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Vehicle rerouting in the case of unexpectedly high demand in distribution systems

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ABSTRACT

Many logistics companies use the same vehicle routes every day when distributing goods to the customers. Unexpectedly high demand in some nodes can cause that one or more of the planned vehicle routes are not feasible any more. In such a situation, the new set of vehicle routes should be generated. We propose in this paper the mathematical formulation of this problem. We also propose the Bee Colony Optimization algorithm and principles of lexicographic optimization to solve the problem. When solving the described problem we tried to minimize the negative consequences of the disturbances caused by the increased customer demand. We tested the proposed concept on the Solomon's benchmark example. The obtained results show that Bee Colony Optimization metaheuristic can find high quality solutions in reasonable CPU time.

1. Introduction

Many warehouse and distribution companies usually serve the same (or similar) set of customers on a daily basis. As a consequence, in many distribution companies, vehicle routes are created in advance and repeated every day. Companies usually use the same set of created, "stable" routes during the longer period of time (few months or more). This way of freight distribution organization and vehicle routing have the following advantages: (a) it is easier to plan the fleet size and vehicle mix within the fleet; (b) it is easier to plan the necessary number and working hours for the drivers and other employees; (c) the future costs are less uncertain; (d) drivers became familiar with the routes and clients they served, etc. On the other hand, the fixed set of vehicle routes can, in some situations, generate higher transportation costs, since it is possible to create the set of cheaper (shorter) routes for a particular day.

Unexpectedly high demand in some nodes can cause that one or more of the planned vehicle routes are not feasible any more. As a consequence, the operator is unable to perform routinely daily freight delivery. In such a situation, it is necessary to find the new set of vehicle routes in such a way to minimize the negative consequences of the unexpectedly high demand in one or more nodes. The process of re-planning of vehicle and/or crew activities is known as disruption management. Disruption management concepts was for the first time applied to flight scheduling (Teodorović and Guberinić, 1984). The disruption management strategies and concepts have had the greatest number of applications in the air transportation (Teodorović, 1985; Teodorović and Stojković, 1990, 1995; Argüello et al., 1997, Bard et al., 2001), since flight delays and or cancellations are related to high cost. The other applications include public transit (Teodorović and Rallis, 1988; Kepaptsoglou and Karlaftis, 2009; Zeng et al., 2012), vehicle rescheduling (Li et al., 2007a,b), vessel schedule recovery

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(Brouer et al., 2013)), distribution management (Li et al., 2009a,b; Mu et al., 2011; Mu and Eglese, 2013; Qi et al., 2004; Wang et al., 2012; Spliet et al., 2014), etc.

In this paper, we consider and analyze the problem of mitigation of the negative consequences of the disruption of planned vehicle routes in distribution systems. The problem is considered in the case when time window is assigned to every customer to be served. In this paper we propose the model to dynamically recover a previously designed set of vehicle routes when extremely high demand avoid the original set of routes from being executed easily. The considered problem belongs to the class of NP hard problems.

To solve this problem, we propose the heuristic approach based on the Bee Colony Optimization (BCO) technique.

The paper is organized in the following way. The statement of the problem is given in Section 2. Section 3 describes the BCO algorithm. The application of the BCO technique to the problem considered is given in Section 4. Numerical examples are given in Section 5. Section 6 contains conclusions, as well as directions for future research.

2. Statement of the problem

Let us denote by $G = (V, A)$ an oriented graph, where V is the set of nodes $V = \{0, 1, \ldots, n, n+1\}$, and A is the set of edges $(i,j) \in A$. Nodes 0 and $n+1$ denote the central depo. We also denote by $N = \{1, 2, \ldots, n\}$ the set of customers. Let us denote respectively by q_i and $[a_i, b_i]$ the forecasted quantity demand of the customer i, and the time window assigned to the customer i. The daily good delivery problem can be treated as the Vehicle Routing Problem with Time Windows (VRPTW).

The following is the mathematical formulation of the VRPTW (Desrochers et al., 1988; Cordeau et al., 2007):

$$\min \quad \sum_{k \in K} \sum_{(i,j) \in A} c_{ij} x_{ij}^k \tag{1}$$

subject to:

$$\sum_{k \in K} \sum_{j \in \delta^+(i)} x_{ij}^k = 1 \quad \forall i \in N \tag{2}$$

$$\sum_{j \in \delta^+(0)} x_{0j}^k = 1 \quad \forall k \in K \tag{3}$$

$$\sum_{i \in \delta^-(j)} x_{ij}^k - \sum_{i \in \delta^+(j)} x_{ji}^k = 0 \quad \forall k \in K,\ j \in N \tag{4}$$

$$\sum_{i \in \delta^-(n+1)} x_{i,n+1}^k = 1 \quad \forall k \in K \tag{5}$$

$$w_j^k \geqslant w_i^k + s_i + t_{ij} - M\left(1 - x_{ij}^k\right) \quad \forall k \in K, (i,j) \in A \tag{6}$$

$$a_i \leqslant w_i^k \leqslant b_i \quad \forall k \in K,\ i \in V \tag{7}$$

$$\sum_{i \in N} q_i \sum_{j \in \delta^+(i)} x_{ij}^k \leqslant Q \quad \forall k \in K \tag{8}$$

$$x_{ij}^k \in \{0, 1\} \quad \forall k \in K, (i,j) \in A \tag{9}$$

where

x_{ij}^k – binary variable that the takes value 1 if vehicle k after visiting node i goes to node j,
w_i^k – decision variable that denotes beginning of the service of node i by vehicle k,
Q – vehicle capacity,
c_{ij} – transportation cost from node i to node j (or the length of the path from node i to node j),
a_i – earliest time point when service can start at node i,
b_i – latest time point by which service should start at node i,
s_i – duration of the service at node i,
q_i – demand of node i,
K– set of vehicle.

$$\delta^+(i) = \{j : (i,j) \in A\}$$

$$\delta^-(j) = \{i : (i,j) \in A\}$$