Systems Engineering — Theory & Practice
Volume 29, Issue 8, August 2009
Online English edition of the Chinese language journal

Cite this article as: SETP, 2009, 29(8): 117–126

RESEARCH PAPER

Multi-Objective Flexible Job-Shop Scheduling Problem in Steel Tubes Production

Li Lin, Huo Jia-zhen*
School of Economics and Management, Tongji University, Shanghai 200092, China

Abstract: On the basis of the distinct characteristics of steel tube production process, the production scheduling problem of seamless steel tubes is described as flexible job-shop scheduling problem. Considering the parallel machines with capacity and speed constraint, maintenance of machines as well as intermediate inventory restriction, it is formulated as mixed-integer-programming(MIP) model to decide the flexible routes for every job and to optimize the sequence of jobs. The objective is not only to reduce delivery delay, but also to minimize idleness of machines and interruption in production. Given the problem is NP-hard (non-deterministic polynomial-time hard), modified genetic algorithm is proposed, whose effectiveness can be well verified in scheduling decision support system for the production of seamless steel tubes in Baoshan Iron & Steel Complex.

Key words: seamless steel tube; multi-objective flexible job-shop scheduling problem; mixed integer-programming model; genetic algorithm; scheduling

1 Introduction

Due to stiff market competition, many developing countries are under great pressure to improve production efficiency and enhance competitive power. One important way to achieve this is through effective production scheduling. In practical production environment, scheduling is made according to the experience of scheduling personnel. However, it is quite difficult to guarantee the optimality of the scheduling when the number of resources (machines, production stages), tasks (orders, production procedure of orders), and production constraints increases. That is the significant motivation for our research. Taking the seamless tube plant of Baoshan Iron and Steel Complex in China as research background, this article aims at providing a theoretical methodology for scientifically establishing the machine and sequencing schedule in steel industry.

Scheduling problem in iron and steel industry has been a hot research focus in recent years. However, there is rarely attention been paid to seamless steel tube scheduling, which differs from the scheduling of other steel products such as strip because of its distinct process features. Seamless steel tubes often have various categories and specifications, which further require complicated operations in production. Tang studied the main production scheduling of hot rolling steel tube[1−2]. The relationship among steel making, continuous casting and hot rolling, and the design of production scheduling simulation system are studied in many articles[3−8].

Generally speaking, there are two kinds of scheduling problem: FSP (Flowshop problem) and JSP (Jobshop problem)[9]. Considering the different production routes required by multi-variety and multi-specification orders, it is appropriate to adopt JSP to describe the scheduling problem in seamless steel tube production. Numerous research works on JSP focus on ideal simplified model and algorithm with several severe assumptions, which make it impossible to be applied into practical sequencing problem[10−18]. With regard to the real problem in the production, Tang developed a MIP model with objective of minimizing the sum of weighted completion times of all orders to solve the strip production scheduling problem[19]. The feasible idea of transforming non-preemptive job-shop scheduling problem into preemptive job-shop scheduling problem is put forward in Zhong[20]. However, their studies assume that the production routes and machines are fixed, which is quite different from our research in this article.

Considering the real-world environment, the production of seamless steel tube is characterized as: (i) multiple stages are involved and several machines are parallel in each stage; (ii) multiple objectives, including the reduction of idleness on machines, and the improvement of production continuity are considered. Therefore, there are two principle tasks of scheduling: one is to determine which orders allocated to every machine (determine the flexible production route of orders); the other is to determine the sequence of orders allocated to each stage. To our best knowledge, this kind of problem has not been studied in the reference before.

2 Description of problem

Seamless steel tube is one of the major products in iron and steel industries. The varieties and specifications of tube are diversified including different outside diameter, wall thickness, steel grade, tube-end type, thread etc, which require different production procedure and operations.

Received date: August 6, 2008
∗ **Corresponding author:** Tel: +86-15921034390; E-mail: lilin012000@163.com;huojiazhen@163.com
Foundation item: Supported by the National Natural Science Foundation (No.70832005)

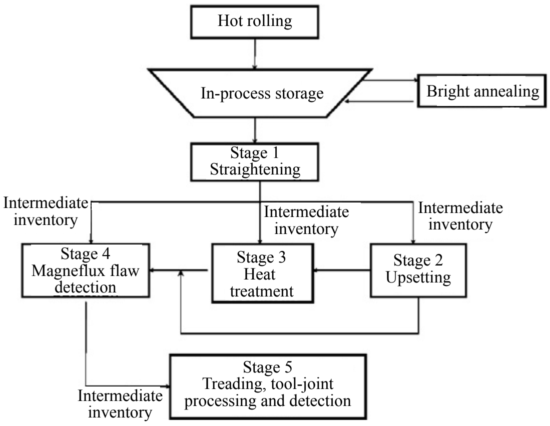

Figure 1. Production process schematic for seamless steel tube

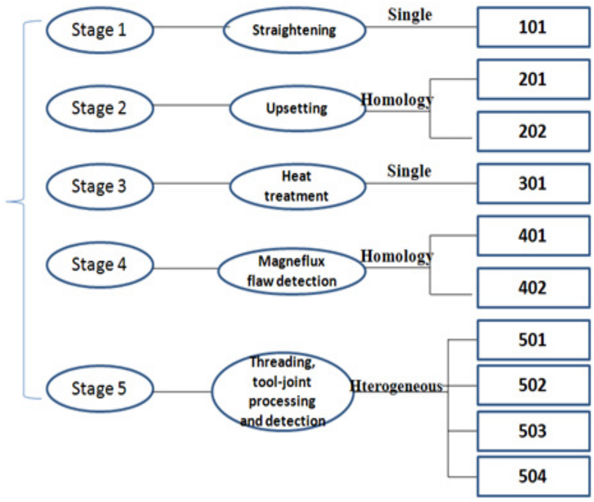

Figure 2. Machines in each stage in seamless steel tube plant

The steel tube scheduling differs from scheduling of other steel products such as strip steel for its distinct process features.

The whole production process of the seamless steel tube can be described as follows: the round steel tube billet is perforated and deformed in hot rolling process, then the diameter-reduced semi-finish steel tube is straightened, upset, heat treated, cooled, cut, trimmed, and verified into a steel tube with required specification and performance. The latter process is called cold treatment process, which is composed of 5 stages. According to varied category and specification, different production routes of orders are required. Note that not all the tube to be produced must pass through every stage, which means some stage can be excluded for certain orders. Figure 1 illustrates the stages and possible production routes. Due to the buffer storage between adjacent stages, the production of seamless steel tube in cold treatment process is semi-continuous (the production in each stage is continuous).

In each stage, there are different numbers of machines in parallel. Some of machines are homogeneous, which means each of machines can be chosen to process jobs even with different speed and setup time, but some are not. Taking the seamless steel tube plant in Baoshan Iron and Steel Complex for example (see Figure 2), the stage of upsetting (denoted as Stage 2) includes two identical machines, while the last stage (denoted as Stage 5) comprises four dissimilar machines with special tool. It is obvious that flexible routes decision need to be made only in the stages with homogeneous (identical) machines.

In each stage, setup cost (time) appears when different specifications (diameter, wall thickness, steel grade, material, tube-end type, thread) are switched because of the time required for preparation and replacing the tools. The setup cost (time) in the fifth stage is the highest, which requires the tubes with similar specification scheduled as adjacent jobs in the sequence.

To sum up, with the consideration of intermediate buffer, maintenance planning, and practical production constraint, the task of scheduling problem is to decide the production routes for the orders, choose the flexible machines in each stage, and determine the sequence of the orders on each machine in order to achieve the objective of greatest reduction of idle time on machines and waiting time of orders during semi-continuous production process.

3 Modelling flexible job-shop scheduling problem

According to the above description, the production routes are different based on specification of jobs (orders). Moreover, because of several identical machines in parallel, there exists flexibility of production scheduling. Therefore, we can view the scheduling decision as a flexible job shop problem (FJSP) with more complicate settings including intermediate inventory, maintenance, and production constraints derived from practical production environment.

Setup time caused by switch of specification between adjacent jobs and waiting time of jobs during the process are chosen as multi-objective function of FJSP for this measurement criterion related to the production efficiency. In this article, the above scheduling problem of seamless steel tube is generalized to be a multi-objective FJSP.

3.1 Notation

There are I jobs with P items of specification, J successive processing stages with J_j unrelated machines in parallel in each stage $j(j = 1, \cdots, J)$, and $L(\sum_{j=1,\cdots,J} J_j = L)$ machines in all. The following notations are used for depicting the parameters and variables.

Parameters

$M(i)$ the set of stages included in production route for job i

M_i the number of elements in $M(i)$

MS_i the number of flexible stages in which parallel machines need determining for job i

Q_i the weight of the ith job when it completes all the production process

w_{lp} the setup time on the lth machine for changeover of the pth item of specification between contiguous jobs

φ_{ij} the set of machines can be used to produce the ith job on stage j. If $j \notin M(i)$, then $\varphi_{ij} = \emptyset$. The number of elements in φ_{ij} is denoted as n_{ij}

I_{ij} the weight of material can be used to produce job i in inventory on stage j. If the ith job do not pass through