Chapter 6
An Ant Colony System Algorithm for the Hybrid Flow-Shop Scheduling Problem

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ABSTRACT
An integrated ant colony optimization algorithm (IACS-HFS) is proposed for a multistage hybrid flow-shop scheduling problem. The objective of scheduling is the minimization of the makespan. To solve this NP-hard problem, the IACS-HFS considers the assignment and sequencing sub-problems simultaneously in the construction procedures. The performance of the algorithm is evaluated by numerical experiments on benchmark problems taken from the literature. The results show that the proposed ant colony optimization algorithm gives promising and good results and outperforms some current approaches in the quality of schedules.

INTRODUCTION
The hybrid flow shop (HFS) consists of a set of two or more processing stages (or centers) with at least one stage having two or more parallel machines. The hybrid characteristic of a flow-shop is ubiquitously found in various industries. The duplication of the number of machines in some stages can introduce additional flexibility, increase the overall capacities, and avoid bottlenecks if some operations are too long. Scheduling in a HFS has a great importance from practical point of view.
In order to solve HFS problems we have to define both an assignment and a sequencing sub-problems. The former concerns the assignment of each operation to a machine. The latter orders the operations on the machines. In this paper, our objective is to find a schedule that minimizes the makespan, i.e., the time needed to complete all the jobs. This problem is \( NP \)-hard for the simplest case of two stages and at least two machines available in one of the stages (Gupta, 1988). The HFS models differ in the type of machines at the stages. The machines may be identical, uniform or unrelated (Blazewicz, Ecker, Pesch, & Schmidt, 1996).

The purpose of this paper is to present an integrated ant colony optimization algorithm. This proposed approach considers simultaneously the assignment and the sequencing sub-problems in order to solve an HFS problem with identical machines at each stage.

The remainder of this paper is organized as follows. In section 2, we review the literature for the different methods proposed to solve the HFS problem. Section 3 is dedicated to the description of the considered scheduling problem. In section 4, we introduce our proposed meta-heuristic algorithm. Computational results are provided in section 5. Finally, conclusions and further research directions are given.

LITERATURE REVIEW

In order to solve HFS problems, many solution methodologies are proposed in the literature (Linn & Zhang, 1999) and (Ruiz & Vázquez-Rodríguez, 2010). Exact approaches are suitable for small-sized problems but get very time consuming when the size is large. For practical purposes, it is more appropriate to use approximate methods. In fact, they are able to achieve good solutions (or eventually optimal) for scheduling problems in an acceptable time.

We quote hereafter, some recent studies carried out on the HFS problem minimizing the makespan. Exact techniques included branch and bound algorithms (B&B) (Vignier, Commandeur, & Proust, 1997; Néron, Baptiste, & Gupta, 2001; Haouari, Hidri, & Gharbi, 2006), mixed integer programming (Guinet, Solomon, Kedia, & Dussa, 1996), or dynamic programming-based heuristic (Riane, Artiba, & Elmaghraby, 1998). For solving the two-stage HFS problem, some heuristic methods based on Johnson’s algorithm (Johnson, 1954) are developed (Guinet, Solomon, Kedia, & Dussa, 1996; Lee, Cheng, & Lin, 1993). Santos et al. (1996) adapted some pure flow-shop heuristics in the HFS environment. Various intelligent heuristics and meta-heuristics have become popular such as simulated annealing (SA) (Gourgand, Grangeon, & Norre, 1999; Jin, Yang, & Ito, 2006), tabu search (TS) (Nowicki & Smutnicki, 1998), genetic algorithms (GA) (Portmann, Vignier, Dardilhac, & Dezalay, 1998; Jin, Ohno, Ito, & Elmaghraby, 2002; Besbes, Loukil, & Teghem, 2006), approaches based on artificial immune systems (AIS) (Engin & Döyen, 2004).

Recently, ant colony optimization (ACO) approaches are increasingly used to solve combinatorial optimization problems (Yagmahan & Yenisey, 2010). For solving the HFS scheduling problem, Alaykýran et al. (Alaykýran, Engin, & Döyen, 2007) presented an improved ACO by adapting the classical ant system (AS) (Colorni, Dorigo, & Maniezzo, 1991). Likewise, in (Khalouli, Ghedjati, & Hamzaoui, 2008) another approach based on an ant colony system algorithm (ACS) (Dorigo & Gambardella, 1997) is proposed. It consists on solving the HFS problem by two phases: the first deals with the assignment by using some static heuristics and the second used the ACS approach to determine the processing sequences on the machines. In this paper, we propose a new ACS method different from existing ones. The particularity of this approach is the integration of the assignment and the sequencing decisions.