Advanced Engineering Informatics 32 (2017) 176–187

Contents lists available at ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

Full length article

Heuristic approach for solving employee bus routes in a large-scale industrial factory ☆

Komgrit Leksakul [a,b,*], Uttapol Smutkupt [b], Raweeroj Jintawiwat [b], Suriya Phongmoo [b]

[a] Excellence Center in Logistics and Supply Chain Management, Chiang Mai University, Chiang Mai, Thailand
[b] Department of Industrial Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, Thailand

ARTICLE INFO

Article history:
Received 19 May 2016
Received in revised form 26 January 2017
Accepted 19 February 2017

Keywords:
Clustering
Routing
Ant colony optimization
Bus stop allocation
SBRP

ABSTRACT

This paper compares different methods for solving a location-routing problem (LRP), using real-world data from the bus transport service for employees of a large-scale industrial factory in Thailand. We tested four AI (artificial intelligence) techniques Maximin, K-means, Fuzzy C-means, and Competitive Learning and two hybrids of these four K-means with Competitive Learning and K-means with Maximin to allocate the bus stops. The efficiency of the algorithms was compared, in terms of the quality of the solutions. The K-means with Maximin provided the best solution, as it minimized number of bus stop locations and employees' total traveling distance while satisfied employee at maximum radius 1.73 km, compared to K-means with Competitive Learning, as the same number of bus stop it provided higher total traveling distance and maximum radius. The other non-hybrid techniques provided higher number of bus stop locations.

We then used ant colony optimization (ACO) to determine the optimal routing between the 300–700 bus stops as allocated by K-means with Maximin. The optimal bus routing to transport the factory's 5000 plus employees required 134 buses (134 independent routes) covering 500 bus stops and traveling nearly 5000 km. While optimal, this routing was costly and created monitoring difficulties. To address these concerns, we constrained the number of bus routes; while this dramatically increased the total distance, it provided a more practical solution for the factory.

1. Introduction

Many large-scale industrial factories in Thailand are facing the problem of employee shortages. It has become necessary to consider hiring people who live far distances from the factories. Consequently, the factory administrative team has to organize transportation service systems to facilitate the commute of remote employees. Designing an effective employee transportation service system entails selecting appropriate bus stops within the employees' acceptable distance and determining the optimal bus routes. Determining the optimal bus route for transporting employees to work is classified as a vehicle routing problem (VRP) in the field of logistics optimization. As the number of employee residences increases, the problem becomes more complex. Our employee transportation service system can be modeled as a school bus routing problem (SBRP). The SBRP has been constantly studied since the first publication on it by Newton and Thomas [21]. Li and Fu [18] note that there is no single dominant approach for the study of SBRP. SBRP consists of two main sub-problems: bus stop selection and optimal bus route generation. The combined problem of bus stop selection and optimal bus route generation is classified as location-routing problems (LRPs). Park and Kim [22] provided a comprehensive review of SBRP and presented five sub-problems of SBRP: data preparation, bus stop selection, bus route generation, school bell time adjustment, and route scheduling. They also introduced the studies that addressed these sub-problems.

In our work, we attempted to find the optimal bus route for a large-scale industrial factory, which means accommodating a large number of employees. To solve for the optimal bus route effectively, we divided the problem into two parts: bus stop selection and bus route search. Selecting bus stop locations is an important, but often neglected, part of the bus routing problem [16]. Generally, two methods are used for solving bus stop location problems: the location allocation routing (LAR) strategy and the allocation routing location (ARL) strategy [4]. LAR determines a set of bus

☆ This paper should not be disseminated without written permission of the authors.

* Corresponding author at: Excellence Center in Logistics and Supply Chain Management, Chiang Mai University, Chiang Mai, Thailand.

E-mail address: komgrit@eng.cmu.ac.th (K. Leksakul).

http://dx.doi.org/10.1016/j.aei.2017.02.006
1474-0346/

stops without concern for their effect on generating routes; infeasible solutions may be generated by this strategy. ARL groups residents into clusters based on bus capacity. Then, for each cluster, the bus stop locations are selected and the route is generated. In our case, the ARL strategy is applied. Employees are grouped into clusters by artificial intelligence (AI) techniques, such as Maximin, K-means, Fuzzy C-means, and Competitive Learning, based on satisfying constraints (e.g., the maximum traveling distance from their addresses). The centroid of each cluster is calculated and assigned to the nearest bus stop. After the bus stop locations are determined, ant colony optimization (ACO) is performed to determine the optimal route among all proposed bus stop locations. Vehicle route searching allows for any combination of bus stop locations when determining the collecting route for each vehicle. The vehicle routing problem is a combinatorial optimization problem, where the number of feasible solutions increases exponentially with the number of employees to be collected. The vehicle routing problem is closely related to the traveling salesman problem, where an out and back tour from a central location is determined for each vehicle. Because there is no known polynomial algorithm that will find the optimal solution in every instance, the vehicle routing problem is considered NP-hard. For NP-hard problems, heuristics is a reasonable approach to find solutions.

The structure of employee bus routing problem is similar to school bus routing, all of bus stop locations are known and routes need to be determined that visit each selected stops. Two steps have to consider, employee home locations clustering simultaneously with bus stops selection and determining routes that visit all selected stops, such that the total distance travelled by the bused routing problem. For SBRP which studied by Schittekat et al. [24] and Kinable et al. [17], they tried to optimize SBRP by combining all considering steps simultaneously. Consequently, the formulation of SBRP mathematical leads to the complexity model. Of cause, conventional approach like exact solution couldn't obtain the solution in the limit of time either the near optimal solution. Schittekat et al. [24] and Kinable et al. [17] proposed heuristic approaches; neighborhood descent (VND) and column generation with heuristic pricing algorithms, respectively. Their experiments showed that the heuristic exhibits excellent performance and finds optimal or close-to optimal solutions of large instances of the SBRP in very limited computing times. However, we proposed separating two computational steps, as decomposition may simplify the computational process, offering a faster and/or better solution. Four AI (artificial intelligence) techniques Maximin, K-means, Fuzzy C-means, and Competitive Learning and two hybrids of these four K-means with Competitive Learning and K-means with Maximin to allocate the bus stops are originally proposed for employee home locations clustering step. For second step, we originally proposed inbound and outbound ACO approached to find the optimal bus routed. We tested these proposed methods against Schittekat et al. [24] and Kinable et al. [17] for computational effectiveness and efficiency. Finally, we are the pioneer for introducing the combined clustering with ACO to solve large-scale problem like the industrial factory (5000 plus employees' home locations and more than 300 bus stop locations) in our case study.

This research paper presents a comparison of different methods to find a bus stop allocation and routing solution for the bus stops found in the process. The AI approach was used to cluster employees, and centroids of employee clusters were assigned to the nearest bus stop. The ACO approach was applied to find solutions to the vehicle routing problem with regard to assigned bus stops. ACO simulates the behavior of ant colonies in nature as they forage for food and find the most efficient routes from their nests to food sources. The decision-making processes of ants are embedded in the artificial intelligence algorithm of a group of virtual ants, which is used to provide solutions for vehicle routing problems.

2. Literature review

Park and Kim [22] suggested dividing SBRP into five sub-problems: data preparation, bus stop selection, bus route generation, school bell time adjustment, and route scheduling. In the data preparation sub-problem, the road network is specified. Students' addresses are collected and transformed to coordinates (latitude and longitude) for use in the geographic information system (GIS). A distance matrix can be calculated based on various shortest path algorithms. The bus stop selection sub-problem is classified into the location allocation routing (LAR) and allocation routing location (ARL) strategies [4]. The LAR strategy first determines a set of bus stops for a school and assigns students to these stops. A heuristic approach based on the LAR strategy was presented by Bodin and Berman [3], Dulac et al. [11], and Desrosiers et al. [5]. In the ARL strategy, the students are classified into clusters while satisfying the vehicle capacity constraints. To solve the bus stop selection problem, many techniques in the computational intelligence system are introduced. Clustering is a powerful computational intelligence system technique and is known as the unsupervised learning process. Clustering, unlike supervised learning, does not use a classification function and the class type of each data object is unknown. Clustering matches a data item with one of the several clusters, where clusters are common groupings of data items based on similarity measures [28]. Bus routes can be generated by two main approaches: exact and heuristic. We can accept that the exact method can generate the optimal bus route for a fewer number of school bus stops, while the heuristic method can generate appropriate routes for large-scale problems with acceptable computational runtimes. Schittekat et al. [24] introduced a metaheuristic for SBRP. The experiments showed that the metaheuristic exhibits excellent performance and finds optimal or close-to-optimal solutions for large instances of SBRP in very limited computing times. Kinable et al. [17] introduced a column generation approach for school bus routing. To increase the performance of column generation, exact and heuristic pricing algorithms, bounding procedures, a column pool manager, stabilization techniques, and a more rigid branching approach were introduced. Kinable et al. [17] performed a number of experiments in which the number of bus stops and the number of students were limited to 40 and 800, respectively. The results were compared with the results published in Schittekat et al. [24]. Riera-Ledesma and Salazar-González [23] proposed a branch-and-cut-and-price (BCP) algorithm to solve SBRP. They reported that their proposed algorithm can obtain the solution corresponding to 100 potential bus stops and 100 students using vehicles with capacity for 38 users within a 1-h time limit.

3. Selection of bus stop locations

In our study, we determined bus stop locations first. To find the optimal bus stop, we attempted to cluster the students/employees by their addresses and assign the students/employees to a single bus stop (centroids of each cluster) while minimizing the sum of the distances between the bus stop and the student/employee addresses. Students/employees living near the factory were assumed to walk to the bus stop rather than to the factory. To find the optimal bus stop locations, we proposed a clustering algorithm for grouping student/employee addresses together. The centroids of the proposed clustering results were to be used as the bus stop locations. In data mining, clustering is a useful technique to discover groups and identify interesting distributions in the underly-