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A modified two-part wolf pack search algorithm for the multiple traveling salesmen problem

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ABSTRACT

This paper proposes a modified two-part wolf pack search (MTWPS) algorithm updated by the two-part individual encoding approach as well as the transposition and extension (TE) operation for the multiple travelling salesmen problem (MTSP). Firstly, the two-part individual encoding approach is introduced into the original WPS algorithm for MTSP, which is named the two-part wolf pack search (TWPS) algorithm, to minimize the size of the problem search space. Secondly, the analysis of the convergence rate performance is presented to illustrate the reasonability of the maximum terminal generation of the novel TWPS algorithm deeply. Then, based on the definition of the global reachability, the TWPS algorithm is modified by the TE operation further, which can greatly enhance the search ability of the TWPS algorithm. Finally, focusing on the objective of minimizing the total travel distance and the longest tour, comparisons of the robustness and the optimality between different algorithms are presented, and experimental results show that the MTWPS algorithm can obtain higher solution quality than the other the ones of the other two methods

1. Introduction

The multiple traveling salesmen problem (MTSP), which is the extension of the traveling salesman problem (TSP), is a well-known and important problem in operational research. The characteristic of the MTSP can be summarized as: m ($m \geq 2$) salesmen visit n cities ($n \geq m$) and their paths between the cities and the fixed depots form a group of Hamilton circuits without sub-tours. The purpose of the MTSP is to seek an optimal path in these paths. So the main difference between MTSP and TSP is that the tasks of the MTSP demand more than one salesman, which leads to higher complexity. Similar to the TSP, in essence, the MTSP is a non-deterministic polynomial hard (NP-hard) problem, which means that this problem cannot be solved in polynomial time on a regular computer. So seeking out a high-efficient algorithm to obtain a sub-optimal solution in an acceptable CPU time is the main challenge for the MTSP.

Compared with the TSP, even though the MTSP has a higher difficulty of solution-finding, it has a wider range of applications, especially in various routing and scheduling problems. According to the number of depots, the MTSP can be divided into four forms according to Ref. [1], which can be used in different scenes and different practical applications. For example, when the MTSP has only one depot, it is more suitable for express delivery services [2]. On the other hand, when the MTSP includes multiple depots, which is a more adequate simulation of real life situations, it can be used in many problems, such as hot rolling scheduling [3], vehicle scheduling problem (VSP) [4] and so on. Additionally, if the tasks of MTSP consider the time window constraints, the MTSP can be viewed as a multiple traveling salesmen problem with time windows (MTSPTW) [5,6]. One of the famous applications of the MTSPTW is the mission planning problem. The mission planning problem generally arises in the context of autonomous mobile robots and unmanned aerial vehicles (UAV). The applications of the MTSPTW in mission planning problem are reported by the following references: M. Alighanbari et al. make a research on the task allocation problem for a fleet of UAVs with tightly coupled tasks and rigid relative timing constraints [7]. L. Evers et al. tackle this online stochastic UAV mission planning problem with time windows and time-sensitive targets using a re-planning approach under the frame of the MTSPTW [8]. Besides the mission planning problem, the MTSPTW is also applied in some situations about the transportation of goods. For instance, B. Skinner et al. solve the transportation scheduling problem of the containers in the Patrick AutoStrad container terminal [9]. Moreover, X. B. Wang and A. C. Regan solve the local truckload pickup and delivery problems in

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the view of the MTSPTW [5]. In short, it is extremely significant and valuable to research the MTSP and its variations.

The heuristic optimization methods, which are powerful tools for the NP-hard problems, have captured much attention of the researchers. In order to solve the MTSP, a novel heuristic optimization algorithm called two-part WPS (TWPS), which is inspired by Refs. [10] and [11], is presented in this paper. Then, its weakness is discussed around the global reachability of the initial population updated by the TWPS algorithm. Finally, aimed at overcoming this weakness, a transposition and extension (TE) operation, which dramatically improves the solution quality, is introduced to modify this algorithm. The main contributions of this paper include: the presentations of the TWPS algorithm based on two-part individual representation technique for the MTSP, the discussions of the reachability problem and the convergence generation of the TWPS algorithm, and the modification of the TWPS algorithm (the MTWPS algorithm).

This paper is organized as follows: In Section 2, a literature overview of current works on solving the MTSP and a brief survey of related works on the WPS algorithm are introduced. Section 3 presents the original WPS algorithm and the TWPS algorithm updated by the two-part individual representation technique for the MTSP. Then, the discussion of the convergence generation of the TWPS algorithm and the definition of the gobal reachability of the initial population in the TWPS algorithm are finished in Section 4. Subsequently, the MTWPS algorithm based on the TE operation is presented to overcome the serious weaknesses of the algorithm in Section 5. Section 6 presents the experimental results. At last, the conclusion and summary of this study are presented in Section 7.

2. Literature review

As a widely applicable problem, the MTSP has been solved by many approaches. In the tactical and problem conversion level, these approaches can be divided into two kinds: direct approach and transformation approach. The direct approach means that this approach can solve the MTSP directly, without any transformation to the TSP. And if not, it is a transformation approach. For example, one of the first direct approaches to solve the MTSP is presented by Laporte and Nobert [12]. They propose an algorithm whose main characteristic is the relaxation of most of the constraints of the problem during its solution. Because the classical TSP has received a great deal of attention and it is also a test problem for most optimization methods, a lot of optimization methods can be used to solve a standard TSP. Therefore, the transformation approach, which means to transform the MTSP into the standard TSP, is a common idea to solve the MTSP. In this way, most optimization methods used in the TSP could be applied to the MTSP. For example, one of the pioneers using the transformation approach is Gorenstein S, whose main ideas are to add m-1 additional home cities to a MTSP with m traveling salesmen and to set the home-to-home distances as infinite at the same time [13]. In the recent literature, P. Oberlin1 et al. present a transformation approach to a multiple depots, multiple traveling salesmen problem, and then use the Kernighan-Lin (LKH) heuristic algorithm, which is one of the best heuristics for solving the travelling salesman problem, to obtain the solution [14]. Even though some transformation approaches are simple and feasible, the obtained TSP may be seriously deteriorated, which leads to the solving difficulty of the new problem and is even harder to solve the original MTSP [15].

In the sense of the optimization methods, these approaches can also be classified into two kinds: exact algorithms and heuristic algorithms [15]. The exact algorithms are a kind of early algorithms, which are based on the rigorous mathematical theory. The most famous and commonest exact algorithm is the branch-and-bound method, which is firstly proposed to solve the large-scale symmetric MTSP by Gavish and Srikanth [16]. Then, there are some other kinds of branch-and-bound methods in solving the MTSP. For example, S. Saad et al. combine the branch-and-bound algorithm with the Hungarian method to solve the MTSP [17]. Although the exact algorithms have rigorous mathematical foundations, their problem-solving ability is completely dependent on the size of the problem. When the size of the problem grows, the solving time will become unacceptable. As a result, there are a growing number of scholars turning to the research of the heuristic algorithms, which can easily obtain an optimal, sub-optimal or feasible solution for the large-sized MTSP in an acceptable CPU time.

With the development of computer technology, the heuristic algorithms are developed quickly and applied broadly. There are many heuristic algorithms that are used to solve the MTSP, such as: greedy algorithm [6], evolutionary algorithm [18,19], tabu search [20], simulated annealing (SA) algorithm [21,22], market-based algorithm [23], artificial neural network (NN) approaches [24–26] and so on. In these methods, there is one kind of methods continuously concerned by the researchers: genetic algorithms (GA).

The development process of GA in the MTSP is around the chromosome coding representation. The first reference utilizing the GA for the solution of MTSP seems to be due to C. Malmborg [4]. He develops a GA with two chromosomes representation technique, which means that the first chromosome provides a permutation of the n cities and the second one assigns a salesman to each of the cities in the corresponding position of the first chromosome, for the MTSP. Similarly, based on the same two chromosome representation technique, Park Y.-B. proposes a hybrid genetic algorithm (HGAV) incorporating a greedy interchange local optimization algorithm for the vehicle scheduling problem with service due times and time deadlines [27]. Beyond that, Tang, L. et al. use a different GA with one chromosome representation technique, whose length of chromosome is $n+m$-1, to solve the MTSP model developed for the hot rolling scheduling [28]. In later reference, Arthur E. Carter and Cliff T. Ragsdale put forward a new chromosome encoding scheme with a two-part chromosome representation [4]. Based on these methods, Shuai Yuan et al. point out that two chromosomes encoding schemes based on Refs. [27] and [28] have a larger number of redundant solutions in the search space compared with the latter two-part chromosome representation based on Ref. [4]. Additionally, in the recent literature, the authors of Ref. [28] present a multi-structure GA. Even though this representation doesn't have the redundant problem, it may lead to the overlarge storage space of the chromosome and the overly complex updated process of crossover and mutation operation, when the size of the MTSP is large. In a word, the two-part chromosome representation is the best coding scheme so far, so this representation is used to improve the original WPS algorithm in this paper.

In view of all the above heuristic algorithms, most of them can obtain the optimal/sub-optimal solution of the middle and small-sized problem easily, but for the large-sized problem their solution effects are tremendously different. Therefore, it is imperative to find more efficient heuristic algorithms for the large-sized MTSP. In this paper, the WPS algorithm is introduced and modified to solve the MTSP. The idea of the WPS algorithm is first presented by Chenguang Yang et al., which is used to be the local searching to replace the worker in Marriage in Honey Bees Optimization (MBO) algorithm [29]. Then, it is presented again by Hu-Sheng Wu and Feng-Ming Zhang with a few modifications and renamed as wolf pack algorithm (WPA). At the same time, some test optimization functions are solved by the WPS algorithm compared with the GA, the particle swarm optimization (PSO) algorithm, the artificial fish swarm (ABC) algorithm, the artificial bee colony (ACO) algorithm, and the firefly algorithm (FA) [30]. The results show that