김일성종합대학학보 JOURNAL OF KIM IL SUNG UNIVERSITY
(자연과학) (NATURAL SCIENCE)
주체103(2014)년 제60권 제6호 Vol. 60 No. 6 JUCHE 103(2014).

A Method of Hot Rolling Process Scheduling using Multiple Traveling Salesman Problem

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Making production schedules in hot rolling production processes is of great importance for production management.

Up to now, there have been many researches into production schedules in rolling production processes. However, those methods are not yet developed satisfactorily since each method needs some specific conditions for its use and has some limitations.

Some literatures [1, 2] have considered rolling scheduling models and their solving methods for enhancement of products' standard package and productivity for a continuous rolling production processes.

Literatures [3, 4, 5, 6, 7] proposed optimal methods for generating approximate optimal solutions for models of hot rolling scheduling problem.

Literatures [8, 9, 10] proposed more appropriate models for finding out optimal solutions by optimal search techniques.

The shortcomings of preceding methods for the hot rolling scheduling problem are as follows.

First, the previous researches mostly conducted analysis of models for the continuous hot rolling production processes but didn't consider models for the hot blooming rolling production processes.

Second, there has never been a detailed research enough for models of the hot blooming rolling production processes. So there could be no solution of methods for the models.

Therefore we conduct modeling for hot blooming rolling production processes by using multiple traveling salesman problems and propose a solving method with GA.

1. MTSP Model of the Hot Rolling Scheduling Problem

The blooming mill is often considered as the bottleneck of the overall production process, and in conformity with the different gauges of products, roll grooves must be replaced in production processes. Therefore, arise problems such as increment of roll groove replacement cost, production time and energy consumption.

Hot rolling scheduling of the blooming mill is a framing of production turns reflected with rolling sequence of slabs to roll in a shift. Production turn means the continuous production in conformity with settled gauges by means of one kind of roll groove.

First, to convert hot rolling scheduling into an MTSP, we introduce M dummy nodes. One of them let all turns start from it and end at it. That is, this dummy node acts as both of source node and destination node to make closed routes. Then $M-1$ dummy nodes are introduced to ensure that M closed routes are made and every node should be visited by only one salesman.

Assume that N slabs with numbers (slabs assigned number) are to be rolled in M rolling turns on one shift.

Then, these N slabs with numbers may be viewed as N nodes and M turns may be regarded as the tours by M traveling salesmen. That is, N slabs with numbers are correspond to N cities to be visited by M roll grooves. By adding M dummy nodes $N+1,\ N+2,\ \cdots,$ $N+M$, the rolling scheduling problem can be viewed as an MTSP.

Now, assume that one salesman visit $N+M$ cities MTSP can then be reduced to a single TSP. These variables and parameters may be viewed as three kinds of numerical formula.

$$X_{ij}=\begin{cases}1 & \text{if slab with number } j \text{ immediately follows slab} \\ & \text{number } i \text{ in the same turn} \\ 0 & \text{otherwise}\end{cases},\quad i,\ j\in(1,\ \cdots,\ N),\ i\neq j$$

$$X_{ij}=\begin{cases}1 & \text{if slab with number } j \text{ is the first} \\ & \text{to be produced in turn } i-N \\ 0 & \text{otherwise}\end{cases},\quad i\in\{N+1,\ \cdots,\ N+M\},\ j\in\{1,\ \cdots,\ N\}$$

$$X_{ij}=\begin{cases}1 & \text{if slab with number } i \text{ is the last} \\ & \text{to be produced in turn } j-N \\ 0 & \text{otherwise}\end{cases},\quad i\in\{1,\ \cdots,\ N\},\ j\in\{N+1,\ \cdots,\ N+M\}$$

Appling P_{ij} (penalty constant for production changeover from slab with number i directly to slab with number j), the mathematical model of blooming rolling scheduling can then be formulated as follows:

Objective function:

$$\min\sum_{i=1}^{N+M}\sum_{j=1}^{N+M}P_{ij}X_{ij} \tag{1}$$

Subject to

$$\sum_{i=1}^{N+M}X_{ij}=1,\quad j\in\{1,\ 2,\ \cdots,\ N+M\} \tag{2}$$

$$\sum_{j=1}^{N+M}X_{ij}=1,\quad i\in\{1,\ 2,\ \cdots,\ N+M\} \tag{3}$$

$$\sum_{i\in S}\sum_{j\in S/\{i\}} X_{ij} \le |S|-1,\ \ S\subset\{1,\ \cdots,\ N+M\},\ \ 2\le|S|\le N+M-2 \tag{4}$$

$$X_{ij}\in\{0,\ 1\},\ \ i,\ j\in\{1,\ \cdots,\ N+M\} \tag{5}$$

Constraints (2) ensure that only one task is rolled before order j. Constraints (3) guarantee that only one slab is rolled after slab i. Constraints (4) makes avoid subschedules (corresponding to subtours for TSP) in the feasible solutions. Constraints (5) means that the variables only take integer values of 0 or 1.

The solution of this model gives a complete schedule consisting of M turns for each start from a dummy node and the complete schedule corresponds to a optimal path in the TSP.

2. Solving Method for TSP Model with GA

A general GA for TSP may be described as follows.

First, we use general coding method that an object(genotype) corresponds to an appropriate traveling path(phenotype). Assume N slabs with numbers are cities with assigned numbers 1 to N to be visited, then visiting sequence is viewed as $(t_1,\ \cdots,\ t_N)$ and gives city's list W (positive numbers) appropriately arranged. Then represent i th visited city for any number in unvisited city's list $W-\{t_1,\ \cdots,\ t_{n-1}\}$ and assume it is gene l_i. At this time, $1\le l_i\le N-i+1$ is concluded. Thus, let the acquired list $L=(l_i,\ \cdots,\ l_N)$ as a chromosome and form a GA.

Second, crossover method uses partially mapped crossover (PMC) which is one kind of crossover operation method. PMC adds to point to point crossover procedure which keep correctness of permutation. Suppose phenotype (path) is permutation $T=(t_1,\ \cdots,\ t_{n-1})$ and consider it as genotypes. At this time, genotypes of two parent generations X and Y as T^X and T^Y, respectively, then two descendant X' and Y' are generated by PMC and that procedure is as follows.

① Arbitrarily select two-crossover point.

② Parent copy genes to descendants respectively. Therefore

$$t_p^{X'}=t_k^X,\ \ t_k^{Y'}=t_k^Y\ \ (k=1,\ \cdots,\ N)$$

③ First, find the value of q satisfying $t_p^Y=t_q^{X'}$ for interspace between crossover points $P=i+1,\ \cdots,\ j$, and value of r satisfying $t_p^X=t_r^{Y'}$. Then replace $t_p^{Y'}$ with $t_r^{Y'}$.

Last, mutation operation uses general method in which two gene's positions are selected randomly.

Purpose function is not negative and the purpose is minimization, then, fitness function is as follows.

$$g=\frac{1}{f(x)}10^4$$

3. A Numerical Results

We made a hot rolling schedule with production data of ×× blooming rolling processes and its purpose is minimization of penalty cost.

Parameters are set as follows.

Maximum number of generations=100,

Population size=10,

Probability of crossover=0.99,

Probability of mutation=0.01.

Penalty structure for rolling gauge considers specific characters and various constraints of the object are shown in Table 1. Then, Table 2 shows actual rolling sequence made by manual agent and proposed method.

The object function value of manual rolling sequence table is 120 and the object function value of MTSP rolling sequence table is 80, so it is clear that the total penalty of the solution by proposed method is far less than that by manual sequencing. In this experiment the total penalty of the schedule generated by the MTSP/GA method has decreased by 33.4% as compared with the result of manual scheduling.

Table 1. Rolling gauge penalty structure

Gauge	55	51	53	56	71	73
55	—	10	20	30	40	50
51	10	—	20	30	40	50
53	10	20	—	30	40	50
56	10	20	30	—	40	50
71	10	20	30	40	—	50
73	10	20	30	40	50	—

This result demonstrates that a hot rolling schedule produced with the proposed MTSP/GA is superior to one created from the manual experience.

Table 2. Rolling sequence table

No	Manual				MTSP			
	S.N	R.G	S.V	R.W	S.N	R.G	S.V	R.W
1	1011	55	C	20t	1011	55	C	20t
2	1012	55	E	20t	1012	55	E	20t
3	1013	51	A	10t	1013	51	A	10t
4	1013	53	A	10t	1015	51	E	10t
5	1015	71	E	5t	1016	51	B	10t
6	1015	51	E	10t	1015	55	E	5t
7	1015	55	E	5t	1016	55	B	10t
8	1016	55	B	10t	1017	55	D	20t
9	1016	51	B	10t	1013	53	A	10t
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
100	1017	55	D	20t	1015	71	E	5t

Conclusion

This paper set the scheduling problem of the blooming mill as multiple traveling salesman problems, proposed solution algorithm and verified its effectiveness through simulation.

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