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Dynamic green bike repositioning problem – A hybrid rolling horizon artificial bee colony algorithm approach

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ABSTRACT

This paper introduces a new dynamic green bike repositioning problem (DGBRP) that simultaneously minimizes the total unmet demand of the bike-sharing system and the fuel and CO_2 emission cost of the repositioning vehicle over an operational period. The problem determines the route and the number of bikes loaded and unloaded at each visited node over a multi-period operational horizon during which the cycling demand at each node varies from time to time. To handle the dynamic nature of the problem, this study adopts a rolling horizon approach to break down the proposed problem into a set of stages, in which a static bike repositioning sub-problem is solved in each stage. An enhanced artificial bee colony (EABC) algorithm and a route truncation heuristic are jointly used to optimize the route design in each stage, and the loading and unloading heuristic is used to tackle the loading and unloading sub-problem along the route in a given stage. Numerical results show that the EABC algorithm outperforms Genetic Algorithm in solving the routing sub-problem. Computation experiments are performed to illustrate the effect of the stage duration on the two objective values, and the results show that longer stage duration leads to higher total unmet demand and total fuel and CO_2 emission cost. Numerical studies are also performed to illustrate the effects of the weight and the loading and unloading times on the two objective values and the tradeoff between the two objectives.

1. Introduction

Bike-sharing systems (BSSs) are evolving worldwide. They provide numerous advantages such as reducing the short-distance motorized trips, complementing public transport, and reducing the greenhouse gas emissions. These systems escalate bikes to become a convenient and efficient transport mode by offering an automatic rental use of bikes in all bike-sharing stations within a city and allowing the users to return the bikes in any stations. Due to the characteristics of the stations, such as altitude, proximity to the public transport stations, time of day, or the regions they sited, some stations have bike surpluses while some stations have bike deficits. With bike deficiency, some cyclists cannot rent bikes at those deficit stations, leading to unmet demand. Therefore, the BSS operators need to redistribute their bikes among stations regularly to minimize the demand dissatisfaction. This redistribution can be done by employing vehicles to pick up their bikes from bike

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surplus stations to bike deficient stations. The redistribution problem is currently known as a bike repositioning problem (BRP).

The aim of a BRP is to determine optimal truck routes and the loading/unloading activities of each truck at stations based on the design objective, subject to various constraints related to the repositioning vehicles, stations, and operational constraints. This problem is more complicated than the classical vehicle routing problem (VRP) and the classical traveling salesman problem (TSP) because the repositioning problem further requires determining the pick-up and drop-off quantities at each station (Ho and Szeto, 2014).

The unique problem setting of a BRP has attracted the interest of many researchers in recent years. Table 1 has summarized the BRP publications according to their operation types and design objectives. In terms of operation type, the problems can broadly be classified into two classes: static and dynamic. The static problem considers nighttime operations in which station demand variations are negligible, while the dynamic problem considers daytime operations and real-time station demand variations. As seen in Table 1, a large portion of studies focuses on static BRPs while very few studies have addressed on dynamic BRPs. The contrast in the number of publications is mainly due to the difficulty in handling the varying demand during the operational period. In dynamic BRPs, the routes need to be updated regularly to resolve the demand variations arisen from time to time. Table 1 also illustrates that the existing studies adopt various objectives, such as minimizing vehicle travel time or cost (e.g., Benchimol et al., 2011; Lin and Chou, 2012; Chemla et al., 2013), minimizing total unmet demand (e.g., Contardo et al., 2012; Szeto et al., 2016), minimizing maximum tour length (Schuijbroek et al., 2017), minimizing the sum of travel and handling costs (Erdoğan et al., 2014), minimizing total relocation and lost user cost (e.g., Caggiani and Ottomanelli, 2012), and minimizing a weighted sum of total travel time, the total absolute deviation from perfect balance at each station, and the total number of loading and unloading quantities (e.g., Raidl et al., 2013; Rainer-Harbach et al., 2013, 2015). From these reviewed papers, the objective highlighted most is to minimize the total absolute deviation from perfect balance in public bike sharing systems, either by directly determining the number of bikes or indirectly in the form of penalty functions. Minimizing total unmet demand is a similar objective while it only focuses on bike deficits and neglects bike surpluses. These studies show that total unmet demand is a crucial indicator for the repositioning activity, but there are other important considerations for an optimal repositioning strategy. Specifically, Wiersma (2010) highlighted the threat of bike repositioning activities by vehicles to the environmental creditability of bike sharing systems, given that the bikes are generally relocated by fossil-fueled vehicles. Therefore, a repositioning plan that solely focuses on minimizing total unmet demand may result in long repositioning routes or heavy vehicle loads, which may adversely affect the environment by producing more air pollutants. However, to the best of our knowledge, no existing BRP studies have considered environmental needs (or green elements) in their design objectives.

As a first step to consider environmental objectives, this study proposes a new problem, referred to as a dynamic green bike repositioning problem (DGBRP). This problem considers total carbon dioxide (CO_2) emission related cost as the environmental objective, which has been widely adopted in other types of green logistic problems (e.g., Demir et al., 2012; Koç et al., 2014), as CO_2 is regarded as one of the most serious threats to the environment through the greenhouse effect (Ericsson et al., 2006) and road transport, especially road freight transport, constitutes a large portion of CO_2 emissions (Jabali et al., 2012). As bike repositioning is also a logistical activity that heavily relies on fossil-fueled vehicles (Wiersma, 2010), minimizing total CO_2 emission related cost is a representative and significant environmental objective for the DGBRP.

With respect to the emission minimization objective, the DGBRP is similar to a pollution routing problem (PRP), in which the designated route should minimize the pollutant emissions. For a PRP, its design objective is to minimize emission cost, plus other costs if any; and the quantities of commodities delivered to each customer (or node) are known at the beginning of the operation. In other words, some routing problems that are not named as PRPs should be considered to be PRPs or their variants, given that they consider emission minimization (or fuel consumption minimization or the corresponding cost minimization) to be the sole objective or one of the objectives in their design problems, and the quantities delivered to each node are known at the beginning of the operation. Examples include eco-routing problems (e.g., Ericsson et al., 2006) and emission vehicle routing problems (e.g., Figliozzi, 2010; Kopfer et al., 2014). The proposed DGBRP, however, differs from the above-mentioned problems in several ways. First, the pickup or drop-off locations are not given, and therefore any node (i.e., any station and the depot) can be a source or destination of bikes. Second, the pickup or drop-off quantity at each node is a decision variable and has an effect on the objective function value (i.e., total unmet demand and the total fuel and CO_2 emission cost). Third, the pickup or drop-off quantity at each node varies with respect to time. These three points distinguish the DGBRP from existing PRPs.

To measure the CO_2 emissions or their cost, the conventional approach is to determine the vehicle emissions based on existing fuel consumption models as the emissions are directly proportional to the fuel consumption (Demir et al., 2012). As greenhouse gas emissions from transportation have received attention for a long while, there has been a wide range of fuel consumption and vehicle emission models in the literature. Demir et al. (2014) categorized fuel consumption (vehicle emission) models into three main groups with respect to data complexity: factor models, macroscopic models, and microscopic models. Factor models adopt simple fuel consumption methods, e.g., the distance-based method introduced in GHG Protocol (2013) and the emission factor calculation by DEFRA (2012), to convert fuel consumption to vehicle emissions, and are particularly useful when the information of traffic flow and operation is insufficient. Due to the lower level of data complexity, factor models are adopted in some green logistic problems (e.g., Kopfer et al., 2014; Zhang et al., 2014). In macroscopic models, the fuel consumption is generally formulated as a function of average speed, which reflects the empirical findings that the fuel consumption rate varies with respect to speed (e.g., Demir et al., 2011) and is consistent with the vehi-

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