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Design and development of a hybrid ant colony-variable neighbourhood search algorithm for a multi-depot green vehicle routing problem

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ABSTRACT

The traditional distribution planning problem in a supply chain has often been studied mainly with a focus on economic benefits. The growing concern about the effects of anthropogenic pollutions has forced researchers and supply chain practitioners to address the socio-environmental concerns. This research study focuses on incorporating the environmental impact on route design problem. In this work, the aim is to integrate both the objectives, namely economic cost and emission cost reduction for a capacitated multi-depot green vehicle routing problem. The proposed models are a significant contribution to the field of research in green vehicle routing problem at the operational level. The formulated integer linear programming model is solved for a set of small scale instances using LINGO solver. A computationally efficient Ant Colony Optimization (ACO) based meta-heuristic is developed for solving both small scale and large scale problem instances in reasonable amount of time. For solving large scale instances, the performance of the proposed ACO based meta-heuristic is improved by integrating it with a variable neighbourhood search.

1. Introduction

The traditional distribution planning problem in a supply chain is solely concerned with the economic benefits and the optimal operational plans developed are cost or profit centric. The total cost reduction models and the profit maximization models designed vehicle routes on the basis of minimization of distance travelled or travel time. However, in recent decades, there is a growing awareness about the effects of anthropogenic pollutions. This has forced the global economy to respond to the challenges and address the socio-environmental concerns by effective control of carbon emissions arising directly or as a byproduct of the industry/organizations (Mohammed et al., 2017).

In the last decade of the twentieth century, the environment-friendly designs and the conceptual frameworks for greening the organizational activities have shown a strong growth (Ubeda et al., 2011). The International treaty of 1992 in the United Nations (UN) Earth Summit at Rio de Janeiro outlined the framework for the negotiation of protocols among its member countries. This United Nations Framework Convention on Climate Change (UNFCC) laid the foundation to the Kyoto Protocol in 1997. The Kyoto protocol (implemented in 2005) stipulates the amount of anthropogenic emissions. The subsequent governmental regulations and outcries from the environmentalists encouraged the beginning of an era of green economics and since then, it has achieved considerable attention. Thus, greening the economy has become a necessary objective due to the involvement of governmental and other

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national and international bodies. The transportation sector, being one of the sources of the major pollutant emission and its excessive reliance on the fossil fuel burning for energy production, has become one of the focal points of the green research (Yu et al., 2016; Fan and Lei, 2016; Wang et al., 2015). As a direct contributor of fossil fuel combustion, freight transportation is one of the significant Greenhouse Gas (GHG) emission generators (Singh et al., 2017; IEA, 2016). Furthermore, carbon dioxide (CO_2) is the prominent GHG and its emission is mostly due to the fuel combustion. In the supply chain design context, the prospect of the green distribution network planning leads to the Green Vehicle Routing Problem (GVRP), which is a variant of the classical Vehicle Routing Problem (VRP).

To address the CO_2 emission reduction in a transportation problem, the trend is to focus on emission-reduction models that consider the following three major focal points (Sbihi and Eglese, 2007; Lin et al., 2014a,b; Demir et al., 2014a,b):

Engine technology (Demir et al., 2011; Erdoĝan and Miller-Hooks, 2012; Markkula et al., 2013; Yang and Sun, 2015; Yavuz et al., 2015; Bergthorson and Thomson, 2015)
Fuel consumption (Kara et al., 2007; Kuo, 2010; Xiao et al., 2012; Karplus et al., 2013; He et al., 2015)
Distribution plan (Palmer, 2007; Sbihi and Eglese, 2007; Ubeda et al., 2011; Elhedhli and Merrick, 2012; Kwon et al., 2013; Franceschetti et al., 2013; Soysal et al., 2015)

Efficiency and the burning of fuels are studied extensively for the better design of new engines and for introducing alternative fuels. The introduction of alternative vehicles, bio-fuels and introduction of nano-particles to the existing fuels has tremendously changed the design scenario. The trucks suffering from wear and tear from the continuous usage on the road result in the decrease in efficiency and increase in fuel consumption. Consequently, through government legislations and policies for environmental protection, these inefficient vehicles are withdrawn from use. Thus, logistic managers are presented with a set of opportunities and challenges in the preparation of distribution plans. The motivation of the present study is to develop mathematical models with the objectives of economic cost reduction and emission cost reduction for a capacitated multi-depot green vehicle routing problem (MDGVRP).

With the aim to minimize the total supply chain cost, the following managerial decisions are to be taken in the proposed models:

- Allocation of customers to the available depots
- Assignment of customers to different routes from a particular depot
- Sequencing of customer service.

The focus of this work is to develop and analyze the following models for a capacitated MDGVRP:

Model I: Total economic cost reduction model
Model II: Total emission cost reduction model
Model III: Integrated total cost reduction model where the combined influence of emission as well as economic cost on route planning is analyzed.

Model I corresponds to the classical capacitated multi-depot vehicle routing problem, wherein distance based cost structure is adopted and the objective is to minimize the total distance travelled with the use of minimum number of trucks. In Model II, the emission from the routes is the key factor in implementing the environment-friendly routes. The CO_2 emission converted to monetary units is used to plan the routes. Finally, an integrated cost model is proposed as Model III, combining both the aforementioned objectives with equal weights.

Demir et al. (2014a,b) state that the factors affecting fuel consumption are vehicle related (vehicle curb weight, vehicle shape, engine size/type, etc.), environment related (roadway gradient, pavement type, altitude, etc.), traffic related (speed, congestion, etc.), driver related (driver aggressiveness, gear selection, idle time, etc.), and operations related (fleet size and mix, pay load, empty kilometres, number of stops, etc.). Demir et al. (2011) and Demir et al. (2014a,b) provide a review of models that consider fuel consumption/emission in road freight transportation. Lin et al. (2014a,b) present a comprehensive review of Green Vehicle Routing Problem (GVRP) highlighting several areas for research. Thus, GVRP in a single depot has been studied by several researchers, for example, Bektaş and Laporte (2011), Ubeda et al. (2011), Demir et al. (2011), Gajanand and Narendran (2013), Pradenas et al. (2013), Franceschetti et al. (2013), Tajik et al. (2014), Demir et al. (2014a,b), Zhang et al. (2014), Tiwari and Chang (2015), Soysal et al. (2015) and Koç and Karaoglan (2016). Jabir et al. (2014) present two primitive models for MDGVRP with the reduction of economic cost and emission cost independently. However, they have not presented the solution for these models using exact optimization method. These models for MDGVRP were proposed based on the approach adopted by Yu et al. (2010) for location-routing problem. Jabir et al. (2016) present a formulation for MDGVRP with simultaneous pick up and deliveries. More specifically, in the present work on MDGVRP, the objectives of economic cost and emission cost reduction are integrated with equal priorities. Formulation of the integrated total cost reduction model for MDGVRP is a novelty of the present study. Another novelty of this paper is the development of efficient algorithms that provide optimal or near-optimal solution to small scale and large scale instances of MDGVRP.

In the present study, comprehensive computational experiments with different problem sizes are carried out to analyze the effectiveness and efficiency of the MDGVRP formulation and the proposed heuristics. The formulated models are solved with a set of small scale instances using LINGO 9.0 solver and the proposed Ant Colony Optimization (ACO) based meta-heuristic. Depending upon