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A fuzzy ant colony optimization to solve an open shop scheduling problem with multi-skills resource constraints

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Abstract:
An open shop scheduling problem based on a mechanical workshop is described here. The main objective is to find the sequence of jobs which minimizes the total flow time. For that reason, we first formulate the problem as a mixed integer linear programming model which considers different resource constraints related to the personnel assignment. Resource skills and their availability are required to process tasks. A mathematical model is described and solved optimally. Besides that, a fuzzy ant colony optimization method is proposed due to the difficulty to fix the different parameters of an ACO and improve the quality of the solution. Finally, some computational experiments are defined using the references of the literature to get efficiency of ant colony optimisation. A first kind of tests are related to the small-sized instances allowing to evaluate the general performance of the model and the algorithm while a second one involves the large-size instances showing a further evaluation of the algorithm.

Keywords: Scheduling algorithms, Operations research, mathematical programming, resource allocation, skills

1. INTRODUCTION

The open shop problem is a subject that has been exposed by many authors as Kyparisis and Koulamas (1997), Liaw et al. (2002) making reference to different objectives and number of machines that can generate particular cases or configurations. The complexity of the problem is related to the involved parameters, from a preemption open shop scheduling problem solved in polynomial duration for an arbitrary number of machines, until a NP-hard problem of a compact scheduling in simplified open and flow shop proved by Giaro (2001).

The open shop scheduling literature shows many different methods as exact methods: Brucker et al. (1997) described a branch and bound algorithm considering a disjunctive graph formulation to minimize the makespan in an open shop scheduling problem. An improved branch and bound method for the preemptive open shop problem to minimize the total completion time is also explained. In spite of the quality of these methods, they have some instance size limitations due to the computational time. Then, several heuristics have been developped to provide good solutions in acceptable times, genetic algorithms, tabu search, bee colony optimization have been applied to minimize total tardiness, total completion time and makespan. In the same way, hybrid methods have also been studied; a hybrid genetic algorithm by Liaw (2000) that incorporates a local improvement procedure based on tabu search to minimize the makespan, a hybrid method between beam search and ant colony optimization has been proposed too.

In our case, the resource limitation has a strong impact on the schedule, leading us to the resource constraints scheduling problem (RCSP). Coelho and Vanhoucke (2011) exposed two types of possible resources: renewables and non-renewables in the minimization of the makespan of a project. The inclusion of resources in the open shop has already been studied on the preemptive case, an open shop with independent jobs, release and due dates under resource constraints to minimize the makespan, and by de Werra and Blazewicz (1992) that considered exactly one unit of resource to execute one task (renewable and non-renewable cases) to minimize the total completion time.

In this research work, we manage human resources (workers) where each one can master different skills to carry out one activity, so that, the problem implies a multi-skilled personnel assignment that has been studied by Kazemipoor et al. (2013) in the project scheduling. The inclusion of resources increases the complexity of this NP - hard problem.

The goal of this paper is to introduce the features of the problem, its mathematical model, then show a fuzzy ant colony optimization algorithm proposed to obtain good quality solutions. Then, the computational experiments expose the different results for the mathematical model

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and the proposed method and finally, a conclusion is provided.

2. PROBLEM FORMULATION

In this section we start to describe an open shop that has a multi-skill resource constraint and the objective function is to minimize the total flow time. It is composed of M machines ($m = 1, 2, 3, \ldots, M$) and a set of N jobs ($i = 1, 2, 3, \ldots, N$) where each job i becomes at most M operations and the processing order can have multiple options according to the product job type. Each operation O_{im} must be processed on the selected machine with a known processing time p_{im}, considering setup time s_{im} and additional availability resource constraints (workers, mastered skills per worker and required skills per operation).

The preemption is not allowed. The setup and the processing times are considered separately; thus the setup task can be started as soon as the machine is free. One job can only be processed by one machine at any time and each machine can process one job at a time. It is assumed that the jobs are available according to their release dates defined by the customer demand and all the machines are always available during the schedule.

The objective function is to minimize the total flow time of job i ($\sum_{i=1}^{N} F_i$), which is the sum of the duration spent by each job from their release date to their completion time.

A human resource (worker) must be assigned to execute a required skill that he masters, he can only use one skill on one task at a given time and any worker that is already assigned to an activity must be on the machine during its entire processing time.

We expose the problem with a mixed integer linear programming model that is used in Campos-Ciro et al. (2014) to get optimal solutions of the described problem.

Parameters

J	Set of jobs $J = \{1, ..., N\}$
L	Set of machines $L = \{1, ..., M\}$
W	Set of workers $W = \{1, ..., N_W\}$
S	Set of skills $S = \{1, ..., N_S\}$
i, j	Job index, $i,j = \{1, ..., N\}$
m, m'	Machine index, $m,m' = \{1, ..., M\}$
w	Worker index, $w = \{1, 2, 3, ..., N_W\}$
s	Skill index, $s = \{1, 2, 3, ..., N_S\}$
G	Large positive number
C_{wim}	Completion time of job i on machine m executed by worker w
C_i	Completion time of job $i = \underset{w\in W, m\in L}{Max}\ C_{wim}$
SE_{im}	Setup time job i on machine m
p_{im}	Processing time job i on machine m
r_i	Release date of job i

$$RE_{ims} = \begin{cases} 1 \text{ if job } i \text{ on machine } m \text{ needs skill } s \\ 0 \text{ Otherwise} \end{cases}$$

$$A_{ws} = \begin{cases} 1 \text{ if worker } w \text{ provides skill } s \\ 0 \text{ Otherwise} \end{cases}$$

$$X_{ijm} = \begin{cases} 1 \text{ if job } i \text{ precedes job } j \text{ on machine } m \\ 0 \text{ Otherwise} \end{cases}$$

$$Z_{imm'} = \begin{cases} 1 \text{ if job } i \text{ is executed on machine } m \text{ then} \\ \quad \text{on machine } m' \\ 0 \text{ Otherwise} \end{cases}$$

$$Y_{wim} = \begin{cases} 1 \text{ if worker } w \text{ executes job } i \text{ on machine } m \\ 0 \text{ Otherwise} \end{cases}$$

$$V_{imjm'} = \begin{cases} 1 \text{ if job } i \text{ on machine } m \text{ precedes job } j \\ \quad \text{on machine } m' \\ 0 \text{ Otherwise} \end{cases}$$

The parameters related to the lists of skills are inspired by other authors who solved the multi-skill scheduling problems as Montoya (2012).

$$Minimize \sum_{i=1}^{N} F_i = Minimize \sum_{i=1}^{N} (C_i - r_i) \quad (1)$$

Subject to the following constraints :

$$C_i \geq C_{wim} \quad \forall w \in W; \forall i \in J; \forall m \in L \quad (2)$$

$$C_{wim} - G(1 - X_{ijm}) \leq C_{wjm} - SE_{jm} - p_{jm} \quad \forall i, j \in J, i \neq j; \forall m \in L; \forall w \in W \quad (3)$$

$$C_{wim} - G(1 - Z_{imm'}) \leq C_{wim'} - p_{im'} \quad \forall i \in J; \forall m, m' \in L, m \neq m'; \forall w \in W \quad (4)$$

$$C_{wim} - G(1 - V_{imjm'}) \leq C_{wjm'} - SE_{jm'} - p_{jm'} \quad \forall i, j \in J; \forall m, m' \in L; \forall w \in W \quad (5)$$

$$X_{ijm} + X_{jim} = 1 \quad \forall i, j \in J, i \neq j; \forall m \in L \quad (6)$$

$$Z_{imm'} + Z_{im'm} = 1 \quad \forall i \in J; \forall m, m' \in L, m \neq m' \quad (7)$$

$$V_{imjm'} + V_{jm'im} \leq 1 \quad \forall i, j \in J; \forall m, m' \in L \quad (8)$$

$$V_{imjm'} + V_{jm'im} \geq Y_{wim} + Y_{wjm'} - 1 \quad \forall i, j \in J, i \neq j; \forall m, m' \in L; \forall w \in W \quad (9)$$

$$V_{imim'} + V_{im'im} \geq Y_{wim} + Y_{wim'} - 1 \quad \forall i \in J; \forall m, m' \in Lm \neq m'; \forall w \in W \quad (10)$$

$$Y_{wim} \leq RE_{ims} \times A_{ws} + (1 - RE_{ims}) \quad \forall i \in J; \forall m \in L; \forall w \in \Gamma; \forall s \in S \quad (11)$$

$$\sum_{i=1}^{N} \sum_{m=1}^{M} Y_{wim} \geq 1 \quad \forall w \in W \quad (12)$$

$$\sum_{w=1}^{W} Y_{wim} = 1 \quad \forall i \in J; \forall m \in L \quad (13)$$