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Discrete honeybee mating optimization algorithm for the routing of battery-operated automated guidance electric vehicles in personal rapid transit systems

Ezzeddine Fatnassi [a,*], Olfa Chebbi [a], Jouhaina Chaouachi [b]

[a] Institut Suprieur de Gestion, Tunis University, 41 Rue de la liberté, Le Bardo 2000, Tunisia
[b] Institut des Hautes Etudes Commerciales,Carthage University, Carthage, Tunisia

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ABSTRACT

Reducing the amount of energy consumed by mass transit systems can be a challenging task. The present study focuses on minimizing the energy consumed by a relatively new transportation system called a personal rapid transit (PRT) system. PRT systems provide automated direct nonstop transit services to their users. This study explores the routing problem associated with PRT where the aim is to minimize the energy consumption while considering the battery capacity of PRT vehicles. The honeybee mating optimization algorithm is adapted to this problem. A specific enhancement procedure is proposed that boosts the performance of algorithm based on a specific initialization of the population. A multiple-descendant honeybee mating optimization algorithm is also proposed. Finally, the algorithms were verified using a set of 1320 randomly generated instances and extensive statistical analyses were performed to validate the results obtained.

1. Introduction

1.1. Personal rapid transit background

Current concerns about climate change have motivated scientists and governments to consider various options that might reduce anthropogenic effects on the climate. These options include the use of electric and intelligent transportation systems. In fact, electric transportation systems can be viewed as a solution to a variety of environmental problems because electricity can be produced from environmentally friendly sources such as wind, water, and sunlight. These new electric transportation systems include personal rapid transit (PRT) system.

The PRT system is a relatively new public transportation system concept. A PRT system mainly comprises PRT guideways, a network of stations, and PRT vehicles. PRT electric vehicles (also called pods) are similar to driverless taxis. An advantage of PRT systems is that they can combine the best features of private cars and trains. Similar to private cars, PRT vehicles can take individuals or small groups of people (up to six passengers), thereby providing users with a high level of privacy and security. Thus, strangers are not mixed together randomly in the same vehicle and people can choose whether they want to share the same vehicle with other individuals. Similar to trains, PRT vehicles run on dedicated guideways. Thus, there is no congestion due to other forms of transport. PRT resembles taxis because they are an on-demand transportation service. Vehicles normally waits at PRT stations for passengers, who select their desired destination and they are assigned a vehicle that takes them directly to their goal. A major advantage of PRT systems is the ability to provide nonstop travel to users. The pods move directly to their destinations without stopping at intermediate unnecessary stops because the stations are located away from the main tracks.

PRT systems have been investigated since the mid-1950s and over 200 studies related to PRTs have been published since 1964 [1–3].

1.2. The proposed studied problem

For a PRT system, the number of trips requested from a specific station is generally not equal instantaneously to the number of trips departed from that station. This latter results on a set of PRT vehicle moving empty to balance the different transportation requests requested from the different stations. These empty movements represent a wasted capacity of the system. Therefore and in order to be efficient, the PRT system must decide which specific empty PRT pods to move and where to move them. This problem is known in the literature as the empty vehicle redistribution problem (EVR) [4]. The main focus of this paper is on the static EVR for the PRT system. More specifically, we focus on the

* Corresponding author.
E-mail address: ezzeddine.fatnassi@gmail.com (E. Fatnassi).

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operational level of static routing of battery-operated electric PRT vehicles. For this purpose, a special focus could be given to the case of MorganTown PRT, which operates according to schedule and demand modes. In the demand mode, the vehicles run in response to passenger demand. In the schedule mode, vehicles are dispatched based on a pre-scheduled set of origin–destination pairs. The Morgan Town PRT system uses the schedule mode when passenger demand is highly predictable, such as during rush hours. The static problem addressed in the present study can be applied to the routing of vehicles in the schedule mode in PRT systems. The static problem is also very useful in dynamic contexts. In fact, none of the strategies used for routing vehicles in a dynamic context can provide better solutions than that based on the static problem [5]. Assuming full knowledge of the coming of passengers put clearly the static solutions in an advantage against dynamic strategies where information of the coming of passenger requests is revealed online as the algorithm executes. Therefore, solving the static problem can help to provide benchmarks in a dynamic context and thus providing valid lower bounding strategies for dynamic PRT management strategies [6]. Many previous studies have compared static and dynamic problems for vehicle routing (see [7,8] for more details).

1.3. Objectives and contributions of this paper

The main focus of this paper is on using bio-inspired algorithms to tackle a related routing problem to the PRT system. More specifically, the present study focuses on the PRT routing problem presented in [9,10]. In [9], the author presented a constraint generation technique to solve the PRT routing problem. However, this exact method consumes a lot of computational time. In [10], the authors present a constructive heuristic for solving the PRT routing problem. However, this method provides low quality solutions for such a problem. Therefore, our objective is to present a bio-inspired algorithm that is capable to find good quality solution in a small computational time.

The contributions of this paper are several. This paper analyzes the behavior of a battery-constrained PRT system. This research also studies an important static EVR problem related to PRT. When solving problems related to a complex system such as PRT, the quality of the obtained results depends on the problem size. This allows us to use either an exact (i.e. Branch And Bound, Branch And Cut and so on) or a meta-heuristic method (i.e. Genetic Algorithm, Tabu Search and so on). This paper tries to combine both linear programming techniques and meta-heuristic methods. More specifically, it specifies and develops an enhanced meta-heuristic approach based on the principle of honey bee mating optimization algorithm (HBMO) in order to manage efficiently the PRT system. Bee meta-heuristics are known to be a very powerful method for generating high quality solutions for transportation problems [11]. In our developed and specific HBMO algorithm, we integrate many new features such as the use of different crossover operators, a specific intensification strategy as a simulation of a foraging behavior of honey bees as well as an enhanced queen generated solution using linear programming techniques.

This paper also studies the impact of using and adapting a different specific PRT feature into our algorithm. Also, using different comparative studies, statistical and sensitivity analysis, we trace the impact of the different components and features on the performance of the algorithm to reduce the level of energy consumption of the PRT system.

1.4. Outline of this paper

The remainder of this paper is organized as follows. Section 2 presents the PRT system and its advantages. Section 3 defines and formulates the PRT problem. Section 4 presents literature review related to this study. Section 5 describes the proposed honeybee mating optimization (HBMO) algorithm for solving the static PRT routing problem. The experimental design used to test the algorithm and an analysis of the results are presented in Section 6. Section 7 presents comparative analysis of our HBMO algorithm. Finally, conclusions and ideas for future PRT research are given in Section 8.

Fig. 1. An example of PRT vehicle.
Source:http://www.vincentabry.com/en/electric-personal-rapid-transit-prt-at-heathrow-951

2. The personal rapid transit (PRT)

The personal rapid transit (PRT) is a concept of personalized mass transit system. PRT is seen as a combination of individual transportation concept (such as private vehicles) and mass transit concept.

PRT is designed to offer to its users relatively new mode of transport. PRT addresses the needs of urban transportation in various ways. In fact, PRT presents an on demand transportation service which is made directly from origin to destination without any unnecessary stops. This is made possible by the use of small driverless electric vehicles (see Fig. 1) and offline stations. Transportation service in PRT is done in a taxi like service. Passengers arrive at station and request a vehicle. The central control system dispatches automatically to them an idle vehicle which takes them directly to their destination without any intermediate stops. As such, PRT systems provide an innovative paradigm for urban transportation. In the next, we present advantages of implementing such a system.

PRT with its unique characteristics offers the best combination of the use of private cars and public transportation tools. PRT advantages could be enumerated as follows:

- *The use of clean energy*: PRT vehicles run on electricity which considered as a clean source of energy since it can be generated from the sun, the wind, etc. Therefore, PRT is considered as a green transportation tools as it ensure to have a sustainable transit for its users.
- *Low energy consumption*: PRT has a low energy consumption profile than any other means of transportation [12]. This is due mainly to the use of small vehicles that run only on demand which contributes on having a high fill rate of PRT vehicles. We should note also that as the PRT ride is done without intermediate stops, there is a small number of accelerations and decelerations needed after an intermediate stop which reduces considerably the energy consumption of the vehicles.
- *Fast speed*: As PRT vehicles are small and run on dedicated guideways with almost no congestion, the PRT system is able to offer a fast ride to its users [13].