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Discrete Optimization

A priori orienteering with time windows and stochastic wait times at customers



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ABSTRACT

In the pharmaceutical industry, sales representatives visit doctors to inform them of their products and encourage them to become an active prescriber. On a daily basis, pharmaceutical sales representatives must decide which doctors to visit and the order to visit them. This situation motivates a problem we more generally refer to as a stochastic orienteering problem with time windows (SOPTW), in which a time window is associated with each customer and an uncertain wait time at a customer results from a queue of competing sales representatives. We develop a priori routes with the objective of maximizing expected sales. We operationalize the sales representative's execution of the a priori route with relevant recourse actions and derive an analytical formula to compute the expected sales from an a priori tour. We tailor a variable neighborhood search heuristic to solve the problem. We demonstrate the value of modeling uncertainty by comparing the solutions to our model to solutions of a deterministic version using expected values of the associated random variables. We also compute an empirical upper bound on our solutions by solving deterministic instances corresponding to perfect information.

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1. Introduction

The pharmaceutical sales force has experienced a sizable reduction in recent years that is likely to continue. By the end of 2011, the number of pharmaceutical sales jobs in the US dropped to 72,000 from its peak of 105,000 in 2006 (Rockoff, 2012). In 2012, Britain's second largest drugmaker, AstraZeneca, is cutting 1150 sales representatives in its US organizations, which is 24% of its sales force in the US (Arnold, 2012). Pharmaceutical companies have tried to compensate for the reduced sales force through the use of digital tools like websites and smartphone apps that allow doctors to directly query the company. However, sales representatives are not totally replaceable as they provide the means to develop relationships with customers that may otherwise go unreached. Dealing with a reduced number of sales representatives, pharmaceutical companies face the challenge of better managing their reduced sales forces to maximize their benefit to the company.

On a daily basis, pharmaceutical sales representatives must determine a daily schedule specifying which doctors to visit and the order to visit them in order to maximize potential sales. In

general, a doctor's accessibility to a sales representative is limited. Typically, the doctor specifies a time window during which she will meet representatives in between other work obligations (seeing patients, paperwork, etc.). We assume that the doctor meets with the representatives following a first-come-first-served protocol within the time window. To talk with a doctor, a representative must arrive at the doctor's office before the closure of the doctor's time window. However, after arriving, the representative may have to wait while the doctor attends to work obligations or meets with another representative. The time that doctors spend in with other work obligations is uncertain, while the duration of a meeting between a doctor and a representative is typically limited. In fact, representatives develop well-rehearsed sales pitches that fit within their brief time allocation. Thus, we assume that the meeting duration is known and constant while the time that a representative spends waiting to meet with a doctor is uncertain. This daily decision-making problem faced by pharmaceutical sales representatives is shared by other industries such as the textbook industry. Therefore, we more generally refer to this problem as a stochastic orienteering problem with time windows (SOPTW), in which a time window is associated with each customer and a uncertain wait time occurs at each customer.

We model the wait time faced by the representative as a random variable dependent on the arrival time and the queue length (of other representatives) upon arrival. In turn, we model queue

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length as a random variable dependent on the arrival time at the doctor's office. We associate a deterministic economic value with each doctor representing the expected sales to the doctor if the representative meets with the doctor that day. In this paper, our objective is to construct an a priori route for the representative that maximizes the expected value collected on a given day. An a priori route is a pre-planned order of visits to customers (see [Campbell & Thomas \(2008\)](#) for an overview). That is, we seek to construct a static sequence of customers (doctors) that maximizes the expected value collected. A priori tours are usually used as subproblems in dynamic solution approaches (see [Goodson, Ohlmann, & Thomas, 2013](#)).

During the execution of an a priori route, after a random event is realized, a corrective action, often called a recourse action, may be required. In our treatment of the SOPTW, we consider two types of recourse actions, both of which preserve the route's ordering of the visited customers. The first recourse action is motivated by the observation that a representative should skip a customer specified by an a priori route if she will not arrive within the customer's time window. With the assumption of deterministic travel times, the representative can determine whether or not she can arrive at the next customer on the route within the respective time window given the departure time from the current customer. That is, the next customer visited by the representative will be the first customer in the remaining sequence of customers that can be visited within the time window. In Section 3, we generalize this recourse action to allow skipping if a representative will not arrive by any specified time.

The second recourse action operationalizes the notions of balking and renegeing from queueing theory. The basic premise is that the representative may leave the queue immediately after arriving at a customer if observing a sufficiently long queue (balking) or she may leave after waiting in queue for a period of time without meeting with the customer (renegeing). We propose a decision rule that takes as input the observed queue length upon the representative's arrival to a customer to determine the latest time she will wait there. We elaborate on this second recourse action in Section 3.

This paper makes four primary contributions to the literature. First is the formulation of a routing model that explicitly accounts for the stochastic wait times resulting from queues of competing salespeople. Second, the customer-specific recourse action corresponding to the queueing notions of balking and renegeing is a novel addition to routing models. We also derive an analytical formula to compute the expected reward from an a priori tour. Finally, our computational results demonstrate the value of incorporating stochastic information into the routing model for sales representatives.

To position our contribution, we review related literature in Section 2. In Sections 3 and 4, we provide a formal model of the problem and derive a closed-form computation of the objective. We discuss our solution approach to the SOPTW in Section 5. In Section 6, we discuss the generation of input data, notably the data for the transient queueing, for our SOPTW instances. Section 7 presents a deterministic version of the SOPTW in which waiting time distributions are replaced with expected wait times, resulting in an elementary longest path problem solvable via an exact solution method. Section 8 provides a computational comparison and Section 9 concludes with a summary and discussion of future work.

2. Literature review

The SOPTW is rooted in the traveling salesman problem (TSP) with profits. The notion of profit or value can be incorporated in a TSP in several ways and the problem titling typically varies

depending on the treatment of profit. One way to model profit is to minimize the overall travel costs in the objective function while using a constraint to ensure that a certain amount of profit is collected (prize collecting TSP). Another way is to maximize the overall profit collected while limiting the total travel cost to a specific upper bound (orienteering problem or selective TSP). The third way minimizes the travel costs minus collected profit in the objective function (profitable tour problem). Two extensions of the orienteering problem, usually referred to as the team orienteering problem and the selective vehicle routing problem, plan more than one tour and each tour collects rewards during the same period of time. [Feillet, Dejax, and Gendreau \(2005\)](#) provides a survey of the deterministic TSPs with profits and [Vansteenwegen, Souffriau, and Oudheusden \(2011\)](#) conducts a survey of the orienteering problem.

Stochastic elements have been incorporated in TSPs with profits in several ways. [Teng, Ong, and Huang \(2004\)](#) study a time-constrained TSP with uncertain travel and service time whose objective is to maximize the total profit collected on a tour. A limit is set to the total travel and service time of a route. They formulate the problem as a two-stage stochastic problem with recourse, where in the first stage a subset of customers are sequenced before the travel and service time are realized and in the second stage an expected penalty is imposed on the objective function for the violation of the limit time. [Tang and Miller-Hooks \(2005\)](#) propose a selective TSP with stochastic service times, travel times and travel costs. They formulate the problem as a chance-constrained stochastic integer program with an objective to maximize the total profit collected from an a priori tour while restricting the probability that the tour length exceeds a certain threshold to a given value. [Campbell, Gendreau, and Thomas \(2011\)](#) address an orienteering problem with stochastic travel and service times where a customer specific penalty is incurred for each scheduled customer not reached before a given known deadline. They investigate special versions of the problem that can be solved optimally and present variable neighborhood search heuristics to solve general versions of the problem. Similar to [Campbell et al. \(2011\)](#), [Papapanagiotou, Weyland, Montemanni, and Gambardella \(2013\)](#) investigate an orienteering problem with stochastic travel and service times and a given deadline. They focus on developing a Monte Carlo sampling procedure to approximate the objective function. They demonstrate the effectiveness of the objective approximation by comparing it with the exact objective evaluation. [Evers, Glorie, van der Ster, Barros, and Monsuur \(2014\)](#) study an orienteering problem with a stochastic weight on each arc and a hard constraint on the total weight of a tour. They introduce a two-stage recourse model where a recourse action of aborting the tour (returning to the depot) is taken in the second stage. They propose a sample average approximation (SAA) procedure to solve the problem, in which the objective function is approximated via Monte Carlo sampling.

The stochastic elements in the papers we describe in the preceding paragraph are similar to our SOPTW in that the arrival time at a customer is uncertain (in the SOPTW the arrival time at a customer is uncertain due to the uncertain waiting time at previous customers). However, we are unaware of any prior treatment of time windows in a stochastic TSP with profits that compares to our SOPTW. [Voccia, Campbell, and Thomas \(2013\)](#) conduct a study of a probabilistic traveling salesman problem with time windows (PTSPTW). Though inducing uncertain arrival time via uncertain presence of customers, this PTSPTW is not comparative to the SOPTW as the former's objective is to minimize the expected traveling costs and does not consider any measure of profit.

Our work is related to research in queueing theory in terms of investigating the balking and renegeing decision rules ([Burnetas, 2013](#); [D'Auria & Kanta, 2011](#); [Yechiali, 1971, 1972](#)). However, our work differs from the existing queueing literature by considering a network of queues rather than one or two queues ([D'Auria &](#)

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