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A general approach for controlling vehicle en-route diversions in dynamic vehicle routing problems

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ABSTRACT

Previous research has shown that vehicle en-route diversion can improve the efficiency of dynamic vehicle routing processes. However, an uncontrolled utilization of en-route diversions may increase demands on drivers and cause distraction. This is likely to result in more accidents or reduced productivity which generates additional costs. Since the benefits to the solution quality make a prohibition of en-route diversions unattractive, we propose a general penalty cost based approach for controlling diversions. In contrast to known approaches that allow all diversions, the proposed approach also considers negative application-dependent consequences of diversions on drivers. The approach limits diversions to those which improve the solution quality above a customizable and application-dependent threshold that estimates their negative consequences. We evaluate the proposed general approach by applying it on an exemplary basis to recent deterministic and pro-active real-time routing approaches. Computational experiments show the impact of different penalty cost values on the resulting number of diversions as well as on the attained solution quality. Based on these results, we derive reasonable application-dependent penalty cost values for considering both the contradicting aims of quick request delivery and reducing diversions to a desired extent.

1. Introduction

In dynamic vehicle routing problems (DVRPs), a vehicle en-route diversion (or, in short, a diversion) describes a situation where a vehicle is currently traveling to a request location when another request, which is to be serviced next, is assigned to the vehicle by a dispatching center. This is possible due to advances in communication technology that allow for locating vehicles in real-time as well as sending new commands to the drivers using appropriate on-board units (Giaglis et al., 2004; Larsen et al., 2008). If a new event happens during the transportation process, changing a vehicle's next request is beneficial in many situations. For instance, if a new request arrives close to the remaining route taken by a vehicle when traveling to a request, a diversion can redirect the vehicle to the new request first. Thus, diversion allows ongoing travel activities to be adapted, which increases flexibility. In what follows, we focus on DVRPs in which new requests arrive over the day. For other types of information changes in DVRPs, see Ferrucci (2013, pp. 59–60).

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1.1. Literature review

DVRPs have been a vital research area for decades. A variety of aspects is addressed by numerous approaches (for a recent survey, see Pillac et al., 2013). Early research on diversion in dynamic routing applications can be found in Regan et al. (1995, 1998). These studies investigate diversion strategies that yield positive results on the system performance in truckload routing applications. Besides these studies, diversion is only considered in a few other approaches. Ichoua et al. (2000) considers a long-haul courier service application. The objective is to minimize a weighted sum of travel distance and lateness at customer locations. In order to enable diversion, a variant of the real-time routing approach of Gendreau et al. (1999) is applied. Computational results show that diversion can significantly improve the solution quality. Richter (2005) examines a dynamic traveling salesman problem (DTSP) as well as a DVRP. Scenarios with 50–200 customer requests and with a degree of dynamism between 20% and 80% are evaluated. According to Larsen et al. (2002), the degree of dynamism measures what percentage of requests arrive during the execution of the transportation process. Two objective functions aiming at minimizing travel distance as well as customer waiting times are evaluated. Richter concludes that if the minimization of customer waiting time is pursued, diversion significantly improves the solution quality on the tested DTSP. In Attanasio et al. (2007), a real-time management system that uses diversion for coordinating a fleet of same-day urban couriers is presented. The objective is to maximize the quality of customer service and the average number of serviced customers per courier. While providing no computational results, the authors mention that the use of the system has increased the quality of service as well as courier efficiency. Branchini et al. (2009) consider a DVRP with soft time window constraints. The authors generate test instances with a degree of dynamism between 60% and 80% and evaluate different routing approaches. Computational results show that approaches which make use of diversion perform best among the tested concepts. In the work of van de Klundert and Wormer (2010), the authors consider a real-world application which they denote as the After Salesman Problem. The primary objective is minimize the average waiting time of dynamically arriving customers. Computational results indicate that in heavy traffic scenarios, diversion improves the solution quality by over 20%. The works of Respen et al. (2014a,b) analyze the impact of tracking devices in dynamic routing problems if new requests as well as changing travel times are considered. The authors suggest tracking and evaluating vehicle positions permanently so that diversions can be used for direct and effective adaptation of the transportation process.

Another important aspect of real-time routing approaches is the simultaneity of plan adaptation and plan execution activities. As Goel (2007, p. 42) points out, performing a diversion should not be based on the current vehicles' position but rather on anticipated ones in future. However, although this is a prerequisite for approaches modifying complex transportation services in real-time, procedures for anticipating future positions and fixing decisions occurring within a specified time horizon are rare (see Ichoua et al., 2000; Bent and van Hentenryck, 2004; Ferrucci et al., 2013).

In general, DVRPs are specific variants of the standardized static VRP which is known to be strongly NP-hard (cf. Lenstra and Rinnooy Kan, 1981). Due to limits on computation time in DVRPs, heuristic solution methods are often applied. As mentioned in Pillac et al. (2013), there are deterministic and pro-active (stochastic) solution approaches for DVRPs. Among pro-active solution approaches are approaches where stochastic knowledge is generated from a given probability distribution (see, e.g., van Hemert and La Poutré (2004), Ichoua et al. (2006), Bent and van Hentenryck (2007), Hvattum et al. (2007), Thomas (2007), and Ghiani et al. (2012)) or where request arrival probabilities have to be generated from past request data (Ferrucci et al., 2013). Besides DVRPs, many approaches have been proposed for other dynamic routing variants, such as the dynamic pickup and delivery problem (DPDP) or the dynamic dial-a-ride problem (DDARP) (see, e.g., Mitrovic-Minic et al. (2004), Mitrovic-Minic and Laporte (2004), Fabri and Recht (2006), Ghiani et al. (2009), Ferrucci and Bock (2014), and Hosni et al. (2014)).

All described diversion approaches assume that diversions do not cause any negative consequences. Since diversions are integrated as a flexibility-increasing measure that is available without causing any drawbacks, frequent use of diversion is often proposed. However, this does not necessarily apply to real-world applications. Despite the aforementioned positive effects, frequent diversions are likely to lead to serious drawbacks. Apart from technical equipment required for establishing communication between drivers and the dispatching center, the route to the next request has to be replanned when the vehicle is diverted. This can be a challenging task for drivers depending on whether or not the vehicles have navigation systems. A diversion also often requires a driver to react fast during his journey. Hence, visual and cognitive distractions increase demands on drivers. As shown, for instance, by Owens et al. (2010) and Kaber et al. (2012), distractions increase driver workload and lead to longer and more frequent off-road glances. As a result, the driver is increasingly distracted from the roadway which is one of the main causes of driver errors that contribute to accidents (Governors Highway Safety Association, 2011; Young and Salmon, 2012; Young et al., 2013; Stavrinos et al., 2013) and, therefore, reduce the safety and efficiency of the transportation processes. Placing high demands on drivers is also likely to result in increased psychological job strain that may cause decreased motivation and more staff to quit their job (By de Croon et al., 2004). This means that there are frequent changes in staff. The new drivers are often inexperienced and not familiar with the transportation process. Hence, cost decreasing experience curve effects (see Yelle (1979)), that can be attained only if staff becomes experienced over time, are reduced which further lowers the overall efficiency of the transportation process. The mentioned setbacks might make it impossible to implement the advantages of frequently applied diversions. On the other hand, a complete prohibition of diversion is not reasonable since diversion also lead to significant benefits. Approaches that consider this trade-off, i.e., allow for an efficient control of diversions, are reasonable.