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Pro-active real-time routing in applications with multiple request patterns

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ABSTRACT

Recent research reveals that pro-active real-time routing approaches that use stochastic knowledge about future requests can significantly improve solution quality compared to approaches that simply integrate new requests upon arrival. Many of these approaches assume that request arrivals on different days follow an identical pattern. Thus, they define and apply a single profile of past request days to anticipate future request arrivals. In many real-world applications, however, different days may follow different patterns. Moreover, the pattern of the current day may not be known beforehand, and may need to be identified in real-time during the day. In such cases, applying approaches that use a single profile is not promising. In this paper, we propose a new pro-active real-time routing approach that applies multiple profiles. These profiles are generated by grouping together days with a similar pattern of request arrivals. For each combination of identified profiles, stochastic knowledge about future request arrivals is derived in an offline step. During the day, the approach repeatedly evaluates characteristics of request arrivals and selects a suitable combination of profiles. The performance of the new approach is evaluated in computational experiments in direct comparison with a previous approach that applies only a single profile. Computational results show that the proposed approach significantly outperforms the previous one. We analyze further potential for improvement by comparing the approach with an omniscient variant that knows the actual pattern in advance. Based on the results, managerial implications that allow for a practical application of the new approach are provided.

1. Introduction

Dynamic vehicle routing problems (DVRPs, see Psaraftis, 1988; Ghiani, Guerriero, Laporte, & Musmanno, 2003; Eksioglu, Vural, & Reisman, 2009; Pillac, Gendreau, Guéret, & Medaglia, 2013) are vehicle routing problems (VRP, see Toth & Vigo, 2002; Golden, Raghavan, & Wasil, 2008) in which some information is only revealed during the day (see Larsen, Madsen, & Solomon, 2002, 2007). Such information can be new customer requests (for short, requests), vehicle disturbances, or traffic incidents (see Ferrucci, 2013, pp. 59–60). Due to such information changes, the tour plan (for short, the plan) has to be adapted during its execution. In this paper, we focus on new request arrivals.

In the literature, many DVRP approaches that integrate new requests upon arrival can be found (see for example Savelsbergh & Sol, 1998; Gendreau, Guertin, Potvin, & Taillard, 1999; Ichoua, Gendreau, & Potvin, 2000; Ghiani et al., 2003; Giaglis, Minis, Tatarakis, & Zeimpekis, 2004). It has also been shown that using *stochastic knowledge* about expected future requests allows for considerable improvements in DVRPs (for an overview of corresponding approaches for other routing problems, see Ferrucci (2013, pp. 108–137)). Bertsimas and van Ryzin (1993) study effects of different vehicle dispatching policies on the solution quality. Bent and van Hentenryck (2004b) introduce a sampling-based approach that is extended in Bent and van Hentenryck (2004a, 2004c, 2005, 2007). Further information is provided in van Hentenryck and Bent (2009). In van Hemert and La Poutré (2004), vehicles are relocated to fruitful regions where requests are expected to arrive. Ichoua, Gendreau, and Potvin (2006) extend the approach of Gendreau et al. (1999) so that a vehicle waits at the location of its last request if the probability of new, nearby requests is high. Hvattum, Løkketangen, and Laporte (2006) propose a sample scenario hedging heuristic that uses stochastic knowledge about future requests. In Hvattum, Løkketangen, and Laporte (2007), the authors improve this heuristic by integrating it into a branch-and-regret heuristic. Branchini, Vinícius, and Løkketangen (2009)

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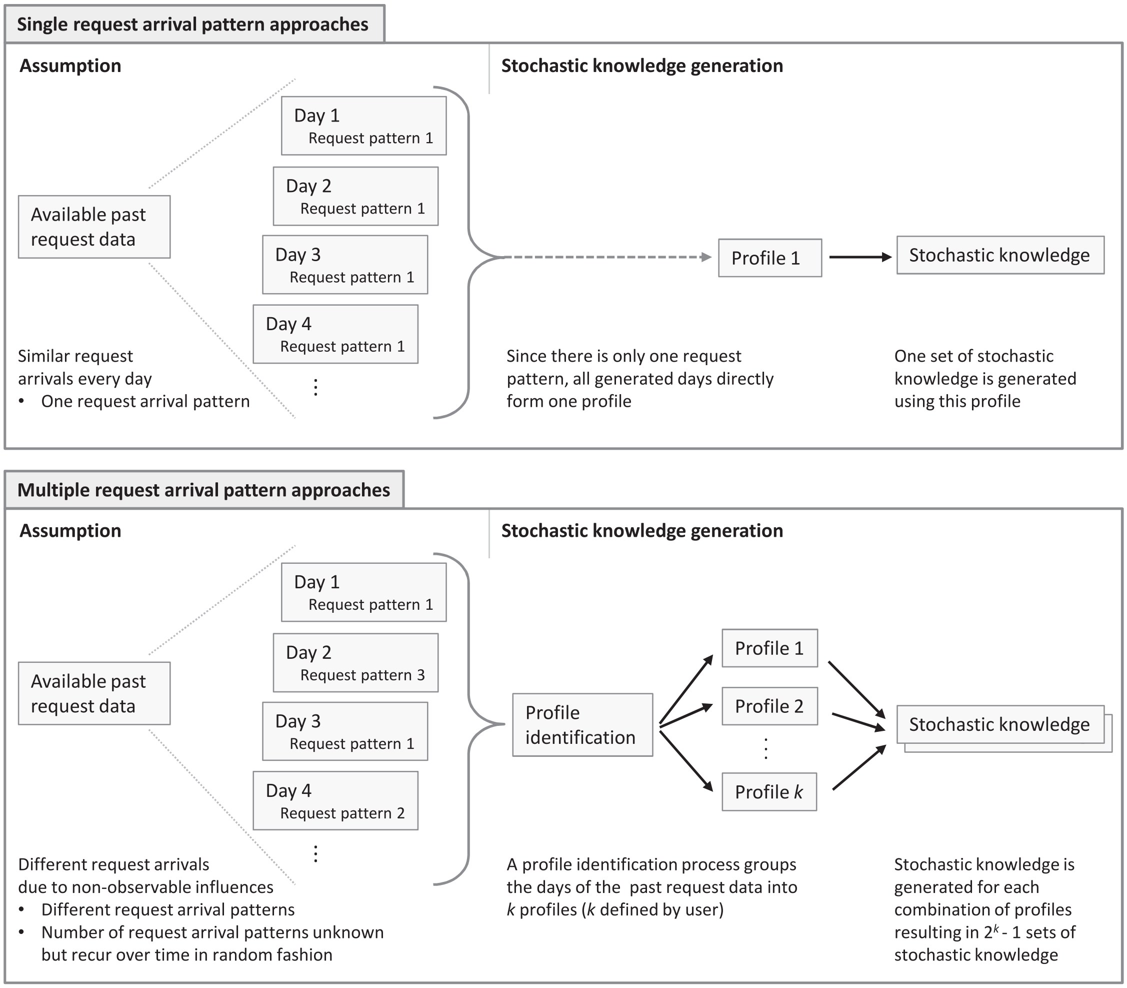

Fig. 1. Comparison of single and multiple request arrival pattern approaches.

derive strategic waiting positions based on historical data. Kleywegt, Savelsbergh, and Uyar (2009) analyze a multi-period routing problem and use stochastic knowledge in order to decide about request to period assignments. Ferrucci, Bock, and Gendreau (2013) propose an approach that generates stochastic knowledge from past request data and guides vehicles to request-likely areas when requests are expected there.

All these approaches assume that request arrivals on different days follow an identical request pattern (for short, *pattern*). In this paper, the term pattern refers to the spatial and temporal structure of request arrivals throughout a day. Since this structure (i.e., the pattern itself) is unknown, it is estimated by stochastic knowledge. As a result, a so-called *profile* is derived from request data of past days or from assumed distributions. By selecting a set of past days that are assumed to be representative of the spatial and temporal structure of incoming requests, a profile with a specific request arrival structure is generated from these days. All approaches in the literature assume that stochastic knowledge about future request arrivals can be derived by a *single profile* that adequately maps the existing pattern (see Fig. 1). Although this profile can map scenarios where request arrival probabilities change spatially and temporally during the day, it is assumed that the same profile is applicable every day. This assumption does not always apply to real-world routing processes. When past request arrivals of many real-world routing processes are analyzed, it can be observed that in each of these processes there are days which seem to follow different patterns. As a consequence, modeling these processes by a single profile may substantially reduce the quality of stochastic knowledge that can be derived. Unfortunately, request arrival patterns in real-world routing processes often depend on various external factors that are unknown or unmeasurable. Hence, it is often impossible to determine an adequate profile which can reliably model future request arrivals of the current day in advance. Thus, a suitable profile or a combination of profiles has to be identified in real-time during the execution of the ongoing transportation process.

In this paper, we propose a pro-active real-time routing approach for DVRPs that can deal with *multiple profiles* (see Fig. 1). This paper substantially extends the single profile approach of Ferrucci et al. (2013) by making the following contributions:

- **Automatic identification of profiles.** In an offline step, the approach identifies k profiles by applying a k-means algorithm that analyzes available past request data. In order to provide well-defined information for grouping past days into profiles, we propose a distance measure that reflects differences in spatial and temporal request arrivals.
- **Stochastic knowledge generation.** Based on the identified profiles, the approach generates appropriate stochastic knowledge for all combinations of identified profiles in a second offline step.
- **Real-time profile identification and dynamic knowledge adaptation.** During the day, request arrivals are analyzed. Using the proposed distance measure, profiles that match the current day are identified and appropriate stochastic