Since 1995, particle swarm optimization has been proven to succeed in continuous problems But for the combinatorial problems, it is still a new field.

For the TSP, the present position is the basic path. It is difficult to express its velocity. Here, we solve the problem based on the GA's principle.

(1) Mutation operation

A mutation operation is applied to changing the sequence of cities in the tour so as to produce the newly generated solutions based on a mutation probability. In our improved PSO, the mutation operation is as follows:

Take 2 cities out randomly and exchanges the position of cities.

(2) Crossover operation

The crossover operation combines features of the two parent solutions and passes them to the child solutions by exchanging part of their sequences. Since direct exchange of corresponding cities in the two tours may result in infeasible solutions (some cities are visited more than once while some others are not visited), the crossover operators for TSP are specially designed to be capable of repairing the child chromosomes to guarantee feasibility. Several crossover operators have been proposed in the literature (Tao,1998, pp.803), such as: partially matched crossover (PMX), order crossover (OX) and cycle crossover. In our researches, the 3 crossover operators are all studied. For our pseudo TSP, the performance of the 3 operators is near. In the following studies, the PMX operator is used for the crossover operation. Based on the characteristic of PSO, a new crossover probability is introduced into the DPSO algorithm, which is differed to that of the GA. It is called pbset crossover probability (p_{cp}).

(3) Improved DPSO algorithm

Based on the previous discussion, the improved PSO algorithm can be concluded as follows:

While (iterative number < largest iterative number) do

For j=1: n

produce a random number r_p in (0,1);

if $rp < r_p$

Crossover the particle with $pbset$;

Else

Crossover the particle with $gbest$;nd obtain $C''(j)$;

Mutation operation of the result particle;

Compute the fitnesses of every result particle; ;

If the new fitness smaller than that of the older

accept the new path

else

refused the new path;

If $f(j) < f(pbest)$, $f(pbest) = f(j)$ and $pbest = j$.

END For

Find out the $f(gbest)$ and $gbest$;

END While

Output the $f(gbest)$ and $gbest$.

5 APPLICATION EXAMPLES

Now take the practical data in a steel and iron plant as an example. The basic model parameters are listed in Table 1. There are 60 slabs to be arranged. Usually they are arranged into 13 charges according the total weight. The maximum iterative number and population size are set 500 and 200 respectively.

According to the charge model and the Pseudo TSP solution method, the search process is plotted in Fig.4 and the results are listed in Table 2. The best value with fixed charge number is 3884 while it is 3063 when using the pseudo TSP with unknown charge number. In Fig.4, the dashed line represents the search process of the charge plan problem with unknown charge number and the solid line represents the problem with fixed charge number. From Fig.4, it can be seen that this TSP solution method can solve the charge plan problem with unknown charge number better.

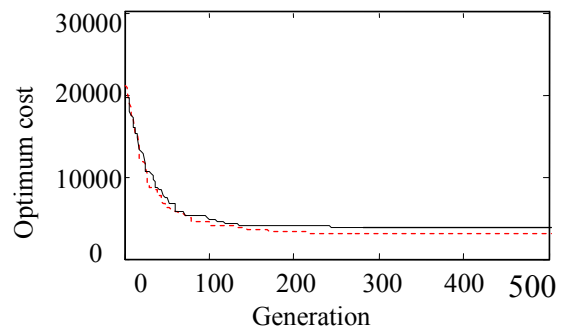


Fig. 4 DPSO search process

6. CONCLUSIONS

Based on the steelmaking process analysis, a mathematical charge plan model of steelmaking-continuous casting (SCC) scheduling in the computer integrated manufacturing systems environment is presented. Based on the analysis of the difficulty to solve the scheduling problem, a pseudo

travel salesman problem model is presented to describe the scheduling model. By using this method, we can solve the optimum charge problem even without known the charge number, while other methods must know the charge number previously. To solve the problem, an improved discrete

particle swarm optimization is also presented. Simulations have been carried and the results show that the pseudo travel salesman problem is very fit for describe the model. The computation with practical data shows that the model and the solving method are very effective.

TABLE 2
COMPUTATION RESULTS WITH FIXED AND UNKNOWN CHARGE NUMBER

fixed charge number			unknown charge number		
Charge number	Slab numbers	weight	Charge number	Slab numbers	weight
1	9,10,13,17,41	93	1	27,28,52,57	83
2	29,30,59,60	40	2	4,6,15,49	99
3	15,46,47,50	92	3	24,25,54,55	96
4	36,44,45,49	100	4	7,38,40,44	90
5	8,11,37,39	92	5	20,34,35,48	96
6	1,2,32,33	100	6	16,19,42,46	95
7	6,7,31,40	89	7	9,10,13,14	88
8	22,27,28,52	86	8	2,3,5,47	98
9	3,4,5,33	100	9	23,26,53,56	96
10	16,20,38,48	97	10	29,30,59,60	40
11	24,25,55,56	96	11	11,12,37,39	90
12	23,26,53,54	96	12	1,32,33,45	98
13	21,51,57,58	86	13	17,18,31,50	94
14			14	8,36,41,43	90
15			15	21,22,51,58	89
Slabs cannot be arranged	12,14,18,19,35,42,43	175	Slabs cannot be arranged	none	0

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