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Fuzzy multi-objective programming algorithm for vehicle routing problems with backhauls

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ABSTRACT

The vehicle routing problem with backhauls (VRPB) is an extension of the standard vehicle routing problem. VRPB has two sets of customers: linehaul customers and backhaul customers. The aim of this study is to propose a new algorithm based on fuzzy multi-objective programming (FMOP-VRPB algorithm) to solve the VRPB. The FMOP-VRPB algorithm has three phases; clustering, routing and local search. In the clustering phase, customers are assigned to vehicles by the proposed multi-objective programming (MOP) model with two objective functions: minimizing the total distance and maximizing the total savings value. The proposed MOP model is solved by fuzzy operators. The weights of the objectives are also calculated by a fuzzy two-person zero-sum game with mixed strategies using membership functions in a fuzzy pay-off matrix. In the routing phase, each vehicle is routed as a traveling salesman problem with backhauls. The local search phase is used to improve the routes.

The primary contributions of the FMOP-VRPB algorithm are to consider the two objectives, to determine the weights of objectives using the proposed fuzzy pay-off matrix in the clustering phase and to use only mathematical programming in both the clustering and routing phases through many customers in an acceptable CPU time. The algorithm will also show that the proposed MOP model defines the seed customers itself in the clustering phase and will always generates feasible clusters, contrary to the reports in the literature.

Benchmark problems from the literature are solved to test the performance of the FMOP-VRPB algorithm. The results indicate that the FMOP-VRPB algorithm generates sufficient solutions, and CPU times are within acceptable limits. In addition, a weekly routing problem for a logistics department of a ceramics firm in Turkey is solved by the FMOP-VRPB algorithm. Additionally, this study is the first to solve a real world VRPB; the solution shows that the FMOP-VRPB algorithm is suitable and effective for real world problems.

1. Introduction

The transportation process involves all stages of the production and distribution systems and represents a relevant component (generally from 10% to 20%) of the final cost of the goods (Toth & ve Vigo, 2002). Thus any improvement in transportation process provides reducing the cost of the goods. The vehicle routing problem (VRP) (Dantzig & Ramser, 1959) located in the distribution system, involves the distribution of goods between depots and a set of customers and the purpose is to generate routes to minimize the total delivery distance or to minimize the total delivery time under the constraints of vehicle capacity and customer demand. In this problem, each customer is served by one vehicle that starts loaded from a depot and returns to the depot after delivering goods to its customers.

In this study, the vehicle routing problem with backhauls (VRPB) that is one of the main variants of VRP is concerned. In VRPB, customers are divided into two groups as linehaul customers (LHs) and backhaul customers (BHs) with the difference of the VRP that has one type of customers. All deliveries are made to LHs before goods are started to pick up from BHs by each vehicle in contradistinction to the Vehicle Routing Problem with Pickup and Delivery (VRPPD) in which each customer is correlated with delivering and picking up. Therefore, BHs can be visited by a vehicle after the vehicle finishes delivering to LHs due to the difficulty of rearranging goods in the vehicles in VRPB while deliveries and pickups are made simultaneously in the VRPPD. Each customer is served by only one vehicle that starts from and finishes at the depot. The total demand of LHs for a vehicle cannot exceed vehicle capacity; this is the same for BHs. Minimizing the total travel

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distance is an aim under the problem constraints (Toth et al., 2002). Fig. 1 presents an example of VRPB.

$165 million saving was estimated by Interstate Commerce Commission for the grocery stores that used backhauling in 1982 (Golden, Baker, Alfaro, & Schaffer, 1985). In that by using the unused capacity of an empty vehicle traveling back to depot, the VRPB reduces the distribution costs. In distribution system of a large company, retail outlets are linehaul customers to be supplied from the depot. At the same time, various vendor are backhaul customers to resupply the depot and are located in the same religion as the linehaul customers. (Goetschalckx & Jacobs-Blecha, 1989) Thus in this study, authors concern with the VRPB that can provide an important improvement to cost of the goods in industry.

Two exact algorithms have been developed to solve VRPB in the literature. Toth and Vigo (1997) describe the first exact algorithm, which uses the Lagrangian lower bound strengthened by adding valid inequalities in a cutting plane fashion; a new mathematical model is proposed. Mingozzi and Giorgi (1999) proposes an exact algorithm based on a new integer programming formulation; this procedure combines different heuristic methods to compute a lower bound and define a new integer formulation. These exact methods enables to optimally solve problems up to 100 customers. For this limitation of the exact methods, heuristics and metaheuristics have developed to deal with the medium- and large-scale problems in the literature.

In the sense of heuristic approaches for the solution of VRPB, Deif and Bodin (1984) propose an extension of the savings algorithm. Goetschalckx and Jacobs-Blecha (1989) propose a two-phase solution methodology in which the first phase is based on space filling curves to generate a high quality initial feasible solution and a second phase to improve the solution by optimization of the subproblems in the mathematical model. In addition, the mathematical model is defined. Salhi and Nagy (1999) investigated an extension to the classical insertion-based heuristic. Ropke and Pisinger (2006) are the first to propose a unified heuristic. Tütüncü, Carreto, and Baker (2009) developed a visual interactive approach based on the Greedy Randomized Adaptive Memory Programing. Wang and Wang (2009) propose a novel two-phase heuristic. The modified parallel C-W savings heuristic generates the initial routes in the first phase, and a reactive tabu search is used to improve the initial solution in the second phase.

Besides the heuristics summarized as above, cluster-first, route-second type of heuristics for the VRPB are presented by Goetschalckx and Jacobs-Blecha (1993) and Toth and Vigo (1999). Goetschalckx and Jacobs-Blecha (1993)'s heuristic named as LHBH has an initialization phase to determine seed customers by solving the location-allocation problem. Toth and Vigo (1999)'s heuristic named as TV may obtain unfeasible clusters at the end of the cluster phase with respect to capacity constraints.

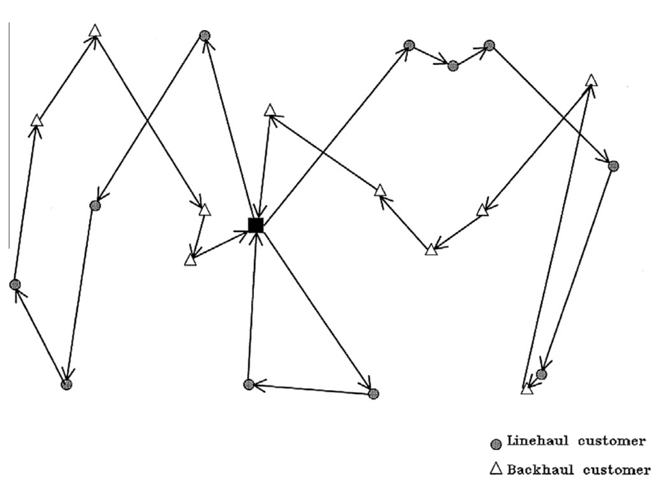

Fig. 1. Example solution of VRPB (Mingozzi & Giorgi, 1999).

Metaheuristics relating to the VRPB can be listed as tabu search (Brandão, 2006; Osman & Wassan, 2002), memetic algorithm (Tavakkoli-Moghaddam, Saremi, & Ziaee, 2006), ant colony optimization (Gajpal & Abad, 2009). In details of these metaheuristics, Osman and Wassan (2002) propose a reactive tabu search. Tavakkoli-Moghaddam et al. (2006) developed a memetic algorithm that uses different local search algorithms, and a mixed integer programming formulation is proposed. Ghaziri and ve Osman (2006) developed a self-organizing feature algorithm. Brandão (2006) presents a tabu search algorithm that is the first to use pseudo-lower bounds for the initial solution. Gajpal and Abad (2009) are the first to use a multi-ant colony system that has a new construction and also uses two multi-route local searches. Zachariadis and Kiranoudis (2012) propose a local search metaheuristic that uses exchanging variable-length customer sequences with a Static Move Description.

Mathematical models developed in literature have not been used to solve the VRPB due to NP-hard structure of the VRPB. For the same reason, exact algorithms solves the VRPB up to 100 customers. Heuristics and metaheuristics algorithms overcome this situation however they need accurate parameter settings and requires efficient codding to generate solutions in reasonable time in other word expertise is required to apply a heuristic or metaheuristic. If an algorithm using the standard optimization software is developed, then the VRPB can be solved effortless even by a non-expert in codding and heuristics and metaheuristics. Though the VRPB should be separated into fewer phase to solve it by mathematical models effectively. In this study, a novel cluster-first route-second methodology is proposed to solve the VRPB, the clustering phase are handled with two objectives. While determining the weights of objectives, game theory are useful tool to fully achieve of each objective. Therefore objectives have different scale in multiobjective models, fuzzy pay-off matrix provides raising the achieving degree of each objectives separately. The membership function value indicates the achieving degree of each objective functions. Fuzzy pay-off matrix for multiobjective is firstly take place in literature. Therefore, linear programming model of game theory is modified by using the membership functions. In this algorithm, proposed fuzzy membership functions methods are a novel contribution to determine the weights of objectives in multi-objective programming by setting fuzzy pay-off matrix that includes two-person zero-sum game with mixed strategies (FTZG with MS). Additional, the FTZG with MS provides to not take any detailed information from decision maker.

The aim of the paper is to develop an algorithm to solve the VRPB by using mathematical models thereby this prevents the need for any specialization on codding and heuristics and metaheuristics thereby the need any parameter setting and this also prove to save time due to easy to implement by using the standard optimization software to solve the mathematical models. For this purpose three phase is constructed as clustering phase, routing phase and local search phase. Clustering phase is designed with two objectives to generate more influential clusters and in order to reduce the step size, the proposed multiobjective programming (MOP) model defines the seed customers by itself. In addition, the MOP model is converted into fuzzy case with fuzzy operators to find solution as close as the optimum value of each objectives. The routes are built by the mathematical model of Travelling Salesmen Problem with Backhauls (TSPB). The routes is improved by local search that is easy to implement and consist of insertion and interchange operations. Hereby, the FMOP-VRPB algorithm is easy to implement and does not need any information from decision maker except location of the depot and customers and demand of customers.