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Technical Paper

A robust optimization approach for pollution routing problem with pickup and delivery under uncertainty

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ABSTRACT

Organizations have recently become interested in applying new approaches to reduce fuel consumptions, aiming at decreasing green house gases emission due to their harmful effects on environment and human health; however, the large difference between practical and theoretical experiments grows the concern about significant changes in the transportation environment, including fuel consumptions, carbon dioxide (CO_2) emissions cost and vehicles velocity, that it encourages researchers to design a near-reality and robust pollution routing problem. This paper addresses a new time window pickup-delivery pollution routing problem (TWPDPRP) to deal with uncertain input data for the first time in the literature. For this purpose, a new mixed integer linear programming (MILP) approach is presented under uncertainty by taking green house emissions into consideration. The objective of the model is to minimize not only the travel distance and number of available vehicles along with the capacity and aggregated route duration restrictions but also the amount of fuel consumptions and green house emissions along with their total costs. Moreover, a robust counterpart of the MILP is introduced by applying the recent robust optimization theory. Computational results for several test problems indicate the capability and suitability of the presented MILP model in saving costs and reducing green house gases concurrently for the TWPDPRP problem. Finally, both deterministic and robust mathematical programming are compared and contrasted by a number of nominal and realizations under these test problems to judge the robustness of the solution achieved by the presented robust optimization model.

1. Introduction

Carbon dioxide (CO_2) is one of the elemental green house gases emitted through human resource activity. Increasing CO_2 becomes a major problem for the natural cycle in ecosystem as the nature always maintain the equilibrium between the amount of CO_2 unleashed and the amount of CO_2 refined; therefore, human resource activity is responsible for that rising has come about. CO_2 emissions in United State went up by about 12% between 1990 and 2010 [1]. In 2010, it accounted for quiet 84% of all United State so that the main human resource activity causes CO_2 emissions with the combustion of fossil fuels (e.g., coal, natural gas and oil) for producing energy and transportation. The amount of CO_2 emission of fuel combustion in transportation, such as gasoline and diesel, after electricity producers is the second largest source of CO_2 pollutants. It is responsible for 31% of total United State CO_2 emissions and 26% of total green house gas emissions [1]. The road transportation accounts for 78% of green house emissions, including CO_2 growing the concern about hazardous effects on ecosystem [2], which makes scientists and researchers develop adaptive approaches and models to explicitly reduce the amount of the above pollutants.

The vehicle routing problem (VRP) determines the optimal set of routes to be performed by a fleet of vehicles to serve a given set of customer under specific constraints. Besides, the vehicles are start from, and end to a depot [3–5]. The classical version of the VRP is capacitate VRP (CVRP), in which all customers correspond to deliveries and the demands are deterministic, and it may not be split and only capacity restrictions are considered for the vehicles. Fung et al. [6] represent a capacitate arc routing problem which uses memetic algorithm to find a set of routes holding the minimum cost of transportation. The computational results illustrate that the quality of the solution is high in a reasonable time.

Another common variant is time window VRP (TWVRP) that is an extension of CVRP, at which each customer is associated to an interval, called time window, and each of them must be met at its interval. The significance of the application of this TWVRP in real world has made researchers do efforts to find appropriate and strong algorithm to solve these types of VRP models. For example,

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Nagate et al. [7] introduce a memetic algorithm for TWVRP using new penalty function to eliminate violation of time window constraints as well as original constraint uses in common memetic algorithm. The experimental result of this model asserts that the developed algorithm performs well. Zachariadis et al. [8] represent a hybrid solution approach as a combination of tabu search and guided local search which has ample power to explore a vast space to find a better solution for VRPPD with simultaneous pickup and delivery services. Jeon et al. [9] develop the main VRPPD model and consider double trip, multi depot, and heterogeneous vehicles and suggest a hybrid genetic algorithm in order to solve the large scale problems.

An extended variant in this paper is introduced as VRP with pickup and delivery (VRPPD), in which some customers have demand to deliver and some of others have loads to pickup. The typical class of VRPPD is picking up load from the entire customer related to, and then delivering load to all remained customers. Tersan and Gen [10] consider a pickup delivery problem in which vehicle can deliver and collect goods simultaneously in order to model real world problem such a reverse logistic and then examine the mathematical model by genetic algorithm and represent the results which approved the accuracy of the model. Another introduction of VRPPD with simultaneous pickup delivery announced by Goksal et al. [11]; In this paper, a heuristic solution based on particle swarm optimization is presented which uses annealing-like strategy to preserve the diversity of swarm. For the literature on the VRP and its extensions, readers can be referred to [12–18].

There is a great deal of effort at extending the traditional VRP objectives and constraints not just to account for the economic costs but to consider more comprehensive environmental and ecological impacts. A certain amount of works reduces the CO_2 emissions with lowering the amount of fuel consumptions. By way of illustration, Erdugan and Miller-Hooks [19] introduce a mathematical model by keeping fuel consumptions to a minimum via minimizing the total traveled distance while considering the needs for refueling in the route plans so optimized as to avoid the risk of running out of fuel. Ubeda et al. [20] represent a distance-based model affected by multiplying an emission factor depended on average weight of a typical vehicle and fuel conversion factor. This study shows that introducing backhauls to avoid empty running benefit from both economic and ecological more efficient.

Apart from the above-mentioned studies, some of other works involve factors depended on the features of the vehicle, the fuel that vehicle consumes, and the route it travels to deplete the amount of CO_2 emitted. Suzuki [21] shows that the less distance a delivery vehicle is anticipated with heavier load traveled the less fuel consumptions. Also, they consider the fuel consumptions that are relevant to waiting time in customer service place. Figliozzi [22] represents an analytical model of CO_2 emissions involved in a variety of time-definitive customer demands by using time dependant vehicle routing method in order to plan vehicles routes. Bektas and Laporte [23] shed light on the trade-off between different parameters, such as vehicle load, speed, and aggregate cost and environmental green vehicle routes, and they represent a model named pollution routing problem (PRP).

The review of the related literature indicates that there is a significant gap on the applying the new economic-friendly and ecological-friendly VRP to pickup and delivery systems. Most studies have failed to pay attention to the effect of some economic impacts on ecological influence in the VRP networks. In addition, consuming the realization of some influential parameters seems to be necessary because of the importance of building mathematical models in the real-world applications. This paper is to address a new time window pickup-delivery pollution routing problem (TWPDPRP) to deal with uncertain input data for the first time in the literature. The presented problem combines conventional VRP and technical and mechanical approaches to establish a new mixed integer linear programming (MILP) model by considering economic and environmental issues concurrently.

The main innovations of this paper to differentiate the efforts from those already published on the subject are as follows: (1) introducing penalty costs for pickup nodes in order to create a sequence of pickup nodes to reducing the amount of traveling time and then the amount of fuel consumptions and CO_2 emissions; (2) integrating time window constraints into the VRPPD in order to decrease the arrival time to delivery nodes. Both (1) and (2) show up the economic effects that enrich environmental influences in the model; (3) applying robust optimization within the constraints considering the velocity of vehicle as an uncertain parameter in order to achieve a practical model; for instance, this uncertainty is related to traffic flow, stops at fuel stations and traffic lights. All of the above considerations bring the mathematical model closer to reality, unlike the previous studies by considering the velocity as a set of numbers that can be chosen from in order to optimize the VRP model [22,23]; (4) considering the changes of the CO_2 emissions cost and the fuel consumptions cost over the time to think over the altering in the real world applications. By taking (3) and (4) into consideration robust optimization imports in the TWPDPRP as a new way to create a trade-off between economic and ecological issues and combines them to the natural cases; (5) taking into account the robust concept for service time of each customer to deal with different situations; and (6) thinking over the physical feature of each vehicle, such as the front surface the weight, the slope and the fraction factor of roads and bring them into the TWVRPPD to get the best sequence pickup and delivery nodes so that the fuel consumptions and CO_2 emissions cost get down considerably.

The remainder of this paper is organized as follows. Sections 2, 3 and 4 provide a formal description of the TWPDPRP, the proposed mathematical model and the robust counterpart mathematical model, respectively. Computational results on deterministic and robust solutions are presented in Section 5. Also, in this section the sensitivity analysis is reported on various parameters of the proposed MILP model. The final section ends with the conclusions.

2. Problem definition

This paper addresses a new TWPDPRP including two groups of nodes. The first one contains customers whose loads should be picked up, and the second one covers customers whose demands should be delivered. The model employs a group of vehicles for service tasks, unlike the previous studies with only one vehicle mentioned in Section 1. As illustrated in Fig. 1, after servicing all pickup customers, their loads are carried by trucks (i.e., the loads picked up from the first group nodes and the loads that are needed to be picked up from depot at the beginning for supplying total demands accurately), the vehicles distribute the loads among delivery customers. Hence, the amount of the product which each vehicle loaded up at the start node (i.e., depot) is the total demands of delivery nodes in which they visit during their routes minus the total loads collected from pickup points during traveling the routes that they are associated to. If total picked up products are over or equal to the total delivery demands during the relevant route the vehicle follows, it leaves the depot empty. In addition, the physical feature of each vehicle, such as the front surface the weight, the slope and the fraction factor of roads, are considered based on [24].

Calculating the velocity value: Due to assuming vehicles motion with constant acceleration, the maximum value of velocity during traveling from point i to point j with the distance amount, d_{ij} is achieved from the below equation [24]:

$$v_{ij} = \sqrt{v_0^2 + 2ad_{ij}} \quad (1)$$