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Real-time control of express pickup and delivery processes in a dynamic environment

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ABSTRACT

In this paper we introduce the Dynamic Pickup and Delivery Problem with Real-Time Control (DPDPRC) in order to map urgent real-world transportation services. Specifically, the DPDPRC considers intra-day transportation services of express courier service companies and integrates real-world aspects that are crucial for a practical application. Vehicles have heterogeneous properties and operate on a detailed real road network. Various dynamic events that may occur unexpectedly during the day, such as new request arrivals, traffic congestion, and vehicle disturbances, are integrated. Because of the mentioned urgency, minimizing lateness at request locations is the primary objective. As a secondary objective, the minimization of vehicle operating costs is pursued. In order to adapt the transportation plan in response to dynamic events and enable a timely service of requests, a real-time control approach that performs plan adaptations simultaneous to the execution of the transportation service is applied. Plan adaptations are carried out by a Tabu Search algorithm whose search process is guided by a multi-stage neighborhood operator selection scheme which dynamically switches between intensification and diversification phases. We evaluate various test scenarios which comprise different occurrences of the dynamic events. Computational results show that a continuous adaptation of the transportation plan according to dynamic events improves the solution quality in many scenarios.

1. Introduction

Daily transportation services of express courier service companies are characterized by a highly dynamic environment in which the system situation frequently changes by the occurrence of various *dynamic events*. A key characteristic is that dynamically arriving requests have to be transported from pickup locations to delivery locations on the same day. Since it is highly desired that requests are fulfilled within given time windows, transportation activities are often carried out under high time pressure. Moreover, road networks are frequently congested and unreliable. Consequently, besides the arrival of new requests, traffic congestion and vehicle disturbances, i.e., slowdowns and breakdowns, have to be managed in real-time. Thanks to advances in information and communication technologies, information about dynamic events which is only available during the execution of the transportation service can now be utilized (Larsen, 2000, p. 12 et seq.; Giaglis et al., 2004).

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1.1. Contributions

In this paper, we propose a new real-time control approach for efficiently coordinating dynamic transportation services of express courier service companies. In order to provide practical decision support, this approach is based on an extended Dynamic Pickup and Delivery Problem (DPDP) that integrates various sources of dynamic events as well as several real-world aspects. We denote this new variant as the *Dynamic Pickup and Delivery Problem with Real-Time Control* (DPDPRC). It is specifically designed in order to efficiently control urgent real-world transportation services which are executed by express courier service companies. The main contributions of this paper are:

- **Consideration of various real-world aspects.** The DPDPRC extends the DPDP by considering realistic aspects that are typical of the considered transportation services. Vehicles are heterogeneous in terms of capacity, personnel costs, travel speed, and route-dependent travel costs. Soft request time windows with variable lateness costs are integrated as well as legal driving time restrictions. The primary objective is to minimize lateness at request locations and the secondary objective is to minimize vehicle operating costs. Moreover, vehicles travel on a detailed real road network.
- **Dynamic environment comprising various types of dynamic events.** Besides newly incoming requests, further dynamic events such as traffic congestion, vehicle slowdowns as well as vehicle breakdowns are integrated. The integration of these sources of dynamic events, which are common in real-world transportation services, ensures the practical applicability of the DPDPRC.
- **Real-time control and appropriate solution method.** In the DPDPRC, transportation services are coordinated by a real-time control approach that handles the concurrency of tour plan execution and tour plan adaptation. In order to efficiently adapt the existing transportation plan according to the consequences of occurring dynamic events, a specifically designed Tabu Search approach is applied. Due to the resulting extended adaptability, many challenging scenarios with tight time windows and a large number of different types of dynamic events can be efficiently handled.
- **Generation of appropriate test instances.** In order to evaluate the efficiency and practicability of the proposed approaches under different possible situations, various test scenarios with different types of dynamic events are generated. For this purpose, we propose new methods for generating problem instances of desired complexity. Furthermore, a new approach for simulating traffic congestion in road networks is introduced.

The practicability of the proposed real-time control approach is evaluated by means of a comprehensive computational study.

1.2. Literature review

The considered transportation services can be modeled as a variant of the Pickup and Delivery Problem (PDP) which is a generalization of the well-studied Vehicle Routing Problem (VRP, see Toth and Vigo, 2002; Golden et al., 2008) and a special case of the General Pickup and Delivery Problem (GPDP, see Savelsbergh and Sol, 1995). Variants of PDPs have become a vital research area because of their practical relevance. A closely related problem that focuses on passenger transportation is the Dial-a-Ride Problem (DARP, see Cordeau and Laporte, 2007; Cordeau et al., 2007; Paquette et al., 2013; Kirchler and Wolfler Calvo, 2013). In the DARP, additional driving constraints and convenience objectives are considered.

In the literature, approaches for static PDPs are distinguished from dynamic concepts. In approaches for static PDPs it is assumed that the problem data is known in advance with certainty (see, e.g., Nanry and Wesley Barnes, 2000; Lu and Dessouky, 2004; Bard and Jarrah, 2009). Hence, on account of the absence of dynamic events, no plan adaptation is necessary during the execution of the transportation service. In contrast, real-time concepts can handle unexpected changes of the system situation caused by dynamic events (see Ghiani et al., 2003; Mitrovic-Minic et al., 2004; Mitrovic-Minic and Laporte, 2004; Fabri and Recht, 2006). With regard to the focus of this paper, only real-time approaches are described in what follows. An overview about dynamic PDPs can be found in Berbeglia et al. (2010).

Powell (1988) considers a truckload DPDP. He gives an overview of different techniques for modeling the problem in the single and multiple vehicle variant and presents different deterministic and stochastic model formulations. Swihart and Papastavrou (1999) study a single-vehicle DPDP with newly arriving requests using analytical methods. The authors derive new bounds for the system performance in light and heavy traffic situations and evaluate different dispatching policies. Fleischmann et al. (2004) study an urban truckload DPDP with soft time windows in which dynamic events arise from newly incoming requests as well as changes in travel times. The transportation service is carried out on a real road network and the objective function pursues the minimization of request lateness and transportation costs. Different solution methods are evaluated. In Yang et al. (2004), a multi-vehicle truckload DPDP with soft time windows in which dynamically arriving requests have to be serviced is considered. Requests can be rejected at additional costs. The objective is to maximize the total profit resulting from request profits, penalties, lateness, and travel costs. Different policies are evaluated and it is shown that reoptimization approaches outperform other policy-based solution approaches. Pankratz (2004) considers a DPDPTW for long-distance freight forwarding with newly arriving requests. A solution approach based on a genetic algorithm is proposed. In Attanasio et al. (2007), a real-time system for coordinating a DPDP with dynamically arriving requests and uncertain travel times is presented. The objective is to maximize the quality of customer service and the average number of serviced customers per courier. The authors state that the proposed system has increased the quality of service. Sáez et al. (2008) develop a