Minimizing Fuel Consumption in Capacitated Vehicle Routing Problem

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1. Introduction

The classical Vehicle Routing Problem (VRP) aims to design optimal delivery routes of a fleet of vehicles based at a depot and serving a set of customers with specified demands. For many decades, the VRP objective was focused only on economic issues by minimizing the total distance traveled or the total travel costs.

Recently, studies aware of the dire effects of the pollution caused by the transportation and industrial sectors, the VRP objective was extended to deal with environmental sustainability. In this context, the Green Vehicle Routing Problem (GVRP) has emerged as a key to tackle environmental threats from the transportation sector. Thus, in the recent literature, many studies have been addressed to deal with Green logistics. For instance, Aras et al. (2011), Ramos and Oliveira (2011) considered the pickup and collection problems of useless products; Bauer et al. (2010) and Faulin et al. (2011), have studied the VRP with minimization of CO2 emission; Kuo (2010)and Xiao et al. (2012) studied the minimization of the fuel consumption.

In this paper, we tackle the minimization of the fuel consumption for the Capacitated Vehicle Routing Problem (FCVRP). We take into consideration the vehicle's load and the distance traveled as factors impacting the fuel consumption rate. As this problem is NP-Hard, we propose to solve it by an Iterated local search ILSFC-SP. The proposed ILSFC-SP operates in two phases : in the first phase we model the FCVRP as a set-partitioning problem and we solve the corresponding model using CPLEX. In the second phase, an iterated local search is proposed in order to improve the quality of the solutions obtained by CPLEX.

2. Problem description and modeling

Let $G = (V, E)$ be a graph where V = {0,1,...,n} is the set of vertices and E = {(i,j) | i,j ∈ V, $i < j$} is the set of arcs. The Vertex 0 represents the depot while the remaining vertices represent the n customers. Each vertex $V/\{0\}$ is associated with a non-negative demand q_i and each arc (i,j) is associated with a distance d_{ij}. A fleet of homogeneous vehicles is available at the depot. Each vehicle has a loading capacity that can not be exceeded. A vehicle route must start and end at the depot after serving a set of customers. Each customer must be served only once by a single vehicle. The objective is to minimize the total fuel consumed while serving all the customers. It is known that the fuel consumption rate depends on different factors such as distance, load, speed, road gradient, driver wages, etc. In this work, we consider the load and distance as factors influencing the fuel costs such as in the work of Xiao et al. (2012). According to these last authors, the fuel cost C^f_{ij} for traveling from customer i to customer j is expressed as $c^f_{ij} = c_0 p_{ij} d_{ij}$ where p_{ij} is the consumption rate along the route from i to j and c_0 is the unit fuel cost. We use this formula in our work.

We propose to model The FCVRP as a set-partitioning problem. Let Ω be the set of feasible vehicle routes. X_k is a decision variable corresponding to the route k, its value is 1 if the route k is selected in the solution otherwise it is equal to 0. a_{ik} a binary coefficient which equals to 1 if the customer i is included in the route otherwise $a_{ik} = 0$. C^f_k is the fuel cost of the route k. This cost should be calculated as the sum of the fuel cost of all arcs composing the route. The formulation of the FCVRP as a set-partitioning problem is as follows.

$$Min \sum_{k \in \Omega} C^f_k X_k \tag{1}$$

$$S.t. \sum_{k \in \Omega} a_{ik} X_k = 1 \quad \forall i \in \{1..n\} \tag{2}$$

$$X_k \in \{0, 1\} \quad \forall k \in \Omega \tag{3}$$

3. ILSFC-SP algorithm

The proposed approach consists to develop in a first step an effective heuristic based on mathematical programming using the set-partitioning problem as a formulation, then an Iterated Local search is applied in order to improve the results of the heuristic. In our heuristic, we simplify the previous mathematical programming in order to solve it easily. We build a reduced subset $\Omega' \subset \Omega$ of feasible and promising routes. Then we solve the reduced partitioning problem by CPLEX.

In a second step, we propose an Iterated Local Search to explore the neighborhood of the resulted solution. This metaheuristic is composed of two phases : the local search phase and the perturbation phase. For the local search phase, we propose a descent method with the shift and swap moves. In the perturbation phase, we propose the destroy and repair operators (Pisinger and Ropke, 2007).

4. Computational experiments

In order to evaluate the performance of our approach, we carried out several experiments on two classes of instances. The first class contains 7 small/medium-scale CVRP instances from Christofides (1979) with 50 to 199 customers and the second class is composed of 6 large-scale CVRP instances from Golden et al. (1998) with 240 to 420 customers. We have compared the performance of our approach with the simulated annealing SMSH of Xiao et al. (2012).

Table 1: Computational results and comparison on solving the instances of Christofides (1979)

Instance	SMSH	ILSFC-SP
$CMT_1(50)$	751.11	746.388*
$CMT_2(75)$	1181.61	1192.35
$CMT_3(100)$	1147.83	1170.22
$CMT_4(150)$	1449.81	1472.66
$CMT_5(199)$	1842.77	1911.98
$CMT_{11}(120)$	1514.46	1512.92*
$CMT_{12}(100)$	1174.02	1174,57

Table 2: Computational results and comparison on solving the instances of Golden et al. (1998)

Instance	SMSH	ILSFC-SP
$Golden_{13}(252)$	1296.67	1292.73*
$Golden_{14}(320)$	1637.93	1626.34*
$Golden_{17}(240)$	1057.42	1068.15
$Golden_{18}(300)$	1494.16	1516.14
$Golden_{19}(360)$	2055.6	2080.76
$Golden_{20}(420)$	2687.85	2799.53

Table 1 and Table 2 show some preliminary results. We note from Table 1 that our ILSFC-SP algorithm outperforms the SMSH algorithm in the two cases CMT_1 and CMT_{11}. For the rest of instances, results are very close.
Table 2 shows also that ILSFC-SP finds better solutions than the SMSH in $Golden_{13}$ and $Golden_{14}$. In conclusion, we can claim that this first version of the proposed approach is promising.

5. References

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