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Time-dependent green vehicle routing problem with stochastic vehicle speeds: An approximate dynamic programming algorithm

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ABSTRACT

This paper addresses a Time Dependent Capacitated Vehicle Routing Problem with stochastic vehicle speeds and environmental concerns. The problem has been formulated as a Markovian Decision Process. As distinct from the traditional attempts on the problem, while estimating the amount of fuel consumption and emissions, the model takes time-dependency and stochasticity of the vehicle speeds into account. The Time Dependent Capacitated Vehicle Routing Problem is known to be NP-Hard for even deterministic settings. Incorporating uncertainty to the problem increases complexity, which renders classical optimization methods infeasible. Therefore, we propose an Approximate Dynamic Programming based heuristic as a decision aid tool for the problem. The proposed Markovian Decision Model and Approximate Dynamic Programming based heuristic are flexible in terms that more environmentally friendly solutions can be obtained by changing the objective function from cost minimization to emissions minimization. The added values of the proposed decision support tools have been shown through computational analyses on several instances. The computational analyses show that incorporating vehicle speed stochasticity into decision support models has potential to improve the performance of resulting routes in terms of travel duration, emissions and travel cost. In addition, the proposed heuristic provides promising results within relatively short computation times.

1. Introduction

The Vehicle Routing Problem (VRP) concerns the decision of defining routes for a number of vehicles for visiting a set of customers. The basic problem with general assumptions fits with many real-life cases where the problem is delivery or collection of goods or people. Accordingly, both academic and industrial interest in solving the problem is considerable. Many variants of the VRP have been studied in theliterature. For a detailed information on the variants of the VRP, the interested reader is referred to the literature reviews conducted by Laporte (1992), Eksioglu et al. (2009) and Lin et al. (2014).

There exists a steady growth in freight volumes throughout Europe, and accordingly traffic congestion is listed as one of the major challenges of transportation sector by authorities (European Comission, 2011b). The growth of transport activity raises concerns of society for its environmental sustainability. The drive towards environmentally sustainable logistics, or

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so-called 'green logistics', has been recently receiving a significant interest. The growing awareness on environmental issues especially related to global warming and oil scarcity leads to an increasing attention on developing environmentally-friendly policies in many decision problems, including the Vehicle Routing Problems (VRPs). For instance, European Union (EU) sets new policies to increase the efficiency of freight logistics and to reduce corresponding environmental externalities (TRIP, 2015). According to a technical document, the goal of EU is to achieve 60% cut in transport emissions by the middle of the century (European Commission, 2011a).

Based on these developments, especially in the last decade, companies have come under mounting pressure to account for the environmental impact of their logistics operations (McKinnon, 2010). For many companies, emission reduction is already one of the key targets, and this is an upward trend. The motivation behind being more sensitive to environment is not only related to the legal restrictions, but also is related to the fact that having an environmentally friendly business saves money and appeals to customers who want to support sustainability. For instance, the Deutsche Post DHL implements the GoGreen program that includes several activities such as using state-of-the-art carbon optimization tools, web-based operation systems and real time emission estimation applications to achieve saving in fuel, energy and emission consumption. [1]

As a result of the above-explained practical needs, decreasing total fuel consumption and/or emissions has become one of the main objectives in decision support models for theVRPs. In this context, even general VRPs without concern for environmental performance indicators contribute to green logistics, since shorter routes or durations usually result in lower fuel consumptions than consumptions of non-optimized (random or manually made, for instance) routes. Yet, the literature involves a number of studieson the Green VRPs, addressing the importance of taking environmental performance indicators into account in VRP models to guarantee more sustainable results (e.g., Kara et al., 2007; Bektaş and Laporte, 2011; Suzuki, 2011; Xiao et al., 2012; Gaur et al., 2013; Kwon et al., 2013; Zhang et al., 2015; Norouzi et al., 2016; Soysal, 2016). Hence, developing Green VRP decision support models are receiving a growing attention in the literature. For an overview of some of the recent developments on the Green VRPs, the interested reader is referred to the recent study of Bektaş et al. (2016).

Apart from the Green VRPs, another variant of the VRPs named the Time-Dependent Capacitated Vehicle Routing Problem (TDCVRP) addresses the dependence of travel speed on time of travel between nodes due to traffic congestion. In practice, roads (arcs) between supply chain actors (nodes) often allow lower speeds than the average speed due to traffic congestion at certain times of a day (rush hours), certain days of weeks (weekdays) or certain weeks of years (beginning and ending days of long holidays). Taking these changes in average speeds of vehicles due to time of travel into account affects the optimal routing decisions to make. Studies such as Figliozzi (2011), Jabali et al. (2012), Franceschetti et al. (2013), Soysal et al. (2015), Setak et al. (2015), Wen and Eglese (2015), Ehmke et al. (2016) and Xiao and Konak (2016) consider nonconstant travel times among the nodes. In these studies, the time of travel between nodes (e.g., rush hour or not) or locations of nodes (e.g., urban or rural area) has impact on vehicle travel speed. These studies present the benefit of accounting for time-dependent speed in decision support models for the VRPs.

In real-life routing problems, travel times on individual arcs are stochastic in nature (Tas et al., 2014; Lecluyse et al., 2009). Travel times can be affected from random factors such as bad weather conditions, car accidents, constructions, and special events that might cause traffic congestion (Duan et al., 2015). Assuming deterministic travel times on arcs, therefore, is a strong assumption for a real-life environment. The stochastic time-dependent capacitated vehicle routing problem (STDCVRP) addresses TDCVRP with stochastic vehicle speeds on arcs. To develop applicable decision support models for real-life routing problems, a number of studies in theliterature address either stochastic travel times (e.g., Ando and Taniguchi, 2006; Russell and Urban, 2008; Li et al., 2010) or deterministic time-dependent travel times (e.g., Malandraki and Dial, 1996; Ehmke et al., 2012; Soysal et al., 2015). A few studies (e.g., Lecluyse et al., 2009; Tas et al., 2014; Duan et al., 2015; Sun et al., 2015) consider both time-dependent and stochastic travel times for VRP applications. These studies, however, do not have environmental (energy usage or emissions) concerns.

Our brief literature review shows that (i) there is a growing attention paid to sustainable VRP decisions, (ii) there is a significant interest in the TDCVRP and, partly, the STDCVRP, (iii) to the best of our knowledge, there is not any attempts to incorporate environmental concerns (energy usage and emissions) in a STDCVRP. Since travel speed is one of the main factors in emission calculations, ignoring time-dependency and stochasticity of the travel times might lead to inaccurate estimation of energy usage and emissions. This has motivated us to addresses the STDCVRP with environmental concerns. Accordingly, our study adds to the literature on the Green VRP by accounting for the effects of stochasticity in vehicle speeds on fuel consumption in the STDCVRP. This attempt allows decision makers to accurately estimate energy usage and emissions while planning delivery decisions.

We present a Markovian Decision Model for the Green STDCVRP. We would like to note that incorporating uncertainty to the TDCVRP, which are known to be NP-Hard for even deterministic settings, render classical optimization methods infeasible. Therefore, we propose an Approximate Dynamic Programming (ADP) based heuristic algorithm as a decision aid tool for the Green STDCVRP.

The ADP approach has its roots in Machine Learning and Neural Networks. ADP is based on the idea of learning about policies through a simulation. The use of simulation enables to eliminate calculating expected values of policies in stochastic problems. The logic behind the ADP approach has been used in several other studies on the VRP (e.g., Novoa and Storer, 2009;

[1] http://www.dhl.com/en/about_us/green_solutions.html, online accessed on 14.02.2017.