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Dynamic Routing: Anticipation of Emission-Sensitive Traffic Management

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Abstract

Delivery companies are affected by emission-sensitive traffic management systems. These systems are installed in cities to react instantly to emission hot-spots through adapting traffic light programs at intersections. This results in a change of the travel times for the delivery vehicle. In this paper, we model the problem in a dynamic vehicle routing problem with stochastic transition of deterministic travel time matrices. To solve this problem, we apply approximate value iteration, a method of approximate dynamic programming, to anticipate future travel time matrix changes in dynamic routing decisions. We vary the approach in the level of information about the state of the traffic management system. This allows to distinguish the required information for the routing decisions. Further, we compare the dynamic and anticipatory routing policies with a static a priori routing. Computational studies show an improved tour duration of routing with traffic management information over the a priori routing by up to 6.5%. We further show that an efficient representation of the traffic management system status in the approximate value iteration approach is mandatory to achieve sufficient anticipation.

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Keywords: Vehicle Routing Problem; City Logistics; Emissions; Correlated Travel Times; Approximate Dynamic Programming

1. Introduction

Urbanization and the continuous growth of E-commerce have led to an increased freight traffic volume in cities (McCarthy and Knox 2005,Crainic et al. 2009). A majority of these freight volumes are transported as parcels by courier, express and parcel services (CEP). This is done in an transport chain and the last part is known as last mile deliveries (Gevaers et al. 2011). To fulfill these deliveries, CEP route vehicles in an urban environment to each customer.

To compete in the CEP market, an efficient transportation planning is necessary. This is especially challenging in cities due to the traffic uncertainties, like fluctuating travel times. The travel times vary because of commuter traffic load, congestion, or accidents. In cities, the main influence on traffic speeds are traffic lights at intersections (Brockfeld et al. 2001). Until recently, the intersection controller followed a static cycle without any consideration of the current

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traffic load or environmental pollution. Nowadays, it is possible to change the signal program dynamically during the day. This can be done either for a single intersection or within a coordinated approach for successively arranged intersections. The usage of the signal programs is controlled by a dynamic traffic management system (TM). The TM's objective is to enhance city mobility by controlling traffic flows. This is achieved by actions, e.g., changing the street capacities through adapting traffic light programs at intersections, activations of speed limits, variable message signs and dynamic lane control. The key performance indicator for traffic management systems is usually the total travel time of all vehicles on the city roads (Papageorgiou et al. 2003). However recently in Europe, city authorities are also required to monitor the nitrogen dioxide (NO_2) emission, because the EU regulation 2008/50/EC limits air pollution to 40 $\mu g/m^3$ of NO_2 in the yearly average in city areas. The air pollution, e.g., NO_2 and particular matter (PM_x), reduces the living and health quality for the city's residents. Therefore, an increasing number of cities use emission-sensitive TM to control traffic flows to avoid air pollution within the city. In Potsdam, Germany, such a system is already in operation. In Braunschweig, Germany, a system is planned and as of 2016 testing of different intersection signal programs is ongoing. Both systems use a set of dynamically changing traffic signal programs to restrict access to the polluted areas of the active hot-spots. However, inside the polluted areas, the main traffic flow direction receives longer and coordinated green light intervals to reduce stop and go behavior.

The NO_2-emissions depend not only on traffic volume, but also on weather conditions. The emission-levels are often uncertain and pollution may occur spontaneously. Still, NO_2-emissions often accumulate in certain areas of the cities, so called *hot-spots*. These hot-spots are continuously monitored by the city authorities with respect to the emission-levels. For each hot-spot, a coordinated plan with traffic influencing actions is developed. This plan is activated if the emission-level exceeds a certain NO_2 threshold value to reduce further pollution. The combination of all plans for all city's hot-spots is called a *traffic strategy* (Papageorgiou et al. 2003). Each traffic strategy is induced by a specific set of active hot-spots.

Traffic strategies significantly impact the travel speeds and therefore the travel times within cities. Travel times in some area are increased and decreased in other areas. This enables the depictions of *correlations* between the travel times of specific streets and street segments. For the CEP, this influences the delivery fleet's travel times significantly. Traversing a polluted area may result in an substantial increase in travel time and costs through prolonged driver working time and additional fuel consumption. Therefore, it may be beneficial to react to realized traffic strategy changes and to anticipate potential future changes based on the current emission levels.

In this paper, we look at the effect a dynamic traffic management system has on the tour planning of a CEP delivery company as this has not been discussed in literature. Therefore, we model a vehicle routing problem that can be described as *dynamic vehicle routing problem with stochastic travel time matrix changes* (DVRPMC). During the day, the strategies, i.e., the travel time matrices change with respect to the emission-levels. Nevertheless, the travel times of the individual matrices are deterministic and only the transitions between the matrices are stochastic. A vehicle serves a set of known customers over the course of a day. The objective is to find a decision policy that minimizes the expected overall travel time. To anticipate future strategy changes, we apply approximate value iteration (AVI), a method of approximate dynamic programming (ADP, Powell 2011). AVI subsequently simulates problem realizations and adapts decision making with respect to the simulations' outcome. We compare an optimal static *a priori* routing solution and three variations of the AVI routing algorithm. The three variations are distinguished by three different information settings that could be acquired by the CEP from a traffic management system. We analyze the approaches for different instance settings with a varying impact of the traffic strategy. Results show that dynamic routing is beneficial compared to static *a priori* routing and that the consideration of TM statuses generally improves solution quality.

2. Literature review

In this section, we give an overview of the related literature. We focus on vehicle routing for emission reduction, vehicle routing with varying travel times, and on ADP for dynamic vehicle routing problems.

Green vehicle routing or pollution routing is an upcoming research field of vehicle routing problems. The goal is to minimize the gas house emissions of vehicles either by optimizing driving speeds (Bektaş and Laporte 2011) or route planning (Ehmke et al. 2016, Figliozzi 2010). These problems differ compared to the DVRPMC. In our case, the