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A static free-floating bike repositioning problem with multiple heterogeneous vehicles, multiple depots, and multiple visits

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ABSTRACT

In this paper, a bike repositioning problem with multiple depots, multiple visits, and multiple heterogeneous vehicles for the free-floating bike-sharing system (FFBSS) is studied. Two types of nodes (i.e., easily and hardly access nodes) with different penalties are defined to represent different convenience levels of getting bikes from the FFBSS. The objective of the repositioning is to minimize the weighted sum of the inconvenience level of getting bikes from the system and the total unmet demand and the total operational time. To solve this problem, an enhanced version of chemical reaction optimization (CRO) is developed. A loading and unloading quantity adjustment procedure with the consideration of the node characteristics, including the type of node and its current state (i.e., in a balanced, surplus, or deficit state) is proposed and incorporated into this version to improve its solution quality. A concept of the nearby-node set is also proposed to narrow the search space. Numerical results are presented and indicate that compared to the traditional CRO and CPLEX, the enhanced CRO improves solution quality and has potential to tackle the repositioning problem for larger, longer repositioning duration, and more vehicle instances. The results also demonstrate the effectiveness of the proposed adjustment procedure.

1. Introduction

A bike-sharing system (BSS) is a short rental service to provide customers with bikes for shared use. It has developed rapidly and worldwide. As of 28 November 2017, public bike-sharing systems were available in about 1488 cities and included approximately 18,740,100 bikes around the world (Meddin and DeMaio, 2017).

There are currently two types of BSSs operated worldwide: traditional BSS and free-floating BSS (FFBSS). In a traditional BSS, users have to rent bikes from the designated docking stations and return them to the available lockers in the docking stations after use. In some FFBSSs, bike racks or any solid frame or standalone can be used to lock bikes instead of docking stations, which are also the most costly component in a traditional BSS. The bike rack cost is low and hence the setup cost is lower than that of a traditional BSS and the number of racks in an FFBSS can be very large. Some FFBSSs (e.g., the Mobike system, China) removed the concept of bike racks or related concept. The locks in those systems simply immobilize the rear wheels and a smartphone provides the user interface for locating, checking out, returning, locking, and payment. With the help of global positioning system (GPS), users can reserve or directly rent the nearest available bike and return it almost anywhere in the operating area at the end of the trip. With this feature, users of FFBSS do not need to spend time on searching for an available locker at a docking station to return a bike. This feature makes an FFBSS more flexible and user-friendly,

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compared to a traditional BSS. However, it also results in a more dispersed distribution of the bikes and raises a problem that some bikes are parked at the locations uneasy to observe by the public (Abdullah, 2017). Users find difficulties in searching for an available bike based on its location provided by GPS as the system continues to operate (Abdullah, 2017). Same as a traditional BSS, reallocating the bikes in an FFBSS is a necessity to improve the system performance, such as the convenience of users in getting bikes from the sharing system and the demand dissatisfaction. This relocation problem is called a bike-sharing repositioning problem (BRP).

The BRPs for traditional BSSs have been examined and solved by many existing studies. Among them, very few studies (Caggiani and Ottomanelli, 2012; Contardo et al., 2012; Regue and Recker, 2014; Brinkmann et al., 2015a, 2015b; Labadi et al., 2015; Zhang et al., 2017; Shui and Szeto, 2018) deal with the dynamic bike repositioning problem that captures the demand variation over the repositioning period. Most existing studies (Benchimol et al., 2011; Nair and Miller-Hooks, 2011; Chemla et al., 2013; Di Gaspero et al., 2013a, 2013b, 2016; Nair et al., 2013; Papazek et al., 2013, 2014; Raviv et al., 2013; Rainer-Harbach et al., 2013, 2015; Dell'Amico et al., 2014, 2016; Erdoğan et al., 2014, 2015; Ho and Szeto, 2014, 2017; Brinkmann et al., 2015a, 2015b; Forma et al., 2015; Alvarez-Valdes et al., 2016; Casazza, 2016; Kadri et al., 2016; Li et al., 2016; Szeto et al., 2016; Cruz et al., 2017; Schuijbroek et al., 2017) focus on the static bike repositioning problem in which it is commonly assumed that there is no or negligible demand during the repositioning operation and the objective is to arrange bikes in the system for the next working day. To solve the real-life BRPs, most of these existing studies developed inexact solution methods, including approximation methods, heuristics, metaheuristics, and hybrid heuristic and exact methods.

To have a good relocation strategy, accurate estimation of bike demand is necessary. Some effort focused on bike demand forecasting. For example, Rudloff and Lackner (2014) developed demand models for bikes and available lockers, which can predict the times when stations tend to full or empty over the course of the coming week. Singhvi et al. (2015) predicted the bike usage pattern of Citi Bike in New York during morning peak hours and bike demand by considering taxi usage, weather, and spatial variables. However, these studies focus on traditional BSSs.

Compared to the studies for traditional BSSs, very few papers focused FFBSSs, including forecasting demand for FFBSSs and free-floating BRPs (FFBRPs). For example, to enhance the bike reallocation, Reiss and Bogenberger (2016) identified the mobility patterns of the bike usage and forecasted the upcoming demand, while Caggiani et al. (2016) proposed a method to generate spatiotemporal clusters and forecasted the bike use trend.

As the time of this writing, only one study deals with an FFBRP. Pal and Zhang (2017) considered a multiple-vehicle static repositioning for the FFBSS. The objectives are to make the FFBSS at its optimal state (i.e., no stations are in a deficit state) and minimize the makespan of the vehicles. Multiple-visits to a station with monotone loading or unloading operation are allowed. Their formulation is only modified from the formulation proposed by Erdoğan et al. (2015) for handling the multiple-vehicle repositioning as if a traditional BRP. To solve this problem, a hybrid nested large neighborhood search with variable neighborhood descent algorithm is proposed. However, they do not consider any unique feature of an FFBSS such as the inconvenience level of getting bikes when formulating and solving the problem. According to Abdullah (2017), it is sometimes difficult for bike users to find unused bikes in an FFBSS as they are put in inconvenience, difficult to see, or uncommon locations. The utilization rates of those bikes are relatively low, which does not allow the demand dissatisfaction in the system to be fully minimized. To improve the utilization rate and demand dissatisfaction, a new methodology is needed to model this unique feature and determine a repositioning strategy.

In this study, we consider the convenience level of getting bikes from the FFBSS. Two types of nodes are defined based on the convenience level: Easily accessed nodes represent the locations well-known to the public (e.g., the designated locations of bike racks or popular locations), whereas hardly accessed nodes are defined as the locations not popular to the public, not easy to be found, or introducing long search time to the public (e.g., the locations of dispersed bikes). In this FFBRP, bikes at hardly accessed nodes are transported to easily accessed nodes, especially to those in deficit. Thus, reallocating bikes for this FFBSS is not only to reduce the total unmet demand, but also to increase the convenience level of getting bikes from the system. This relocation is assumed to be performed in the night time by multiple vehicles and hence the problem is formulated as a multiple-vehicle static FFBRP. To solve this BRP, an enhanced version of chemical reaction optimization (CRO) is proposed. Compared with the traditional version, the enhanced version has four major differences: First, the enhanced CRO considers the characteristics of the FFBRP, i.e., two types of nodes. Second, the enhanced CRO applies a newly proposed operator to adjust loading/unloading quantities, especially at hardly accessed nodes, to improve its solution quality. Third, a solution adjustment strategy is adopted in the enhanced version to ensure the feasibility and good quality of the solutions. Fourth, the enhanced version uses different neighborhood operators and criteria to obtain new routes. To demonstrate the effectiveness of the enhanced CRO, different test scenarios were used and the results obtained from IBM ILOG CPLEX, the original CRO, and the enhanced CRO were compared. In addition, the performance of the proposed subroutine is discussed.

The contributions of this paper are as follows:

- This paper formulates an FFBRP with the consideration of the convenience level, in which this special feature associated with an FFBSS has not been modeled before.
- This problem considers (1) multiple depots; (2) multiple heterogeneous vehicles; (3) fixed starting depot and flexible ending depot for each vehicle; (4) multiple-visits of nodes by the same vehicle, and (5) non-monotone loading and unloading operations at nodes, which is more complicated than existing traditional BRPs.
- An enhanced version of CRO is proposed. It considers the node characteristics in developing a subroutine to adjust the loading or unloading quantities at nodes, especially for hardly accessed nodes. These quantities are adjusted based on the type of node and its current state (i.e., in a balanced, surplus, or deficit state). The results from our experiments show that this subroutine contributes to better solutions.
- This study improves the traditional CRO to solve the FFBRP. A concept of the nearby-node set is proposed to narrow the search space. The results indicate that the enhanced CRO obtains better solutions than the traditional CRO.