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Optimization of ATM cash replenishment with group-demand forecasts

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ABSTRACT

In ATM cash replenishment banks want to use less resources (e.g., cash kept in ATMs, trucks for loading cash) for meeting fluctuated customer demands. Traditionally, forecasting procedures such as exponentially weighted moving average are applied to daily cash withdraws for individual ATMs. Then, the forecasted results are provided to optimization models for deciding the amount of cash and the trucking logistics schedules for replenishing cash to all ATMs. For some situations where individual ATM withdraws have so much variations (e.g., data collected from Istanbul ATMs) the traditional approaches do not work well. This article proposes grouping ATMs into nearby-location clusters and also optimizing the aggregates of daily cash withdraws (e.g., replenish every week instead of every day) in the forecasting process. Example studies show that this integrated forecasting and optimization procedure performs better for an objective in minimizing costs of replenishing cash, cash-interest charge and potential customer dissatisfaction.

1. Introduction

Business analytics is becoming popular in many business practices nowadays. For instance, companies such as Samsung and Coca-Cola have been trying to find ways to utilize available data collected to draw and use the meaningful information for making decisions to improve their manufacturing, logistics or marketing operations. Samsung collects various market data from their retail stores such as customers' sales quantity, inventory level, order and sales forecast. The data there are synthesized for deciding manufacturing orders and schedules (Ko & Han, 2012). Coca-Cola collects what and how much customers are drinking via RFID. This data helps the company to learn how new drinks are doing in the market, identify differences in regional tastes and help fast-food outlets decide which drinks to serve (Weier, 2009). These instances show that collecting data and using them in an intelligent way for decisions is becoming more and more important in today's competitive business environment. This manuscript is an attempt to use the collected data to increase the performance of an ATM network.

ATM cash replenishment studies focus on decisions about time schedules that each ATM should be replenished and amount of money that should be loaded. The studies include both forecasting cash demands and optimizing replenishment schedules. This optimization should satisfy both cost constraints of the bank and demand constraints from customers. The ATM cash replenishment is an important real-life problem. One of the challenges in this type of problem is forecasting quality since it includes complicated and noisy data. If a forecasting model has poor quality in predicting future cash demands in ATMs, the replenishment-policy derived based on the forecasted demands will not be effective. Significance of the study stems from the fact that replenishment below the actual demand leads to customer dissatisfaction, while replenishment more than the demand leads to high opportunity cost for the bank. Hence, a methodology, which will optimize the replenishment amount, will be apparently very useful for the banks.

In the literature forecasting and replenishment-policy were studied separately usually by different groups of researchers/practitioners except for the study of Baker, Jayaraman, and Ashley (2013). That is, forecasting studies do not cover the replenishment-policy. The replenishment optimization literature does not include the forecasting process. These isolated approaches cannot solve the above challenges. For instance, when the individual ATM cash demand is forecasted poorly, the optimization model for replenishment will mislead the replenishment decisions.

Consider the vast amount of data variations in each ATM's demand. In this study, we forecast demand for a group of ATMs, due to the fact that there will be less variability in the aggregated data, the prediction quality would be better. Moreover, since ATMs

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are not generally replenished every day, daily forecasting does not make sense for reducing labor and transportation costs. In our integrated approach a group of nearby ATMs formulates a cluster. The past cash demands in a cluster are used in a replenishment model for deciding the optimal replenishment time interval, i.e., replenishment schedule (using a mathematical model which minimizes the cost). Thus, the demand data are aggregated over ATMs and time intervals to provide a better opportunity of getting a much higher quality forecasting model.

In order to improve the model quality, location variables, which were not considered in the literature are also studied. Since cash is replenished to individual ATMs, group forecast is converted to individual forecasts (using the demand proportions of the ATMs in the group in the past), and finally these individual cash forecasts are loaded to the ATMs. Most business analytics studies deal with the forecasting and optimization tasks separately. This research presents a new venture of integrating informatics (e.g., forecasting) and optimization studies in one framework for solving a difficult real-life problem.

In order to show the potential of the proposed methodology, our procedure is compared against the individual ATM based replenishment-policy by means of forecasting performance and total replenishment cost. Specifically, in the case study, demands for the overlapping time periods that we have data of are studied for one cluster of ATMs for forecasting and optimization comparison and illustrations. It has been seen that forecasting quality of the proposed methodology is higher while the cost is lower. By using our method, necessary amounts are loaded to the ATMs, which will potentially increase customer satisfactions for getting needed cash when they visit ATMs.

The paper includes five more sections. The second section summarizes the previous studies while the third section introduces the proposed methodology. Fourth section illustrates the methodology using the data from a bank in Istanbul, and the fifth section shows comparison details and results. Conclusions and discussions are provided in Section 6.

2. Problem background

2.1. Literature review

The existing literature about ATM cash demand forecasting is divided into two groups. The first group includes studies on demand forecasting at daily level. There are several studies on this topic, which will be summarized below. The second group includes cash replenishment studies. These studies use the forecast values and certain constraints to make a decision about the replenishment policy.

Focus on the first group of literature. After "Forecasting Competition for Artificial Neural Networks and Computational Intelligence" (NN5 Competition), the ATM demand forecasting problem became popular. The performance measure was MAPE (mean absolute percentage error) in this competition. The data includes daily cash withdrawals from 111 ATMs in different locations of England. The time frame is two years and the aim is to forecast the next 56 days' demands (Crone, 2008). The rule in this competition is to use the same model for all ATMs. Andrawis, Atiya, and El-Shishiny (2011) took the first place among the computational intelligence models, where they used some rules such as a simple average to combine forecasts from different models for improving model quality. They also tried to forecast weekly values and then converted them to daily values by a simple linear interpolation scheme. Other work for NN5 Competition data includes Coyle, Prasad, and McGinnity (2010) who developed a model based on the self-organizing fuzzy neural network, and Wichard (2011) who utilized forecast combination via a simple average idea for improving forecasting quality. Teddy and Ng (2011) reconstructed missing values in the raw data using the weighted average of the last and the next known withdrawal records in the series. Ben Taieb, Bontempi, Atiya, and Sorjamaa (2012) considered the effects of seasonality, input variable selection, and forecast combination.

There are other ATM data used in forecasting studies. For instance, Simutis, Dilijonas, Bastina, and Friman (2007) applied Artificial Neural Networks (ANN) to the three-year data from a bank in Lithuania. Simutis, Dilijonas, and veBastina (2008) improved forecasting quality by modeling days of the month by labeling each day from 1 to 31. Brentnall, Crowder, and Hand (2010) studied data collected from 190 ATMs in the United Kingdom over a two-year period. Darwish (2013) applied Interval Type-2 Fuzzy Neural Network (IT2FNN), Zandevakili and Javanmard (2014) used Fuzzy Neural Networks and Arora and Saini (2014) employed Fuzzy ARTMAP Network for simulated data. Gurgul and Suder (2013) modeled withdrawals from selected ATMs of the Euronet network, their idea is the application of Switch ARIMA models to the ATM data.

In most studies cited above, MAPE is usually used as a performance measure in the forecasting studies, and it ranges from 20% to 45%.

There are two important gaps in the previous studies. Firstly, some important days such as festivals and holidays that customers usually need more cash and, can be much unhappy when the money in ATMs is all withdrawn. However, these special days were not examined carefully in the literature. This study uses indicator variables to explore their impact to the cash withdrawn and to improve model quality. Secondly, locations of the ATMs could also be important but only one study mentioned it as a future research topic (Simutis et al., 2007). Note that demography information together with urbanicity of the place where the ATM is located and the points of interests (such as schools, plazas, other banks' ATMs, shopping centers etc.) in the vicinity can affect the amount of money withdrawn from the ATM significantly. Location variables will also be considered in our studies.

Forecasting daily withdrawals is a very challenging problem for our data collected from a Turkish bank (see Section 4 for details). Since the daily withdraw variations are high, a good forecasting model is difficult to construct, e.g., R^2 in predicting individual ATM's daily withdraw is around 55% and the MAPE is around 28%. Poor forecast might lead to poor replenishment decisions. If ATMs might not be replenished every day, daily forecasting of withdraws is not needed. This manuscript explores ideas for aggregating daily withdraws for building forecasting models. The aggregation could be done via time interval or cluster of ATMs. The following provides relevant literature to support these ideas.

Aggregation techniques have been used in demand forecasting. Fisher and Rajaram (2000) presented a methodology for resolving two decisions in designing a merchandise test. One of the decisions was to select the stores to conduct the test, and the other decision was to find a way to create a seasonal forecast for the chain, based on the test results. In order to choose the test stores, they aggregated the stores into clusters that are similar based on historical sales of products, location, size and demographics. Federico, Matteo, Stefano, Roberto, and Guilio (2005) and Kalchschmidt, Verganti, and Zotteri (2006) developed forecasting models using aggregation approaches for handling irregular and/or heterogeneous customer demands. Hadavandi, Shavandi, and Ghanbari (2011) also state that forecast results can be improved by data clustering. Recently, Venkatesh, Ravi, Prinzie, and Van den Poel (2014) has advocated the prediction of cash demand for groups of ATMs with similar day-of-the week cash demand patterns. They have clustered ATMs into groups having similar withdrawal patterns.