Systems Engineering - Theory & Practice
Volume 27, Issue 11, November 2007
Online English edition of the Chinese language journal

Available online at www.sciencedirect.
ScienceDirect

Cite this article as: SETP, 2007, 27(11): 111–117

RESEARCH PAPER

Solving a Class of Job-Shop Scheduling Problem based on Improved BPSO Algorithm

FAN Kun*, ZHANG Ren-qian, XIA Guo-ping
School of Economics and Management, Beihang University, Beijing 100083, China

Abstract: Analyzing the special job shop scheduling problem of a large-scale machine shop, considering workers operational qualification and characteristics of discretely concurrent production, a novel mathematical model has been proposed to meet actual production. In addition, an improved binary particle swarm optimization (BPSO) algorithm has been developed for solving the problem of arranging m workers to process n structures, to optimize the minimum completion time of the jobs. In this improved BPSO, a new method of making initial particles has been presented for searching the optimum particle in the feasible dimensional problem space. Besides, importing memory base, modifying Sig function, and considering constraint condition have been used in the algorithm for making updated particles meet the constraint equation of the mathematical model. The research on the algorithm examples demonstrates that the improved BPSO algorithm is effective and can achieve good results. Moreover, the mathematical model has wide application in discrete manufacture.
Key Words: job shop scheduling; binary particle swarm optimization (BPSO); structure

1 Introduction

The job shop scheduling problem (JSP), a typical production scheduling problem, is not only widely appearing in discrete manufacture and flow manufacture, but is also deeply studied by scholars.

The classical JSP can be stated as follows: given n jobs to be processed on m machines; each job consists of several operations to be processed on all or some of the given machines. The operations of a job have to follow the assigned processing route, specific for each job. Given the processing times of all operations, the purpose is to find a schedule that optimizes a certain objective function (such as the total processing time, the total cost, the relative processing time, and so on).

Besides the classical JSP problem[1], scholars all over the world have conducted several researches on all kinds of job shop scheduling problems, including flexible, multi-objective, cyclic, no-wait, stochastic, and dynamic JSP, etc. Over the last 10 years, various heuristic algorithms have been applied to job shop scheduling, including the following: simulated annealing algorithm (SA), taboo search algorithm (TS), neural network algorithm, and genetic algorithm (GA). Recently, some researchers have started using ant colony optimization[2] and particle swarm optimization algorithms[3−4] in JSP studies.

So far, almost all researches on JSP are about the scheduling optimization problems between jobs and machines, while the scheduling between jobs and workers is less seen. However, this scheduling optimization problem also appears frequently in practical applications of a certain discrete manufacture.

In this article, we investigate the structure workshop in a large-scale mechanical factory. By analyzing the special job shop scheduling problem of this workshop, and considering workers' operational qualification and characteristics of discretely concurrent production, a novel mathematical model has been developed to meet the actual production. In addition, an improved binary particle swarm optimization (BPSO) algorithm has been developed for solving the problem of how to arrange m workers to process n structures, to optimize the shortest completion time of the jobs, and good results have been achieved.

2 Production system description

For enhancing the efficiency, two processing workshops are built, i.e., machining workshop and structure workshop. Workpieces and structures are processed in the structure workshop, while they are automatically machined in the machining workshop for the sake of drilling, chambering, or other operations. The works in the structure workshop mainly include assembly and welding, that is to say, workers assemble clipped steel plate and structural steel, which includes steel angle, channel steel, round steel, square steel, pipe, steel rail, et al., and then they weld these materials following design drawing. Since the product is large-sized, not only the manufacture but also the transportation and assemblage must be considered in the stage of design. Thus, a product has to be divided into several parts, with each part composed of several structures, which are jointed by bolt-

Received date: September 18, 2006
∗ **Corresponding author:** Tel: +86-10-82315400; E-mail: fankun@126.com
Foundation item: Supported by the National Nature Science Foundation of China (Nos.70501002 and 70671007) and Aeronautical Science Foundation of China (No. 2007ZG51075)

ing, hinging, and welding. The final product to use is filed mounted (FM). In the structure workshop, each structure will follow the production flow as baiting, fitting up, welding, and truing.

We mainly study the job shop scheduling problem for this certain structure workshop. Since the operations in the workshop are basically welding, each welding worker has his exclusive welding device (CO_2 gas shielding welding machine or hand electric arc welder) in working time. Since each worker has different operation qualification, the process time of the same structure is also different.

3 JSP description and mathematic model

3.1 Problem description

From the production system description, we can get the JSP problem description for the given construction workshop: assume that m workers process n structures (which are simplified as jobs in this article, usually $n \geq m$), and all operations of a job have to be processed by the same worker from start to end; Considering the operation qualifications of the workers, the problem is how to arrange m workers to process n jobs to get the shortest completion time.

We define t_j as the shortest processing time of job j by the most skilled worker, T_j is the waiting time of job j, including the setup time, baiting time, fitting up time, etc. before the process and the break time in the process. We also define k_i as the skill coefficient of worker i ($k_i \geq 1$).

Assume that the processing time of the same job by different worker is determined by the operational qualification of the worker and the waiting time is equal; we can get the efficiency matrix of the JSP problem in this structure workshop as Table 1. In Table 1, the element $k_it_j + T_j > 0(i = 1, 2, \ldots, m; j = 1, 2, \ldots, n)$ indicates the completion time of job j by worker i, i.e., the completion time of a job is the sum of the actual processing time and the waiting time.

The above assumptions, i.e., the processing time of the same job by different worker is determined by the operational qualification of the worker and the waiting time is equal, are in accord with the actual production conditions. Since the processing route, material, structure, and equipment of processing the job are all the same and the only difference is the workers' technique level, the processing time of the same job mainly depends on the worker's operational qualification. In actual, the waiting times of the same job are equal, while the waiting times of the different jobs are unequal because of the different processing route, material, and structure.

Table 1. Efficiency matrix of JSP in structure workshop

	Job 1	$\cdots$	Job j	$\cdots$	Job n
Worker 1	$k_1t_1 + T_1$	$\cdots$	$k_1t_j + T_j$	$\cdots$	$k_1t_n + T_n$
Worker 2	$k_2t_1 + T_1$	$\cdots$	$k_2t_j + T_j$	$\cdots$	$k_2t_n + T_n$
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
Worker i	$k_it_1 + T_1$	$\cdots$	$k_it_j + T_j$	$\cdots$	$k_it_n + T_n$
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
Worker m	$k_mt_1 + T_1$	$\cdots$	$k_mt_j + T_j$	$\cdots$	$k_mt_n + T_n$

3.2 Mathematic model

The objective function of the job shop scheduling problem in the structure workshop is:

$$\min T = \max\left(\sum_{j=1}^{n}(k_1t_j + T_j)w_{1j}, \sum_{j=1}^{n}(k_2t_j + T_j)w_{2j}, ..., \sum_{j=1}^{n}(k_it_j + T_j)w_{ij}, ..., \sum_{j=1}^{n}(k_mt_j + T_j)w_{mj}\right) \quad (1)$$

s.t.

$$\sum_{i=1}^{n} w_{ij} = 1, \quad j = 1, 2, ..., n \quad (2)$$

$$1 \leq \sum_{j=1}^{n} w_{ij} \leq n - m + 1, \quad i = 1, 2, ..., m \quad (3)$$

$$\sum_{j=1}^{n} w_{ij} = 1 \text{ or } 0 \quad (4)$$

In Eq.(1), w_{ij} is the state variable for worker i processing job j, which equals 1 or 0.

$$w_{ij} = \begin{cases} 1 & \text{if job } j \text{ is assigned to worker } i \\ 0 & \text{otherwise} \end{cases}$$

The time t_j is the shortest processing time of job j by the most skilled worker; T_j is the waiting time of job j; the skill coefficient k_i represents the operational qualification of the worker i, $k_i \geq 1$; $k = 1$ indicates that the worker has the most skilled operational technic, i.e., the processing time for the same job is minimum. Usually, $n \geq m$, which indicates that the number of jobs is more than the number of workers.

The objective function $\min T$ represents the shortest time for completing n jobs by m workers. Owing to the concurrent production, i.e., all workers processing at the same time, the shortest completion time of all jobs is the longest time for all the workers completing their assigned jobs.

The constraint (Eq.(2)) guarantees that each job must be allocated to just one worker. Eq.(3) shows that worker i can process $n - m + 1$ jobs at most, which indicates that the other $m - 1$ workers process $m - 1$ jobs (the perfect state is when each worker processes one job). The precondition of Eq.(3) is that $n \geq m$ must be true. When this precondition is neglected, Eq.(3) should be replaced by Eq.(5):

$$0 \leq \sum_{j=1}^{n} w_{ij} \leq n, \qquad i = 1, 2, \cdots, m \quad (5)$$

The feasible solution w_{ij} satisfied with constraints (2)-(4) can be shown by matrix, i.e., solution matrix. A feasible solution matrix for the above objective function is as follows:

$$(w_{ij}) = \begin{pmatrix} 0 & 1 & \ldots & 0 & \ldots & 0 & 1 \\ 1 & 0 & \ldots & 0 & \ldots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \ldots & 0 & \ldots & 1 & 0 \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \ldots & 1 & \ldots & 0 & 0 \end{pmatrix} \quad (6)$$