European Journal of Operational Research 251 (2016) 198–205

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Decision Support

Patient choice analysis and demand prediction for a health care diagnostics company

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ARTICLE INFO

Article history:
Received 18 December 2014
Accepted 26 October 2015
Available online 30 October 2015

Keywords:
OR in health services
Laboratory services
Patient choice
Demand prediction
Location

ABSTRACT

This paper describes a case study for a medical diagnostic laboratory service provider to model the behavior of patients when choosing a patient service centre for their medical tests and to estimate future demand volume. A tool developed based on our methodology allows the management of the diagnostic services to experiment with locations and capacities for locating or relocating service centres. In addition to the focal firm, the methodology considers the impact of decisions on another service provider and hospital laboratories located in the same area. The methodology identifies the most significant service centre attractiveness factors. Our models are validated from different perspectives and show good predictive capability. This case study is used to draw a number of lessons for applying these types of models to other similar services in order to assist other applications.

1. Introduction

Medical diagnostic laboratory services play a crucial role in the detection, diagnosis, and treatment of disease for patients. An estimated 60–70 percent of all decisions regarding a patient's diagnosis and treatment, hospital admission, and discharge are based on laboratory test results (Mayo Clinic, 2010). The medical diagnostic laboratory service industry is a large industry. In the U.S., for example, diagnostic costs were approximately 10 percent of overall health care expenditures in the 1990s (Benge, Bodor, Younger, & Parl, 1997), and this industry recently had revenues of more than 50 billion dollars (Knowledge Source, 2010). British Columbia (BC), Canada, the location of this study, spent an estimated 457 million dollars on laboratory services in 2001–2002 (BC Ministry of Health, 2003).

Medical diagnostic services are offered to both outpatients and inpatients. Inpatients do not concern us here as in countries such as the U.S. and Canada, the vast majority of inpatient tests are done by hospital laboratories. We focus on outpatients. In BC, outpatient tests are conducted by either hospital test centres or private service test centres (commonly called Patient Service Centres or PSCs), in either case funded on a per test basis through the Medical Services Plan (MSP, http://www.health.gov.bc.ca/msp/). MSP is a government administered health insurance plan, and enrolment with MSP is mandatory for all BC residents. Samples from the PSCs will typically be sent to centralized laboratories from which results are forwarded directly to physicians' offices or clinics.

With test revenues regulated, the profit of a private service provider depends on the volume of visits to its PSCs or its market share as well as on controlling costs. This brings us immediately to the core problem addressed in this paper. A private service provider in BC approached us for help in evaluating when and where to relocate a PSC, when to change the capacity of a PSC, and when to extend operating hours; all with the aim of increasing their share of volume of visits. The service provider would also like to know the impact on its PSCs when a competitor makes similar decisions. In the longer term, the service provider would like to experiment with different locations in the face of demographic trends, such as ageing and population growth.

The answer to any of these questions depends on our ability to predict which PSC a patient attends, which in turn means understanding what characteristics of a PSC are instrumental to this decision. For example, does a patient simply go to the nearest from their home, or from their physician, one adjacent to public transit, to a mall or having adequate parking, near other associated diagnostic facilities or PSCs at which they have not waited too long in the past?

Therefore, the primary problem posed was, "how to predict patient demand and market share for PSCs sufficiently well to enable

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http://dx.doi.org/10.1016/j.ejor.2015.10.055
0377-2217/

the evaluation of many managerial choices about location, capacity, and opening hours in terms of the impact on the entire system of PSCs including those of competitors." And to do this, we had the secondary problem, "how to predict patient choice of PSC based on characteristics of those PSCs."

In this paper, we shall describe the methodology that we employed and the results. Our key result is that the use of a probabilistic choice behavior model for patients is superior to other choice models while still keeping the methodology reasonably simple and portable. Although carried out with data pertaining to medical diagnostic facilities, we believe the method and results to be insightful for many other service sectors.

The remainder of the paper is organized as follows. We first present an overview of the relevant literature in Section 2. We then describe the background of the case study, our general methodology, and preliminary analysis in Sections 3, 4, and 5, respectively. In Section 6, we further discuss the explanatory variables included in the models, estimation, and model validation. We then provide a few key insights in Section 7 by comparing our model with three other simplified models. Section 8 concludes the paper.

2. Literature review

There is a rich literature in operations, economics, and marketing that studies the behavior of people choosing among a set of alternatives or predicts the flow of people visiting a set of locations.

Consumer shopping choice is one of the areas that are studied most. Huff (1964) developed an early gravity-type model that included distance to stores and size of stores as independent variables to estimate market shares of retail stores. Many extensions, such as the multiplicative competitive interaction (MCI) model (Nakanishi & Cooper, 1974), have been subsequently proposed and applied (see, e.g., Drezner & Drezner, 2002; Gautschi, 1981; Jain & Mahajan, 1979). These models are usually based on aggregate flows between consumer zones and stores. The flows are predicted as a function of a store's attractiveness factors, such as distance or travel time, store size, floor space, and accessibility. Other models of consumer shopping choice are based on disaggregate (individual) discrete choice models. They assume that the probability of people choosing a certain alternative is influenced by the attractiveness of that alternative. The most well-known models are probably the multinomial logit (MNL) model (McFadden, 1974) and its extensions (Bell & Lattin, 1998; Berry, 1994; Severin, Louviere, & Finn, 2001). As these models can also be applied at an aggregate level, they may be viewed as logical extensions of the Huff model as well.

In the health care sector, the literature focuses primarily on patient hospital choice. While a few earlier works applied the MCI model (Erickson & Finkler, 1985; Folland, 1983; McGuirk & Porell, 1984), most of the studies were based on the MNL model to analyze the patient hospital choice at the individual level (Bronstein & Morrisey, 1990; Cohen & Lee, 1985; Roh, Lee, & Fottler, 2008; Sivey, 2012; Tai, Porell, & Adams, 2004). These studies usually considered both patient characteristics and hospital attractiveness factors. However, there appear to be little literature on medical diagnostic laboratory services and little guidance for governments, health authorities, or service providers who hope to improve patient satisfaction and revenues.

In the location literature, customer choice for alternative facilities is often considered in optimization models to determine the optimal facility locations or capacities. Traditional studies tend to simplify the customer choice behavior, and often assume that customers make their choices based on distance only and seek service from the closest facility (Berman, Krass, & Wang, 2006; Verter & Lapierre, 2002; Wang, Batta, & Rump, 2002). Now, gravity-type or discrete choice models have also been incorporated into location models (Aboolian, Berman, & Krass, 2007; Benati & Hansen, 2002; Haase & Muller, 2014; Marianov, Rios, & Icaza, 2008; Zhang, Berman, & Verter, 2012). Readers may refer to several recent review papers for facility location models (Boffey, ao, & Espejo, 2007; Daskin & Dean, 2004; Klose & Drexl, 2005; ReVelle & Eiselt, 2005).

3. Background

The private laboratory service provider for which we carried out the study is referred to as Firm A throughout the paper.[1] Firm A is located in the southwest of BC (henceforth called the service area). Operating 45 Patient Service Centres (PSCs), it serves 6,000 to 8,000 patients and performs 35,000 tests every day. The number of annual patient visits is around 2 million. Firm A requested assistance from the Centre for Operations Excellence at the Sauder School of Business in the University of British Columbia in understanding patient choice of PSC and developing tools to aid managerial decisions about location and capacity of PSCs.

There are two other main providers of these services in the service area. One is another private provider with 40 PSCs, which we shall refer to as Firm B. In addition, 24 hospitals in this area provide in-house laboratory services for both inpatients and outpatients.

The basic process is as follows. A patient is referred for a panel of tests by a physician, primarily a family physician. With a physician's requisition, a patient can visit any PSC for the service. Usually, no appointment is needed; most PSCs use first-come-first-served protocols. After waiting, a patient enters a medical (phlebotomy) station somewhat misleadingly called a "seat," where the test is taken. The number of "seats" effectively defines the capacity of the PSC. After collection, the sample is delivered to a central laboratory and results are electronically sent to physicians.

In Canada there is mandatory universal health insurance that covers most laboratory services. Insurance coverage is not an important factor in patient choice. As this is a government regulated industry, major operational decisions made by private service providers or hospitals in BC need approval by the BC Ministry of Health. For instance, opening a new PSC, moving an existing PSC to another site, or changing the number of "seats" at a PSC, all require submission of an application with adequate supportive evidence.

The key purpose of the study was to develop a practical and portable tool that can be used by service providers to predict demand or market share subsequent to any changes in the service facility network, such as addition, deletion, or move of a PSC.

4. Data and methodology

4.1. Data

We obtained the following data from Firm A:

- All referrals by physicians of patients to PSCs during 2004–2012, about 14 million records in total. The data includes the patient age, gender, postal code, the panel of tests requested, the date and time of the test, and the signing physician. We primarily used 2007, 2008, 2011, and 2012 data records.
- Information about PSC locations including hours of operation and capacities, meaning the number of "seats."
- Information about physicians, their clinical office address, and specializations.

No data were available about referrals completed at Firm B or the hospitals. However, their locations, hours of operation, and capacities were publicly known. Also, the total volume of visits in the service area was reported each year, including those of Firm A, Firm B, and

[1] The company wishes to remain anonymous, but a letter from the CEO affirming that the paper reflects the implementation of the work has been filed with the Editor and made available to referees.