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Investigation of Ant System parameter interactions by using design of experiments for job-shop scheduling problems

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Abstract

In recent years, one of the most important and promising research fields has been metaheuristics to find optimal or near-optimal solutions for NP-hard combinatorial optimization problems. Improving the quality of the solution or the solution time is basic research area on metaheuristics. Modifications of the existing ones or creation of hybrid approaches are the focus of these efforts. Another area of improving the solution quality of metaheuristics is finding the optimal combination of algorithm control parameters. This is usually done by design of experiments or one-at-a-time approach in genetic algorithms, simulated annealing and similar metaheuristics. We observe that, in studies which use Ant Colonies Optimization (ACO) as an optimization technique; the levels of control parameters are determined by some non-systematic initial experiments and the interactions of the parameters are not studied yet.

In this study, the parameters of Ant System have been investigated on different sized and randomly generated job-shop scheduling problems by using design of experiments. The effects and interactions of the parameters have been interpreted with the outputs of the experiments. Referring to the statistical analysis it is observed that none of the interactions between the Ant System parameters has a significant effect on makespan value. A specific fractional experimental design is suggested instead of the full factorial design. Depending on the findings from the benchmark problems it will be a reliable approach to use the suggested design for saving time and effort in experiments without sacrificing the solution quality.

Keywords: Ant Systems; Parameter optimization; Design of experiments; Job-shop scheduling

1. Introduction

It is well known that many combinatorial optimization problems, especially the complex real life problems arising in computer science, engineering mathematics, management and many other fields cannot be solved exactly within reasonable time limits. In recent years, one of the most important and promising research fields has been generic heuristic methods, which is also called general local search methods or metaheuristics. These

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algorithms borrow some metaphors from physics, biology or social sciences to find optimal or near-optimal solutions for NP-hard combinatorial optimization problems. We can reckon genetic algorithms, neural networks and artificial immune systems from biology; particle swarm optimization and simulated annealing from physics; taboo search from social sciences, and ant algorithms from ethology among the most successful techniques. Their self-adaptation capability to use feedback information for modifying the internal models and their parameters, and the ability to operate with multiple agents may help to find high quality solutions for hard problems in reasonable time. Of course the rapid development of computer systems and the simplicity of both design and computational requirements of the metaheuristics comparing with the mathematical optimization techniques have crucial role on the very fast, exploding growth of this research field.

Ant Colonies Optimization is a class of constructive multi-agent metaheuristic algorithms that are analogous with the behavior of real ants that can be used for the solution of combinatorial optimization problems. Ant System (AS) is the original and most simplistic ACO algorithm. As such, it has been extremely influential in the development of more advanced ACO algorithms. AS are inspired by the foraging behavior of ant-colonies. This system tries to capture the basic mechanisms that allow ants to find the shortest path from their colony to a food source. This mechanism works with a substance called pheromone (Colorni, Dorigo, Maniezzo, & Trubian, 1994). AS is a general-purpose heuristic algorithm, which can be used to solve various combinatorial optimization problems including but not limited to the traveling salesman problem, quadratic assignment problem, vehicle routing, data analysis, scheduling, sequencing, frequency assignment, graph partitioning and reliability optimization. Following the AS algorithm, several extensions and improvements of the original AS algorithm were introduced over the years such as Elitist AS (EAS), Rank-Based AS, Max–Min AS, Ant Colony System (ACS) and Hyper-Cube Framework (HCF). The details of the successful ACO variants can be seen in Blum's (2005a) study. A brief survey of the ACO variants used in the literature and the fields in which they are applied is provided in the Appendix A.

In this study job-shop scheduling problems with the objective of minimization of makespan ($C_{\max}$) are selected as the application area. Job-shop scheduling is one of the best known problems in the area of scheduling. A job-shop scheduling problem considers n jobs processed on m machines. Each job consists of a set of operations $O_{ij}\,(i = 1, 2, \ldots, n; j = 1, 2, \ldots, m)$. Various approaches for solving this problem have been proposed in the literature including heuristics and metaheuristics.

2. Ant System and parameters of the algorithm

Inspired by the study of the ant behaviour, ACO (Colorni et al., 1994) was recently developed for solving combinatorial optimization problems. Ants communicate among themselves through pheromone, a substance that they deposit on the ground in variable amounts, as they move. It has been observed that the more ants use a particular path, the more pheromone is deposited on that path and the more it becomes attractive to other ants seeking food. A greater amount of pheromone on the path gives an ant a stronger stimulation and thus a higher probability to follow it. Since ants reaching the food source by a shorter path will return to the nest sooner than ants via a longer path, the shorter path will have a higher traffic. Therefore, the pheromone on the shorter path will be more strongly reinforced and this path will eventually become the preferred route for the stream of ants (autocatalytic process). These properties lead to the natural application of ACO to the Combinatorial Optimization Problems.

AS is the first ACO algorithm which is applied to Travelling salesman problem (TSP). Suppose that a solution of the problem can be represented by a permutation of n entities, which contribute to the definition of the problem. In the TSP, these entities are towns, and in scheduling problems, the operations. At the beginning of the evolution, all ants are randomly positioned at either one or any of the nodes of the network. The transition probability of any ant to an adjacent node from time t to $t + 1$ is found by using following equation (Colorni, Dorigo, & Maniezzo, 1992).

$$P_{ij}^{k}(t) = \frac{[\tau_{ij}(t)]^{\alpha}[\eta_{ij}]^{\beta}}{\sum_{k \in A_k}[\tau_{ik}(t)]^{\alpha}[\eta_{ik}]^{\beta}} \tag{1}$$