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Modeling and forecasting call center arrivals: A literature survey and a case study

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ABSTRACT

The effective management of call centers is a challenging task, mainly because managers consistently face considerable uncertainty. One important source of this uncertainty is the call arrival rate, which is typically time-varying, stochastic, dependent across time periods and call types, and often affected by external events. The accurate modeling and forecasting of future call arrival volumes is a complicated issue which is critical for making important operational decisions, such as staffing and scheduling, in the call center. In this paper, we review the existing literature on modeling and forecasting call arrivals. We also discuss the key issues for the building of good statistical arrival models. In addition, we evaluate the forecasting accuracy of selected models in an empirical study with real-life call center data. We conclude with a summary of possible future research directions in this important field.

1. Introduction

The call center services industry is large and important, with more than 2.7 million agents working in the United States and 2.1 million agents working in Europe, the Middle East, and Africa (Akşin, Armony, & Mehrotra, 2007). Managing a call center efficiently is a challenging task, because managers have to make staffing and scheduling decisions in order to balance staffing costs and service quality, which always conflict, in the presence of uncertainty as to arriving demand. Most staffing or scheduling plans start with the forecasting of customer call arrivals, which are highly stochastic. Accurate forecasts of call arrivals are key for the achievement of optimal operational efficiency, since under-forecasting leads to under-staffing and therefore long customer waits, while over-forecasting results in money being wasted on over-staffing.

The customer arrivals process is nontrivial. This process can be modeled as a Poisson arrival process, and has been shown to possess several features (Akşin et al., 2007; Ceẓik & L'Ecuyer, 2008; Gans, Koole, & Mandelbaum, 2003; Garnett, Mandelbaum, & Reiman, 2002; Wallace & Whitt, 2005). One of the most important of these features is the fact that the arrival rate is time-varying, which adds to the complexity of the forecasting process. Call arrival rates may exhibit intraday, weekly, monthly, and yearly seasonalities. While a time-inhomogeneous Poisson arrival process can easily capture time dependence in call arrival data, it often fails to capture other characteristics. For one thing, call center arrivals typically exhibit a significant dispersion relative to the Poisson distribution. Thus, a doubly stochastic Poisson arrival process may be more appropriate, e.g., see Aldor-Noiman, Feigin, and Mandelbaum (2009);

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Avramidis, Deslauriers, and L'Ecuyer (2004); Ding and Koole (2015) and Ibrahim and L'Ecuyer (2013). For another, call center arrivals also exhibit different types of dependencies, including intraday (within-day), interday, and inter-type dependence, e.g., see Aldor-Noiman et al. (2009); Avramidis et al. (2004); Channouf and L'Ecuyer (2012); Shen and Huang (2008b); Tanir and Booth (1999) and Whitt (1999b). A reasonable forecasting model needs to account appropriately for some or all of the types of dependencies that exist in real data.

In the presence of intraday and interday dependence in call arrival rates, standard time series models may be applied for forecasting call arrivals, for example *autoregressive integrated moving average* (ARIMA) models and *exponential smoothing* (Hyndman, Koehler, Ord, & Snyder, 2008). In addition, some recent papers have proposed *fixed-effects* models (Ibrahim & L'Ecuyer, 2013; Shen & Huang, 2008b; Taylor, 2008; Weinberg, Brown, & Stroud, 2007) and *mixed-effects* models (Aldor-Noiman et al., 2009; Ibrahim & L'Ecuyer, 2013) to account for the within-day dependence, interday dependence, and inter-type dependence of call arrivals. Dimension reduction (Shen & Huang, 2005, 2008a,b) and Bayesian techniques (Aktekin & Soyer, 2011; Soyer & Tarimcilar, 2008; Weinberg et al., 2007) have also been adopted in the literature.

The remainder of the paper is organized as follows. The key features of call center arrival processes are discussed in Section 2, and various forecasting methods that have been proposed in the literature are examined in Section 3. A case study in which several methods from the recent literature are compared is reported in Section 4, using a Canadian call center data set, which reveals the practical features of those methods. Discussions of future research directions are provided in Section 5 to conclude the paper. The conference paper by Ibrahim, L'Ecuyer, Régnard, and Shen (2012) served as a starting point for this survey.

2. Key properties of call center arrival processes

A natural model to use for call arrivals is the Poisson arrival process (Akşin et al., 2007; Cezik & L'Ecuyer, 2008; Gans et al., 2003; Garnett et al., 2002; Wallace & Whitt, 2005). This model is justified theoretically by assuming a large population of potential customers where each customer makes calls independently with a very small probability; the total number of calls made in a given time interval is then approximately Poisson. As was mentioned by Kim and Whitt (2014a), the so-called Poisson superposition theorem is a supporting limit theorem, e.g., see Barbour, Holst, and Janson (1992).

Recent empirical studies have shown multiple important properties of the call arrival process, many of which are not consistent with the Poisson modeling assumption. This section describes these properties in detail; for a more abridged description, see Section 2 of Ibrahim et al. (2012).

2.1. Time dependence of call arrival rates

One of the most important properties of call arrival rates is that they vary with time. In particular, call arrival rates typically exhibit intraday (within-day), daily,

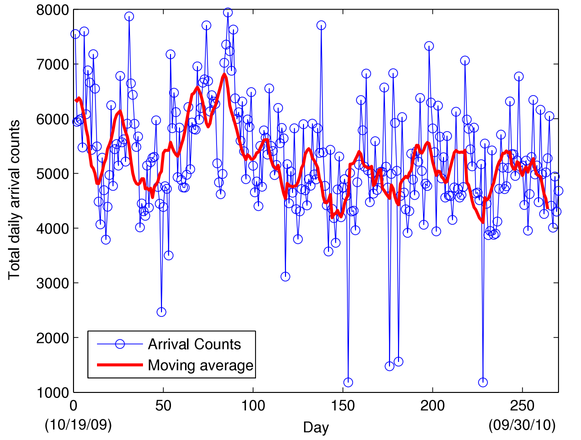

Fig. 1. Daily call arrival counts over successive months in a Canadian call center.

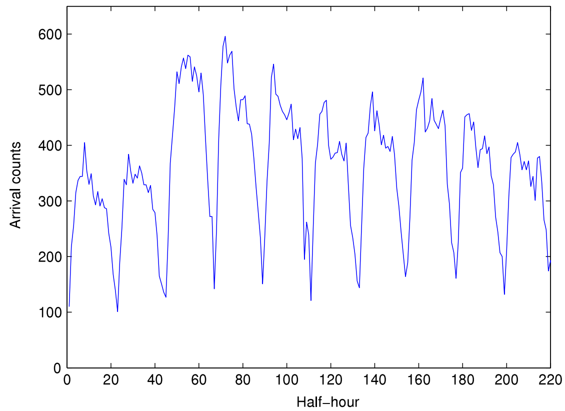

Fig. 2. Half-hourly call arrival counts over two consecutive weeks.

weekly, monthly, and yearly seasonalities. We illustrate this time-dependence property in Figs. 1, 2, and 3 (taken from Ibrahim & L'Ecuyer, 2013), which show arrival patterns that are observed commonly in call centers.

In Fig. 1, we plot the numbers of calls per day arriving at the call center of a Canadian company between October 19, 2009, and September 30, 2010. Fig. 1 shows that there are monthly fluctuations in the data. For example, the moving average line in the plot, which is computed for each day as the average of the past 10 days, suggests that there is an increase in call volume during the months of January and February, i.e., days 54–93 in the plot.

In Fig. 2, we illustrate weekly seasonality by plotting daily arrival counts, of the same call type as in Fig. 1, over two consecutive weeks in the call center. The call center is closed on weekends, so we have a total of 10 workdays in the plot. Fig. 2 clearly shows that there is a strong weekly seasonality in the data. Such weekly patterns are observed very commonly in practice, e.g., see Figure 1 of Taylor (2008) and Figure 2 of Taylor (2012).

For a more microscopic view of arrivals, we plot half-hourly average arrival counts per weekday, in Fig. 3. These intraday averages constitute the *daily profile* of call arrivals. Fig. 3 shows that call volumes are higher, on average, on Mondays than on the remaining weekdays. Fig. 3 also

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