Transportation Research Part E 106 (2017) 320–336

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

The impact of path selection on GHG emissions in city logistics

Martin Behnke, Thomas Kirschstein *

School of Economics and Business, Martin-Luther-University, Gr. Steinstr. 73, 06108 Halle, Germany

ARTICLE INFO

Article history:
Received 10 January 2017
Received in revised form 13 July 2017
Accepted 22 August 2017

Keywords:
City logistics
Green VRP
GHG emissions
Path selection

ABSTRACT

In this paper, we formulate an emission-minimizing vehicle routing problem with heterogeneous vehicles and give rise to the effects of path selection. We take into account different paths for traveling between two locations differing with respect to their emissions. Computational experiments with artificial and real-world data illustrate the effects of path selection by considering networks with different road types like urban roads and highways. The experiments suggest an emission saving potential of about 2–4%. We conclude that in reality a larger emission reduction potential exists when multiple paths are considered in transportation planning.

1. Introduction

Nowadays many urban areas suffer from environmental distress like smog or noise, which is caused by urban transportation to a large extent. As urbanization still advances, environmental issues will become more and more important in urban areas (Savelsbergh and Woensel, 2016). Thus, it is expected that urban transportation has to take environmental objectives into account explicitly in the near future. Particularly urban freight transportation will have to cope with demands for eco-reporting and minimizing the environmental impact of transportation.

Thereby, urban freight transportation is different than long-haul freight transportation in many aspects such as traveled distances, road and traffic conditions, and employed vehicle types. Particularly, urban freight transportation usually requires to take several paths into consideration connecting an origin with a destination. These paths are typically quite similar regarding their lengths and travel times. However, regarding greenhouse gas (GHG) emissions these paths may be quite different as GHG emissions depend on many factors like the vehicle weight, travel speed, technical vehicle specifications as well as traffic and road conditions. Therefore, it is straightforward to take alternative paths into consideration when planning urban freight transports with an environmental focus.

In this paper, we present a decision model for path selection applicable for vehicle routing in urban areas. We assume a road network consisting of different types of roads. To serve a given set of customers, a heterogeneous fleet of vehicles is available. The proposed vehicle routing model seeks to minimize the total emission of GHGs of all employed vehicles for serving all customers from a central depot. Therefore, the road network is overlaid by an organizational network consisting of all emission-minimal paths between two nodes. As vehicle type and payload affect GHG emissions, it is possible that multiple emission-minimal paths exist between two nodes. Therefore, in contrast to classical vehicle routing problems, the constructed organizational network is modeled as a multi-graph (Garaix et al., 2010). We use an emission model taking into

* Corresponding author.
E-mail addresses: martin.behnke@wiwi.uni-halle.de (M. Behnke), thomas.kirschstein@wiwi.uni-halle.de (T. Kirschstein).

http://dx.doi.org/10.1016/j.tre.2017.08.011
1366-5545/

account vehicle-specific characteristics, payload, speed as well as acceleration processes as parameters, see Kirschstein and Meisel (2015).

The remainder of the paper is organized as follows: The relevant literature on emission-oriented vehicle routing is reviewed in the subsequent section. Afterwards, the procedure for constructing the organizational network is described and the Emission-Minimizing Vehicle Routing Problem with Vehicle Classes and Path Selection (EVRP-VC-PS) is formally introduced in Section 3. Section 4 illustrates how emission-optimal paths can be determined in real road networks. Section 5 reports the results of computational experiments with artificial problem instances for the EVRP-VC-PS highlighting the effects of path selection in urban vehicle routing. The manuscript closes with Section 6.

2. Literature

There is a huge amount of literature on vehicle routing problems (VRPs) as well as their variations and applications. For an extensive overview see e.g. Toth and Vigo (2001). Classical approaches seek for routes that minimize travel distance or travel time. In the past years, however, ecological issues became further objectives in almost all business management processes. VRPs dealing with ecological aspects are focusing e.g. on minimizing fuel consumption, GHG emissions, noise, or similar measures and are typically summarized as *green* VRPs. Green VRPSs can be sub-categorized according to various criteria, see e.g. Lin et al. (2014) for an extensive overview. Table 1 summarizes the literature on one particular sub-category: *emission-oriented* VRPs. The papers are categorized by problem type, solution method, and parameters considered for emission estimation such as load, speed, vehicle types, path selection, and acceleration.

At first glance, emission-oriented VRPs should consider the (expected) emissions of a transport process as the objective value. Among all types of emissions, greenhouse gas (GHG) emissions are considered as most important in eco-oriented VRPs. As GHG emissions show an approximately linear relation to a vehicle's fuel and energy consumption, fuel and energy consumption are valid proxies for GHG emissions, as well. Fuel consumption is used e.g. by Kuo (2010) or Suzuki (2011) while energy minimization is pursued by e.g. Kramer et al. (2015) or Fukasawa et al. (2015). Minimizing GHG emissions is also referred to as pollution routing when speed optimization is included in the routing problem (see e.g. Bektaş and Laporte, 2011; Hvattum et al., 2013, or Dabia et al., 2016). For other types of emissions like nitrogen oxides, fine particles or noise, non-linear relations between an engine's energy output and emissions are prevalent, particularly for diesel engines (see e.g. Hausberger et al., 2009). Minimizing these types of emissions does not come along with minimizing energy or fuel consumption necessarily. In literature on green VRPs, this aspect has been neglected so far.

Furthermore some literature uses composite objectives. E.g. Tajik et al. (2014) use GHG emissions as one driver of total cost in addition to driver wages, fuel cost, and tardiness penalties. Likewise, Huang et al. (2017) calculates the total cost consisting of fuel and time-related cost.

Table 1
Literature overview on emission-oriented VRPs.

Reference	Problem type	Solution meth.	Load	Speed	Vehicle types	Path selection	Acceleration
Kara et al. (2007)	VRP	Exact	✓	–	–	–	–
Figliozzi (2010)	TDVRP	Heur.	–	✓	–	–	–
Kuo (2010)	TDVRP	Heur.	✓	✓	–	–	–
Suzuki (2011)	TSPTW	Heur.	✓	–	–	–	–
Bektaş and Laporte (2011)	VRPTW	Exact	✓	✓	–	–	–
Demir et al. (2011)	VRPTW	Heur.	✓	✓	–	–	–
Franceschetti et al. (2013)	TDVRPTW	Exact	✓	✓	–	–	–
Oberscheider et al. (2013)	VRPPDTW	Heur.	(✓)	(✓)	–	–	–
Hvattum et al. (2013)	SOP	Exact	–	✓	–	–	–
Kwon et al. (2013)	VRP	Heur.	✓	–	✓	–	–
Demir et al. (2014)	BOVRPTW	Heur.	✓	✓	–	–	–
Kopfer et al. (2014)	VRP	Exact	✓	–	✓	–	–
Tajik et al. (2014)	SVRPPDTW	Exact	✓	(✓)	✓	–	(✓)
Fukasawa et al. (2015)	VRP	Exact	✓	–	–	–	–
Kramer et al. (2015)	VRPTW	Heur.	✓	✓	–	–	–
Zachariadis et al. (2015)	VRPPD	Heur.	✓	–	–	–	–
Ehmke et al. (2016b)	TDVRP	Heur.	✓	(✓)	✓	✓	–
Fukasawa et al. (2016)	VRPTW	Exact	✓	✓	–	–	–
Dabia et al. (2016)	TDVRP	Exact	✓	✓	–	–	–
Huang et al. (2017)	STDVRP	Exact	✓	(✓)	–	✓	–
This work	VRP	Exact	✓	(✓)	✓	✓	(✓)

–: not considered for emission estimation.
(✓): considered but not decision relevant.
✓: considered and decision relevant.