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Pickup and delivery routing with hub transshipment across flexible time periods for improving dual objectives on workload and waiting time

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ABSTRACT

In contrast to developing routing algorithms, operational policy design of courier services is addressed in this paper with the objective of reducing both courier workload and customer waiting time. A square root law of tour length is verified, extending the literature. A new policy of hub transshipment across flexible time periods is evaluated by mean-value analysis of stochastic routing. Boundary conditions on arrival rate, territory size and transshipment probability in which the new policy outperforms a traditional periodical routing policy are derived. Finally, the effectiveness of the new policy is demonstrated by applying to a large hospital case.

1. Introduction

Pickup and delivery (P&D) routing problems have been widely studied in ambulance service, courier service and transportation logistics. In most problem settings, their mathematical programming models take into consideration the constraints of vehicle capacity, tour time, waiting time, time window, and precedence relation. Routing decisions typically include clustering of customers, customer-vehicle assignment, and P&D sequencing. More sophisticated models allow for transshipment, which permits a customer to be picked up by one vehicle and transshipped to another vehicle. For the P&D routing problems and their modeling, a few survey papers have been published (Berbeglia et al., 2007, 2010; Cordeau et al., 2008; Parragh et al., 2008). Most research efforts have been devoted to developing solution algorithms and metaheuristics, given that routing problems are NP-hard. The objective is either to achieve responsive service or lean capacity reserve, or to find best tradeoffs between them.

P&D routing models can be classified as either static or dynamic, depending on the availability of job information at the time of routing planning. In static models, a set of P&D jobs is given as input. In dynamic models, jobs continue to arrive even after the P&D service has commenced. Therefore, static models are used for a single period of finite duration and dynamic models are used for one continuous time period. There has been very little study on multi-period routing problems. In papers which incorporate multiple periods, routing decisions span multiple time periods because jobs are either postponable

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(Angelelli et al., 2009) or have extended deadline (Wen et al., 2010). In this paper, a courier routing problem of multiple time periods of flexible length with transshipment between time periods is addressed. The problem arises in a courier service problem of a large hospital. We will next describe the service problem before presenting relevant literature survey.

The hospital that we studied is a full-service hospital with 24 clinical departments and more than 200 clinical rooms in a sprawling campus. More than eight thousand patients visit the hospital per day on average. After visiting a particular clinic, some patients are referred to other departments for further diagnosis or treatment. Before a patient can be examined by a second physician, some medical materials of the patient must be transported to the second clinical department through a courier service. Because of inefficiency in P&D services, patients sometimes have to wait at the second department for their materials to be delivered. Patient waiting time is considered an important quality measure but because the hospital campus is very large there are frequent cases of excessive waiting by patients. Because the number of couriers is constrained, the challenge is to improve patient waiting time by designing creative routing solutions without increasing the courier staff. This problem has four characteristics: (1) large service territory, (2) uncertain P&D locations, (3) limited resource of couriers and (4) dual objectives on patient waiting time and courier utilization. In routing problems, as in many other problems, multiple objectives are inherently difficult to achieve. We approach this problem by redesigning operational policy. The following literature review will focus on salient characteristics and innovative policy design for the P&D routing problems.

We use the term operational design to refer to decision-making on operational policy or strategy. It is a task that precedes the development of routing algorithms. Akin to operational design is the task of designing control policy, which is intensively studied in dynamic routing. We will use the words requests, jobs and demands interchangeably to refer to customer requests of P&D services.

There are two solution approaches to dynamic P&D routing problems (Berbeglia et al., 2010). The first approach is to solve a static problem each time a new request arrives. The second approach is to solve a static problem at the beginning to obtain an initial solution and then, with each new request, to revise the tour by using heuristics of inserting and rearranging route segments. Because job arrivals are uncertain, associated with the issue of routing is the decision of vehicle prepositioning in anticipation of future arrivals. In the dynamic environment, the most prominent strategy is related to that of waiting. Mitrovic-Minic and Laporte (2004) compared three waiting strategies with the drive-first strategy based on predetermined P&D routes. With the drive-first strategy, a vehicle will depart for the next service from its current location at the earliest possible time. In contrast, the wait-first strategy will require the vehicle to depart at the latest possible time. The other two waiting strategies are variations of the wait-first strategy. The dynamic waiting strategy calls for adopting the drive-first strategy within a service zone but switching to the wait-first strategy for jobs across service zones. The last strategy is an advanced modification of the dynamic waiting strategy. An upper limit is imposed on the time that the vehicle is allowed to wait. Their simulation study showed that the three waiting strategies outperform the drive-first strategy on tour length in most cases and that the advanced dynamic waiting strategy seems to be the most promising.

Pureza and Laporte (2008) evaluated the effect of a waiting strategy and a request buffering strategy in dynamic P&D problems with time window constraints and uncertain travel time between each pair of locations. Both strategies are postponement strategies. While the waiting strategy is a policy that delays the assignment of vehicles to their next service destination, the buffering strategy is a policy for aggregating non-urgent requests before they are served in a continuous subtour. Three quality measures were used: the number of lost requests, the number of routes and total travel distance. Their simulation results demonstrate the advantage of the two strategies over the traditional drive-first strategy.

Transshipment provides opportunities for multiple vehicles to collaborate in P&D services. By adding flexibility to routing, it has positive effects on reducing the waiting time of the customers and the travel cost of the vehicles (Cruijssen et al., 2007). Nakao and Nagamochi (2008) did a worst case analysis of the maximum travel cost that can be saved when a transshipment point is introduced. They showed that the bounds are in proportion to the square root of the number of routes and the square root of the number of requests. Cortés et al. (2010) developed detailed mathematical formulations and a branch-and-cut algorithm based on Benders decomposition for the P&D problem with transshipment. They compared the computational efficiency of their algorithm with a straight branch and bound algorithm. By experimenting with small problem instances, they concluded that there exist some configurations in which transshipment can be more profitable and they further conjectured that transshipment would be effective under high demand conditions. Mitrovic-Minic and Laporte (2006) applied and evaluated the policy of transshipment on a P&D problem with time window constraints. By using heuristics and simulation with stylized data, they showed that the policy reduces the total travel distance when requests are uniformly generated in the plane. The benefit is more significant when the problem size is large and requests are clustered. In another application with stylized data, Lin (2008) evaluated the benefits of transshipment in local courier service of a multi-national logistics firm. Each request has a pickup time window and a delivery deadline at the depot. The objective is to minimize the sum of fixed and operation costs of courier service. The flexibility of transshipment leads to a cost savings of approximately 10–20%, depending on operation modes.

Information about future arrivals can be exploited to improve routing decisions (Haughton, 2008). Sáez et al. (2009) developed an adaptive control framework to model the dynamic P&D problem by using a predictive state-space representation for vehicle load and departure time. The merit of their modeling approach was validated by using a particle swarm optimization algorithm through a simulated numerical example. Mes et al. (2010) used a pricing and auction mechanism to solve the P&D problem with time window constraints in a multi-agent system. Individual vehicles bid on new jobs in a second-price auction. Both the direct cost of inserting a job and its impact on future opportunity cost are considered. Simulation was used to evaluate the benefits of pricing opportunities compared to simple pricing strategies in various