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An effective greedy method for the Meals-On-Wheels service districting problem

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ABSTRACT

This paper focuses on a specific districting problem related to home health care (HHC) services, that is, the Meals-On-Wheels service districting (MOWSD) problem which is formulated as an integrated mixed-integer programming (MIP) model. The MOWSD problem aims at finding the minimum number of districts to cover all basic units while satisfying the constraints, including capacity and time window limitation, accessibility, compactness, and the indivisibility of locations. Inspired from the thought of the planner who has to solve the MOWSD problem in practice, an effective greedy heuristic method is proposed to quickly construct good districts. The results indicate that the greedy heuristic method can achieve as many good solutions as the Gurobi Optimizer, which is applied to solve the MIP, but with an extremely shorter computation time. We firstly conduct the sensitivity analysis on the key parameters of the MOWSD problem, which reveals that the performance is significantly affected by the available time period for the service delivery, the capacity of a meal cart, and the maximum travel duration between any two basic units in a district. We further compare the resulting districts determined using these two methods with the existing districts identified using manual planning. This comparison claims that the proposed greedy heuristic method is capable of not only improving the design of districts but also achieving better compactness than Gurobi Optimizer.

1. Introduction

The number of elderly citizens in Hong Kong has grown at an average rate of 4.8% over the past 50 years (i.e., from 1961 to 2011). Specifically, the proportion of the elderly in the total population rose from 2.8% in 1961 to 13.3% in 2011, and the elderly dependency ratio increased from 50 in 1961 to 177 in 2011 (CENSUS2011.GovHK., 2013). The life expectancy of the elderly also changed from 67.8 years for males and 75.3 years for females in 1971 to 81.2 years for males and 86.9 years for females in 2014 (CHP.GovHK., 2016). The increasing life expectancy corresponds to an increase in the demand for elderly care. Furthermore, the elderly prefer to grow old in the privacy of their homes rather than in a nursing home, whereas their relatives show a decreasing willingness to perform informal care because of work commitments. Accordingly, organizations providing home health care (HHC) are inclined to optimize their activities to meet the constantly increasing demand for HHC. The Hong Kong Government, in particular, has increased the amount of the annual Elderly Health Care Voucher to HK$2000 per elderly (aged 70 years or above); such increase is aimed at encouraging the elderly to choose a private health care service that suits their needs, seek consultation, and establish a close relationship with private care providers who are familiar with their health conditions (GovHK., 2015). Thus, exploring ways to enhance productivity by reducing cost and improving service quality has become necessary for HHC structures. The Salvation Army-Tai Po Integrated Home Care Service Center (SA-TPIHCS) in Hong Kong is a "social profit" organization providing HHC services, such as personal care, household care, nursing care, and Meals-On-Wheels (MOW) service. In this paper, we focus on the MOW service districting (MOWSD) problem faced by the SA-TPIHCS.

MOW service providers deliver meals to individuals who are at home and unable to purchase or prepare their own meals (Wikipedia., 2016). In the MOW service delivery procedure, vehicles typically start from the same central kitchen to deliver meals to customers; they then pick up the packing and return it to the kitchen. The procedure consists of two steps: first, the vehicles

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Nomenclature

Abbreviations

ANOVA	Analysis of Variance
CCP	Capacitated Clustering Problem
GA	Genetic Algorithm
g-CCCP	Generic Capacitated Centered Clustering Problem
GRASP	Greedy Randomized Adaptive Search Procedure
HHC	Home Health Care
HHCD	Home Health Care Districting
MIP	Mixed-Integer Programming
MOW	Meals-On-Wheels
MOWSD	MOW Service Districting
P&D	Pickup and Delivery
SA	Simulated Annealing
SA-TPIHCS	Salvation Army-Tai Po Integrated Home Care Service center
VNS	Variable Neighborhood Search
VRPTWMD	Vehicle Routing Problem with Time Window and Multiple Deliverymen
TS	Tabu Search

Notations

OBJVAL	the value of the objective function of the proposed MIP model
GAP	the gap between the current optimal objective value and the best lower bound
RUNTIME	the computation time of the proposed MIP model
WM	the maximum walking duration among basic units in the same district
Q	the capacity of a meal cart
T	the total available duration of MOW service

travel from the kitchen to the parking sites of districts; second, the deliverymen (care workers) deliver the meals to the customers' locations on foot. From the daily operational perspective, the process can be modeled as a vehicle routing problem with time window and multiple deliverymen (VRPTWMD) (Pureza, Morabito, & Reimann, 2012), the inputs of which consist of the known parking sites of customer districts and the known service times of each district. The former depends on customer locations, and the latter depends on crew size, deliveryman service strategy, and the demand and geographical dispersion of customers in districts. As a long-term planning strategy, the districting decision of customers can be the base of the VRPTWMD problem, the clustered capacitated vehicle routing problem (Expósito-Izquierdo, Rossi, & Sevaux, 2016), and the capacitated location routing problem (Yu, Lin, Lee, & Ting, 2010). Generally, the districting problem in the service context is to partition the customers in the service region into a number of districts such that each district satisfies a collection of capacity, temporal, and geometric constraints (Jarrah & Bard, 2012). Once the districts are determined, each of them is assigned with one care worker. Planners generally employ the average monthly data of customer demands to design the work areas without considering the dynamic and uncertain nature of customer demands (Jarrah & Bard, 2011).

In this paper, we focus our attention on MOWSD problem because of their critical role as the base of daily operations and their importance in improving the MOW delivery efficiency. As a result of the sustainability of using care workers, the capacity of a meal cart is the primary determinant of district size. Furthermore, the expected time duration of serving all customers in a district and the desire to achieve higher workload utilization must be considered. The challenge faced by the SA-TPIHCS lies in determining a feasible partition of the service region resulting in the minimum number of districts, which leads to the minimum number of care workers, each of whom is responsible for one district, to satisfy all customer demands. The objective of the MOWSD problem is therefore achieve the minimum number of districts to cover all basic units while considering different constraints, such as accessibility, compactness, indivisibility of locations, capacity of districts, and time limitation of service delivery. As a minimum capacitated districting problem, it mainly focuses on district design without regard to tour construction, while VRPTWMD considered by Pureza et al. (2012) focused on tour construction without considering district design. The difference of the MOWSD problem from related districting problems in literature lies in its exclusive focus on the minimum number of districts, whereas minimizing either the workload imbalance or total travel distances was considered by Benzarti, Sahin, and Dallery (2013), or minimizing the dissimilarity and the minimum number of districts simultaneously was studied by Bard and Jarrah (2009). The main contributions of this study are presented as follows:

(1) An integrated mixed-integer programming (MIP) model is proposed and solved by the Gurobi Optimizer for the MOWSD problem. To the best of our knowledge, it is the first study that the operational aspects, such as compactness, the selection of the parking site of each district, and packages and delivery duration limitation, are integrated into an MIP model in the literature of the districting problems in HHC context.
(2) An effective greedy heuristic method, inspired from the thought of the planner of SA-TPIHCS, is proposed for the MOWSD problem. Given that the Gurobi Optimizer requires a long computation time to generate good feasible solutions, the greedy heuristic method is applied to find a good feasible solution with fewer districts in a shorter computation time.
(3) A case study based on a real instance from the SA-TPIHCS is investigated. In the case study, we conduct a sensitivity analysis on some key parameters of the MOWSD problem related to the minimum number of districts and computation time. Furthermore, the existing districts obtained with manual planning are compared with the resulting districts to illustrate the improvement of the district design, which was achieved with the application of the proposed MIP model and greedy heuristic method.

This paper is organized as follows. In Section 2, we present a survey of the literature related to our work, which seeks to explore the districting problems from different aspects. In Section 3, we describe a formal problem statement and formulate the MOWSD problem as an MIP model with objective functions and constraints, followed by the model data preparation and model analysis. In Section 4, we explain the design and analysis of the proposed greedy heuristic method. In Section 5, we detail the results of computational experiments conducted on real data provided by the SA-TPIHCS in Hong Kong. We also verify the proposed model and greedy heuristic method by comparing the resulting and existing districts. Finally, in Section 6, we discuss our conclusions and perspectives for future research.