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Time-dependent vehicle routing problem with path flexibility

Yixiao Huang[a], Lei Zhao[a,*], Tom Van Woensel[b], Jean-Philippe Gross[a]

[a] Department of Industrial Engineering, Tsinghua University, Beijing, 100084, China
[b] School of Industrial Engineering, Eindhoven University of Technology, Eindhoven, Netherlands

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ABSTRACT

Conventionally, vehicle routing problems are defined on a network in which the customer locations and arcs are given. Typically, these arcs somehow represent the distances or expected travel time derived from the underlying road network. When executed, the quality of the solutions obtained from the vehicle routing problem depends largely on the quality of the road network representation. This paper explicitly considers path selection in the road network as an integrated decision in the time-dependent vehicle routing problem, denoted as path flexibility (PF). This means that any arc between two customer nodes has multiple corresponding paths in the road network (geographical graph). Hence, the decisions to make are involving not only the routing decision but also the path selection decision depending upon the departure time at the customers and the congestion levels in the relevant road network. The corresponding routing problem is a time-dependent vehicle routing problem with path flexibility (TDVRP–PF). We formulate the TDVRP–PF models under deterministic and stochastic traffic conditions. We derive important insights, relationships, and solution structures. Based on a representative testbed of instances (inspired on the road network of Beijing), significant savings are obtained in terms of cost and fuel consumption, by explicitly considering path flexibility. Having both path flexibility and time-dependent travel time seems to be a good representation of a wide range of stochasticity and dynamics in the travel time, and path flexibility serves as a natural recourse under stochastic conditions. Exploiting this observation, we employ a Route-Path approximation method generating near-optimal solutions for the TDVRP–PF under stochastic traffic conditions.

1. Introduction

Urbanization has become a worldwide phenomenon during the past decades. Around 54% of the world's population live in cities in 2014 and this is expected to be 66% by 2050. Although in the most urbanized region, i.e., Northern America, 82% of the population live in urban area, only 40% and 48% of the population live in urban areas in Africa and Asia, respectively (United Nations, 2015). However, the rates of urbanization in Africa and Asia are faster than those of other regions, which results in more and more emerging mega-cities in these two regions, such as China and India.

Hand in hand with urbanization (Savelsbergh and Van Woensel, 2016), traffic congestion becomes one of the major challenges not only for commuters but also for logistics companies. For example, Beijing is ranked 15 among over 200 large

* Corresponding author.
E-mail address: lzhao@tsinghua.edu.cn (L. Zhao).

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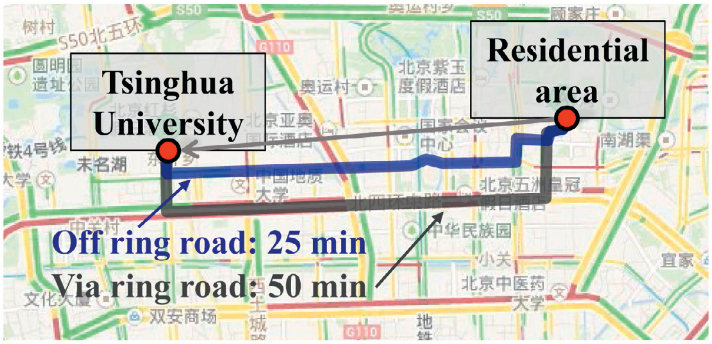
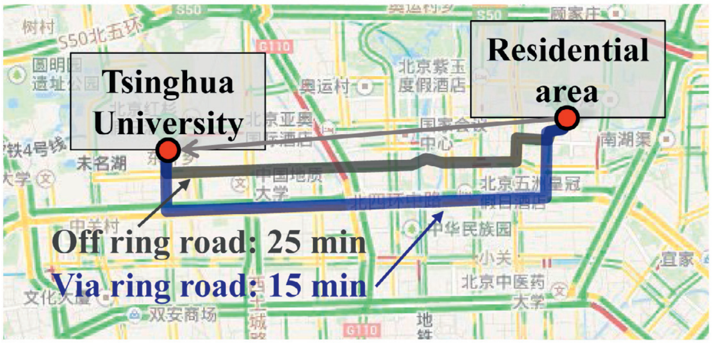


(a) Path off the ring road is faster at 07:30 am on a workday



(b) Path on the ring road is faster at 10:00 am on a workday

Fig. 1. Two popular morning commute paths from a residential area to Tsinghua University in Beijing, China.

cities (population > 800K) in the world, based on the overall congestion level in 2014 (TomTom, 2015). Congestion significantly increases the fuel consumption of vehicles, and therefore increases the cost of logistics companies. In 2011, the cost of delays on roads in the six largest capital cities in Australia is estimated to be around $13.7 billion (Infrastructure Australia, 2015). In China, fuel cost accounts for over 46% of the total operational cost for a logistics company (China Federation of Logistics & Purchasing, 2014).

First mile pickups and last mile deliveries, often modeled as a vehicle routing problem, are more and more situated in these congested urbanized regions. Vehicle routing problems are mostly defined on a customer-based graph. Arcs between these customers are assumed to adequately represent the distances or expected travel time. As such, the path used by a vehicle (in the road network) between a pair of customers is aggregated into the arc cost. When executed, the quality of the solutions obtained depends largely on the quality of this road network representation. Typically, in the literature (see e.g., Fleischmann et al., 2004; Gendreau et al., 2015; Ichoua et al., 2003; Jabali et al., 2012), this traffic dependency is modeled implicitly, resulting in time-dependent and/or stochastic travel time variants of the vehicle routing problem.

This paper takes an alternative approach and explicitly considers path selection in the road network as an integrated decision in the vehicle routing problem that minimizes the total cost, including fuel cost and vehicle depreciation cost. This means that any arc between two customer nodes has multiple corresponding paths in the road network (geographical graph). Hence, the decisions to make are involving not only the routing decision but also the path selection decision depending upon the departure time at the customers and the congestion levels in the relevant road network. We denote the path selection decision as path flexibility (PF). The corresponding routing problem is a time-dependent vehicle routing problem with path flexibility (TDVRP–PF). We formulate the TDVRP–PF models under deterministic and stochastic traffic conditions.

Consider the example given in Fig. 1, there are two typical path options, one via the 4th Ring Road (the lower path) and the other off the ring road (the upper path). Between these two paths, the faster path depends on the actual departure time and on the (spread of the) traffic congestion in the road network. Note that the congestion in the road network is also region-dependent. Consider the example in Fig. 2, where the colors of the roads represent the traffic conditions (green for free flow, yellow for medium congestion, and red for heavy congestion). Observe that the traffic conditions of the ring roads change significantly between peak and off-peak hours, while those of the roads within the 2nd ring remain almost unchanged. Jointly considering routing and path selection decisions makes it possible to explicitly consider the temporal and spatial differences of congestion in the road network.