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Tire mixing process scheduling using particle swarm optimization

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A R T I C L E I N F O

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A B S T R A C T

The tire manufacturing process consists of four major steps, including mixing, component preparation, building, and curing. Among these, the mixing process is the most important, since it produces a type of synthesized rubber called a compound, which determines various features of the tire and consumes 70% of the overall manufacturing budget. However, despite the importance of mixing, there is little research on this process. Thus, in this study, we consider a scheduling problem for a tire mixing process and suggest an efficient particle swarm optimization (PSO) algorithm for minimizing makespan. Specifically, we design a system in which particle coordination and velocity are used to generate a processing sequence for compounds and machine allocation information, while being updated in successive steps. The superiority of the proposed PSO algorithm is shown with numerical experiments that compare the solutions found by the proposed algorithm with those obtained from a mixed integer linear programming model developed in previous research.

1. Introduction

The tire manufacturing industry is a typical equipment industry that needs large factory sites and various facilities. A considerable amount of investment is required as a result of maintenance costs for smooth equipment operation and productivity enhancement (Ferrer, 1997). The manufacturing processes used in the tire industry are similar to those for a flexible job-shop, and its company-wide management is difficult because of the complex, extensive moving route of the semi-finished products (Klepper & Simons, 2000). Therefore, quality and productivity should be continuously improved with efficient scheduling as well as the development of new manufacturing technology to maintain the competitiveness of a tire industry, which requires vast capital and labor.

Generally, a tire is manufactured through four processes, as shown in Fig. 1: mixing, component preparation, building, and curing (Lee & Lee, 2000). Rubber for the tire is produced from a mixing process that combines raw materials and forms those materials into semi-finished products with additional processes such as extruding, pressing, and beading, according to the characteristics of component of tire. Then, a green tire with a low tensile strength is produced from a building process that shapes the tire. After a curing process, the tread pattern can be completed in accordance with the type of tire by applying steady heat and pressure (Ahn & Park, 2013; Sakai, 1987).

Fig. 2 outlines such a mixing process. The rubber mixture, which is a final ingredient of the tire, is produced from two mixing steps. Carbon black is mixed in the first step, and sulfur is mixed in the second step. A Banbury mixer is used to pulverize natural and synthetic rubber, and to combine another synthetic material with the rubber at this stage in the process. The rubber for the tire that is mixed by the Banbury mixer is classified according to tire characteristics such as tread, sidewall, and inner liner. Sheet rubber obtained from the mixing process undergoes additional processes such as extruding, pressing, and beading to create the semi-final product (Kim et al., 2004).

The characteristics of the tire mixing process are as follows: (i) Each job in the mixing process has a different operation and (ii) an operation can be performed in plural alternative machines. Because of such features, the scheduling of a tire mixing process can be generalized by a flexible job shop scheduling problem (FJSSP), which was introduced by Brandimarte (1993) and is an extension of JSSP. The following assumptions are used in FJSSP, which are appropriate for a tire manufacturing process (Liu, Abraham, & Wang, 2009).

- **Disjunctive constraint:** Each operation is processed in only one machine, which can be expressed as $\sum_l J^l = 1$, where $J^l = 1$ if job J is processed in l th machine, and 0 otherwise.

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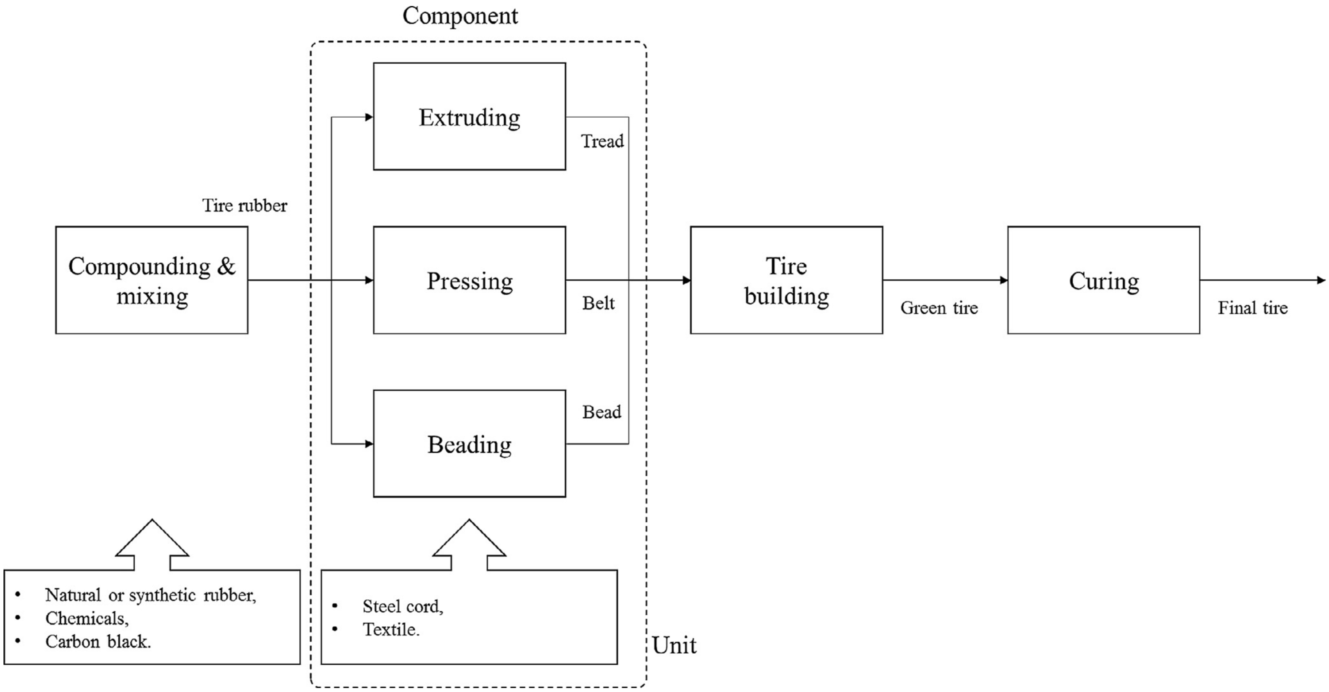

Fig. 1. Tire manufacturing process.

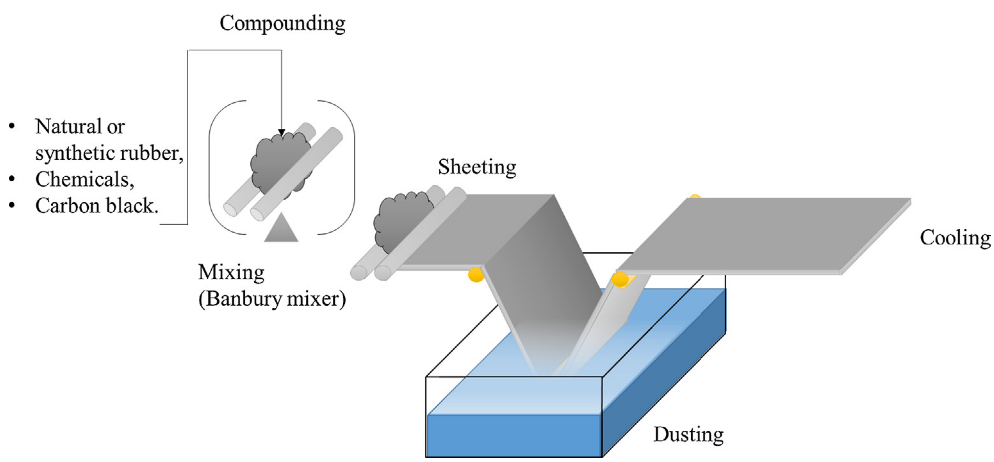

Fig. 2. Outline of tire mixing process.

- **Non-preemption condition:** If an operation starts in a machine, the operation occupies that machine until it is finished.
- **Capacity constraint:** Each machine can begin another operation only if the former job is completed.
- **Precedence/conjunctive constraint:** A job operation is processed according to the predefined processing sequence.
- **Resource constraint:** Operations should be processed in a predefined set of machines.

Moreover, each mixing process operation has a different setup time, according to the processing sequence in the mixer. For example, an alteration to the compound type processed in a certain mixer causes additional setup time, because it changes synthetic product type. Even when compounds are the same, additional setup time is required for the serial input of an operation batch. Floating setup time between consecutive operations is referred to as sequence dependent setup time (SDST), and is meaningfully considered in a typical JSSP or FJSSP. The work of Özgüven, Yavuz, and Özbakır (2012) provides a detailed literature survey of SDST.

The cost of raw materials used in mixing process includes the costs of natural and synthetic rubber and carbon black, which together make up 70% of the overall manufacturing budget. Therefore, efficient mixing process scheduling is essential for enhancing the productivity of the entire tire manufacturing process. However, there are only a few limited studies dealing with tire mixing process scheduling. Rajamani and Adil (1998) dualized a rubber arrangement as (i) an allocation and (ii) a sequencing model for a Banbury mixer. They formulated each of the dual models with a mixed integer linear programming (MILP) and proposed a scheduling method based on simulated annealing for the sequencing model, whose complexity is relatively high. However, this two-step MILP model is quite inefficient, because it requires excessive calculation procedures for the mathematical models. Ahn and Park (2013) suggested a genetic algorithm (GA)-based solution