Transportation Research Part D 47 (2016) 237–250

Contents lists available at ScienceDirect

Transportation Research Part D

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

Reducing carbon emission of pickup and delivery using integrated scheduling

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ARTICLE INFO

Article history:

Keywords:
Carbon emission reduction
Pickup and delivery
Set-partitioning
Integrated scheduling

ABSTRACT

Integrated scheduling is a powerful way to reduce carbon emission of pickup and delivery because the vehicle loading efficiency can be improved. Our study investigates theoretically the potential carbon emission reduction brought by integrated scheduling, and develops the upper and lower bounds. To demonstrate the practical advantage of carbon emission reduction brought by integrated scheduling, we use the real application of pickup and delivery, i.e., "picking up and delivering customers to airport" (PDCA). Using based-on-set-partitioning formulation, we accurately obtain the minimal carbon emissions of non-integrated scheduling and integrated scheduling. We conclude that integrated scheduling reduces carbon emission by approximate 10.8%. However, the cost in integrated scheduling may be more than before, which causes a company unwilling to accept integrated scheduling. The acceptable integrated scheduling is proposed. We identify the situations under which carbon emission can be efficiently reduced in acceptable integrated scheduling based on the extensive experiments of PDCA.

Introduction

Vehicles emissions contribute to various greenhouse gas. About more than 80% of air pollution in cities results from the transportation sector, according to the report of United Nations Economic and Social Council (United Nations Economic and Social Council, 2009). Therefore, the transportation sector is the largest consumer of petroleum products and is the chief culprit for air pollution worldwide (Wang et al., 2015; Fan and Lei, 2016). The growth of energy consumption in transportation is faster than any other sectors, due to the strong transport demands from economic development (Faris et al., 2011). More effective methods and measures therefore should be developed to reduce emissions of transportation sector (Choudhary and Gokhale, 2016).

So far, governments worldwide utilize many measures. These measures can be classified into the following categories: policy management, vehicle technology, low carbon fuels, driver's behaviors and routing optimization (Yu et al., 2014). In the aspect of policy management (Hammadou and Papaix, 2015; Grote et al., 2016; Wen and Eglese, 2016), governments encourage to increase vehicle size (Whitefoot and Skerlos, 2012), to utilize the carbon-based component in the vehicle taxes (Adamou et al., 2012), etc. In the aspect of vehicle technology, more and more low-carbon vehicles, such as electric vehicles

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http://dx.doi.org/10.1016/j.trd.2016.05.011
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or hybrids, were produced (Yao et al., 2011; Pollet et al., 2012; Bickert et al., 2015; Zhang and Yao, 2015). Also, various advanced devices were developed to reduce fuel consumption. These devices include shifting to a higher gear as soon as possible, anticipating traffic flow (Min et al., 2010, 2011), etc. In the aspect of driver's behaviors, carbon emission of vehicle can be reduced by keeping the vehicle in good maintenance, maintaining steady speeds, and accelerating and decelerating smoothly (Ma et al., 2015; J. Tang et al., 2015; T.Q. Tang et al., 2015). Good driver's behaviors can save about 5–15% carbon emission (Min et al., 2011; Evans, 1979; Wåhlberg, 2007). In the aspect of low carbon fuels, rigorous standards of low carbon fuel were executed (Cousins et al., 2007). In addition, natural gas and low carbon biofuels were used in vehicles to substitute petrol or diesel (Yeh, 2007; Leighty et al., 2012). Future fuels are expected to contain less than half the carbon intensity of current petrol and diesel. In the aspect of routing optimization, the optimal solution with the objectives of minimal distance or minimal cost may not be the optimal solution of lowest-carbon emission. Some lowest-carbon models of vehicle routing problem were established and solved by exact, heuristic or meta-heuristic algorithms (Miguel, 2011; Kuo and Wang, 2011; Xiao et al., 2012; Zhang et al., 2015; Li et al., 2015).

In addition, changing the operation mode is a powerful measure to reduce the carbon emission. For example, in pickup and delivery service, if several companies providing service are scheduled in an integrated mode to serve all customers, then the fuel consumption can be reduced because the integrated scheduling improves the vehicle loading efficiency.

Our study focuses on carbon emission reduction brought by integrated scheduling. Integrated scheduling for reducing operational cost in transportation sector has been studied (Shang and Cuff, 1996; Krajewska et al., 2008; Lin, 2008; Frisk et al., 2010). However, the studies on integrated scheduling for reducing carbon emission are sparse. The objective of the paper is to investigate theoretically the carbon emission reduction brought by integrated scheduling. We develop the upper and lower bounds for carbon emission reduction brought by integrated scheduling. To make each participant accept the integrated scheduling, we define the acceptable integrated scheduling. Acceptable integrated scheduling means that the total carbon emission is reduced and each company's operational cost is saved too.

Lowest-carbon PDCA and the based-on-set-partitioning model

Problem description of PDCA

The "picking up and delivering customers to the airport service" (PDCA) emerges in many cities in China (e.g., Beijing, Shanghai, Shenyang, Chengdu etc.) recently. With the PDCA, customers who bought the flight tickets have the rights to be picked up at his preferred time and position, and delivered to the airport within his specified deadline. Flight Ticket Sales Agencies (FTSAs) have earned the fruits from this service because of the significant increases of ticket sales. There are more than five FTSAs providing PDCA in Shenyang, such as Zhongshan, Shuntian, Jiantong, Huasheng, and Jiaxiang.

PDCA is a special case of Pickup and Delivery Problem with time windows (J. Tang et al., 2015; T.Q. Tang et al., 2015). In PDCA, the destination of all customers is airport. PDCA has the following distinctive characteristics:

(1) The capacity (Q) of the vehicles is small because the common used vehicles serving customers are cars (e.g., $Q = 4$).
(2) The customer's ride time is restricted. The total time that the passenger spends on the vehicle is subject to a maximum ride time (MRT_i) constraint, which is proportional to the direct ride time (DRT_i), the travel time from the origin to destination directly without deviation. We adopt the definition of MRT_i described by (Diana and Dessouky, 2004; Wong and Bell, 2006) as $MRT_i = a * DRT_i$, where a is the user-specified parameter (e.g., $a = 1.5$).
(3) It's unacceptable for customers to arrive in airport too early or too late. The time windows can be calculated by customer satisfaction degree in Eq. (1).

The satisfaction degree of customer point w (SD_w) is represent as the following piecewise linear function, and shown in Eq. (1) (Dong et al., 2011).

$$SD_w = \begin{cases} 1 & t_w \in [e_w, l_w] \\ \frac{E_w - t_w}{E_w - e_w} & t_w \in [E_w, e_w] \\ \frac{L_w - t_w}{L_w - l_w} & t_w \in [l_w, L_w] \\ 0 & t_w \notin [E_w, L_w] \end{cases} \tag{1}$$

Assume s is the given customer satisfaction degree. According to Eq. (1), the time window of customer point w can be calculated as $e_w^s \leqslant t_w \leqslant l_w^s$ (Dong et al., 2011).

These distinctive characteristics mean that the number of the all feasible trips of PDCA is small, and so we can use set-partitioning formulation to obtain the optimal solution.

Description of lowest-carbon emission of PDCA

A complete undirected graph $G = \{V, E\}$ is given, where V is the set of vertices and E is the set of edges. We have $V = \{0\} \cup W \cup \{d\}$, where vertex 0 represents the depot and W represents the set of customer points, each having q_w units of customers