Paper:

Solving Truck Delivery Problems Using Integrated Evaluation Criteria Based on Neighborhood Degree and Evolutionary Algorithm

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To solve a real-world truck delivery and dispatch problem (TDDP) that involves multiple mutually conflicting objectives, such as running and loading costs, a concept of neighborhood degree (ND) and an integrated evaluation criteria (IEC) of the solution based on ND are proposed. The IEC makes the weight setting easier than by using conventional methods. To find a high-quality solution to a TDDP in practical computational time, an evolutionary algorithm is proposed. It involves 3 components: (i) a simulated annealing (SA)-based method for finding an optimal or a suboptimal route for each vehicle; (ii) an evolutionary computation (EC)-based method for finding an optimal schedule for a group of vehicles; and (iii) threshold-based evolutionary operations, utilizing the ND concept. The TDDP viewed from real-world application is formulated and the proposed algorithm is implemented on a personal computer using C++. The proposed algorithm is evaluated in 2 experiments involving real-world data representative of the TDDP, and applied to food product delivery to a chain of 46 convenience stores in Saitama Prefecture. In the 2 experiments, our proposed algorithm resulted in a better schedule (with 80%-90% shorter computational time) than a schedule produced by an expert. By incorporating application-specific evaluation criteria, the proposed algorithm is applied to problems such as home-delivery of parcels or mail, and to problems of multi-depot delivery and dispatch.

Keywords: truck delivery and dispatch problem (TDDP), optimal solution, evaluation criteria, evolutionary computation, simulated annealing

1. Introduction

The objective of the vehicle routing, scheduling, and dispatching problem (VRSDP) is to produce a delivery schedule for a group of vehicles, with respect to multiple users, so that - while satisfying constraints - delivery cost corresponding to users' orders is minimized. The VRSDP i.e., using a truck to deliver goods from a depot to supermarkets or retail stores – is widely observed in daily life. Solutions to such real-life VRSDP are indispensable for achieving low delivery cost and high quality service requirements from the enterprises, as well as the integration, rationalization, and standardization requirements from the administration.

The VRSDP is a complex combinatorial optimization problem (COP), in which computational cost increases exponentially with problem size, making it extremely difficult to find an optimal solution of a VRSDP in practical computational time. Simulated annealing (SA), genetic algorithms (GAs), tabu search (TS), and other methods have been proposed to find suboptimal solutions to VRSDPs [1][2][3][4]. Since the 1990s, research on the VRSDP has expanded in Japan, with representative examples being [5] and [6]. The SA-based method of Igarashi et al. [5] proposed and applied to a real-world VRSDP had 2 disadvantages, i.e., (i) it requires manual setting of numerous weights corresponding to components of the evaluation function, which is difficult for an inexperienced user; and (ii) it has high computational cost, required to find a suboptimal solution. Chen et al. [6] proposed a hierarchical multiplex structure (HIMS) computational model, introducing normalization of components of the evaluation function to simplify setting of corresponding weights. The evaluation function of the HIMS model, however, depends on the initial state of its components, which may act negatively effect on the quality of the obtained suboptimal solution.

For the VRSDP, components of the evaluation function, i.e., evaluation criteria, e.g., running cost and loading ratio, etc. are mutually conflicting, in the sense that the running cost must be minimized and, at the same time, the loading ratio must be maximized. With such evaluation criteria, it is difficult for designers of real-world applications to set corresponding weights to reflect designers' intent.

To solve these issues, we propose the following for solving real-world multiobjective truck delivery and dispatch problems (TDDP):

First, an **integrated evaluation criterion (IEC)** that makes the weight setting easier and reflects the intent of real-world application designers is proposed based on a concept of **neighborhood degree** (ND). The ND allows fuzzy quantitative evaluation (within the interval [0, 1]) of a-priori given real cost information between users, i.e., elements of the TDDP. Using the ND, an evaluation method (in the interval [0, 1]) for the running cost and the loading ratio is proposed. Note that running cost and loading ratio are the most important factors that affect the TDDP evaluation function. Based on the proposed evaluation method, the IEC is expressed, that evaluates the solution of a TDDP by uniformly treating these mutually conflicting evaluation criteria. The proposed IEC is characterized by: (i) each individual evaluation criterion is evaluated in the same [0, 1] interval, making the weight setting easier; (ii) based on the value of the integrated evaluation criterion, the quality of the solution of a TDDP can be estimated; and (iii) unlike normalization method [6], initial values of the individual evaluation criteria are not used, implying that the proposed integrated evaluation criterion does not depend on the initial state of its components.

To find a suboptimal solution to a TDDP, an **evolutionary algorithm** (EA) is proposed. The proposed EA involves: (i) an SA-based method for finding a suboptimal route for each vehicle and (ii) an evolutionary computation (EC)-based method for finding a suboptimal schedule for a group of vehicles. By integrating guaranteed convergence characteristics of the SA with the fast computation characteristics of the EC, the proposed method has the potential to efficiently find a high-quality solution. The TDDP is also formulated for real-world applications, and the support system for truck delivery and dispatch is implemented on a personal computer. The efficiency of the proposed integrated evaluation criterion and the evolutionary algorithm is demonstrated through experiments with a real-world TDDP. This problem consists in delivering food products to a chain of 46 convenience stores in Saitama Prefecture, Japan.

In Section 2, the TDDP is formulated for real-world application and ND concept is proposed. In Section 3, a representation of a TDDP solution is proposed, together with an integrated evaluation criterion for evaluating the quality of a solution. The main characteristics of these two are also discussed. In Section 4, the evolutionary algorithm for solving the TDDP is proposed, including evolutionary operations ("move" and "exchange") using the proposed ND concept. In Section 5, the proposed method using real-world data is evaluated.

2. Formulation of Truck Delivery and Dispatch Problem (TDDP) and Neighborhood Concept

First, the TDDP is formulated from the viewpoint of the real-world application, then a concept of neighborhood degree is defined.

(1) **Depot**

In the TDDP, the depot is a place where goods to be delivered to users are stored and where vehicles used for delivering goods are located. For depot D, the most important attributes are working time T_d and moving cost to the user I_d, as follows:

$$D = (T_d, I_d),\ T_d = [DB_d, DE_d], \quad \ldots\ldots \quad (1)$$

where DB_d and DE_d denotes the start and end of the working time. I_d is the index corresponding to the moving cost from the depot to the user.

(2) **Vehicle**

The set of all vehicles, including the case when the loading capacity differs among the vehicles, is denoted by

$$V = \{V_1, \ldots, V_m, \ldots, V_M\}, \quad \ldots\ldots\ldots\ldots \quad (2)$$

where M is the total number of vehicles. Each vehicle is associated with 2 attributes: service time T_m and maximal loading capacity$C_m^{\max}$, denoted by

$$V_m = (T_m, C_m^{\max}),\ T_m = [VB_m, VE_m],\ m \in \{1, 2, \ldots, M\}, \quad \ldots \quad (3)$$

where VB_m and VE_m denote the start and end of service time.

(3) **User**

The set of all users ordering goods is denoted by

$$U = \{U_1, \ldots, U_n, \ldots, U_N\}. \quad \ldots\ldots\ldots\ldots \quad (4)$$

Where,N is the total number of users. For each user U_n, O_n denotes the amount of goods to be delivered within time interval T_n so that the moving cost between the user and depot (or between two users) corresponds to index $I_{c_{ij}}$, denoted as

$$U_n = (O_n, T_n, I_{c_{ij}}),\ T_n = [UB_n, UE_n],\ i \in \{1, 2, \ldots, N\},\ j \in \{0, 1, 2, \ldots, N\} \quad \ldots \quad (5)$$

where UB_n and UE_n denote the start and the end of delivery period, as specified by user U_n.

(4) **Real Cost**

The set of all destinations (depots and users) is denoted as

$$A = \{a_0, a_1, \ldots, a_i, \ldots, a_N\}. \quad \ldots\ldots\ldots \quad (6)$$

a_0 denotes the depot, whereas $a_1, \ldots, a_i, \ldots, a_N$ denote users. The moving cost between an arbitrary pair of destinations i and j is denoted by $c_{i,j}$, and called *real cost*, whereas the collection of these is denoted by

$$R_{\cos t} = (c_{i,j}),\ c_{i,i} = 0,\ i, j \in \{0, 1, 2, \ldots, N\}. \quad \ldots \quad (7)$$

Real cost $c_{i,j}$ is considered to be a-priori given informa-