BMIJ
ISSN: 2148-2586

BUSINESS & MANAGEMENT STUDIES:
AN INTERNATIONAL JOURNAL
Vol.: 6 Issue: 1 Year: 2018, pp. 237-255

Citation: Bilir C. & Doseyen A. (2018), Optimization Of ATM And Branch Cash Operations Using An Integrated Cash Requirement Forecasting And Cash Optimization Model, BMIJ, (2018), 6(1): 237-255 doi: http://dx.doi.org/10.15295/bmij.v6i1.219

OPTIMIZATION OF ATM AND BRANCH CASH OPERATIONS USING AN INTEGRATED CASH REQUIREMENT FORECASTING AND CASH OPTIMIZATION MODEL[1]

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Received Date (Submission Date): 27/02/2018
Accepted Date (Kabul Tarihi): 18/04/2018
Published Date (Yayın Tarihi): 20/04/2018

ABSTRACT

In this study, an integrated cash requirement forecasting and cash inventory optimization model is implemented in both the branch and automated teller machine (ATM) networks of a mid-sized bank in Turkey to optimize the bank's cash supply chain. The implemented model's objective is to minimize the idle cash levels at both branches and ATMs without decreasing the customer service level (CSL) by providing the correct amount of cash at the correct location and time. To the best of our knowledge, the model is the first integrated model in the literature to be applied to both ATMs and branches simultaneously. The results demonstrated that the integrated model dramatically decreased the idle cash levels at both branches and ATMs without degrading the availability of cash and hence customer satisfaction. An in-depth analysis of the results also indicated that the results were more remarkable for branches. The results also demonstrated that the utilization of various seasonal indices plays a very critical role in the forecasting of cash requirements for a bank. Another unique feature of the study is that the model is the first to include the recycling feature of ATMs. The results demonstrated that as a result of the inclusion of the deliberate seasonal indices in the forecasting model, the integrated cash optimization models can be used to estimate the cash requirements of recycling ATMs.

Keywords: *Cash Supply Chains; ATM Optimization; Cash Forecasting; Cash Inventory, Inventory Optimization*

JEL Codes: *C53, C61*

ENTEGRE NAKİT GEREKSİNİM TAHMİN VE NAKİT OPTİMİZASYON MODELİ İLE ATM VE ŞUBE NAKİT OPERASYONLARININ OPTİMİZE EDİLMESİ

ÖZ

Bu çalışma ile entegre bir nakit ihtiyaçları tahmini ve nakit envanteri optimizasyon modeli uygulaması sonuçları ile birlikte sunulmuştur. Bu model, Türkiye'de yer alan orta büyüklükteki bir bankanın hem şube hem de ATM ağına uygulanmış, bankanın nakit tedarik zinciri optimize edilmiştir. Gerçekleştirilen çalışmada temel amaç, müşteri hizmet düzeylerinde (nakit para bulunabilirliğinde) bir azalma olmaksızın, doğru tutarda nakdin doğru lokasyonda bulundurulması yolu ile banka şubeleri ve ATM'lerde yer alan fazla nakdin minimize edilmesi olarak tanımlanmıştır. Bilindiği kadarı ile, burada yer alan çalışma, bankaların hem şube hem de ATM ağına aynı zamanda uygulanan ilk model olma özelliği taşımaktadır. Entegre modelin uygulanması sonucu elde edilen sonuçlar göstermiştir ki, entegre nakit tahmini ve optimizasyon modelleri nakit bulunurluk seviyesinde, dolayısıyla müşteri memnuniyetinde bir azalma olmaksızın, şube ve ATM'lerdeki fazla nakit miktarında ciddi

[1] This work has been supported by P1M1 Cash+ software developed by PlusOneMinusOne (www.p1m1.com)

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azalmalar sağlayabilmektedir. Sonuçların detaylı bir şekilde analizi de göstermiştir ki, nakit miktarındaki azalma şubelerde daha da dikkat çekici seviyedededir. Sonuçlar ayrıca, çok farklı mevsimsel indekslerin kullanımının, banka nakit ihtiyaçlarının tahmin edilmesinde kritik bir rol oynadığını göstermesi açısından da önemlidir. Bu çalışmanın bir diğer eşsiz özelliği ise, geriçevrimli "recycling" özellikli ATM'leri modelleyen ilk çalışma olmasıdır. Çalışmanın sonuçları göstermiştir ki, uygun mevsimsel indekslerin kullanılmış olması şartıyla, bütünleşmiş nakit optimizasyon modelleri, geriçevrimli ATM nakit ihtiyaçlarını tahmin etmede de oldukça başarılı olabilmektedir.

Anahtar Kelimeler: *Nakit Tedarik Zinciri; ATM Optimizasyonu; Nakit Tahminleme; Nakit Envanteri, Envanter Optimizasyonu*

JEL Kod: *C53, C61*

1. INTRODUCTION

The retail banking industry plays a major role in the development of a nation's economy. Banks, as intermediaries, connect several entities and generate and distribute a considerable amount of money. One of the means of this money distribution to individual customers is automated teller machines (ATMs) and branches, which are costly in terms of cash-in-transit (CIT) armored truck operations for security reasons. In contrast, when cash in the branches and ATMs remains idle and is not used for any investment purpose, this is a significant source of cost to the bank. Therefore, cash replenishment scheduling requires optimization between these two complementary costs. Customer satisfaction is also dependent on the availability of money at ATMs and branches. Therefore, it is vital to determine how much money to hold at branches and in ATMs.

In a single day, a medium scale bank will have approximately US$15 million in cash withdrawals on average. To meet the stochastic demand, the money retained in the ATMs is approximately US$35 million, meaning that the difference remains idle. These amounts can easily be on the order of one billion dollars for major banks. From the sheer-size perspective, the above numbers demonstrate the importance of the subject. Thus, proposing a solution to the problem of determining an optimal allocation of money to be distributed for customer withdrawal and for investment purposes is critical.

Another issue is that the problem of cash management is usually understood and addressed only as a demand management problem and not from a cost optimization perspective. In general, three different types of objectives are considered in the cash optimization literature: (1) to minimize cost, (2) to maximize profit, and (3) to improve customer satisfaction. Typical cost components are inventory holding cost, ordering cost and shortage cost (Geismar, Sriskandarajah, & Zhu, 2017). Therefore, the main objective can be stated as adjusting the cash levels such that the total cost is minimized and customer satisfaction, which can be referred to as the primary constraint of the problem and is highly affected by the cash-out situation, is simultaneously guaranteed.

The implementation of cash forecasting and optimization procedures/solutions allows banks to take full advantage of the available money for investment purposes. Basically, the implementation of integrated cash optimization models not only centralizes the cash management logistics process for every branch and ATM but also allows banks to minimize the total costs incurred during physical cash operations and increase customer satisfaction by minimizing cash-outs.

To determine the amount of money to hold in ATMs, future transactions by customers for each ATM must be forecasted. For each type of transaction, ATMs include two separate cassettes: a withdrawal cassette, where money is withdrawn by customers, and a deposit cassette, into which money can be deposited. However, with advancing technology, cash recycling ATMs have been introduced. These types of ATMs make cash deposited by customers available for dispensing once the money has gone through a validation process, and this results in a decrease in costs associated with cash replenishment and servicing. Therefore, the recycling issue needs to be considered in cash optimization models. However, among the many published cash management optimization models, none includes recycling.

Although the branch cash optimization problem has many similarities with ATM cash optimization, there are major differences that need to be considered when predicting the cash demand and optimizing the cash transfers. For example, ATMs have a banknote capacity, whereas branches are assumed to retain as many banknotes as required. The total amount of money that can be withdrawn from an ATM is limited, whereas below a predefined amount, customers are entitled to withdraw any amount of money from branches at any time. Above the predefined threshold, customers are obliged to notify branches in advance. ATMs operate at night, weekends, and holidays, whereas branches are closed at these times. These differences need to be considered when building both forecasting and optimization models.

In this paper, the cash management problem of a mid-sized financial institution in Turkey is presented. To optimize the cash supply chain of the bank, an integrated cash requirement forecasting and cash inventory optimization model is implemented at both the branches and ATMs of the institution. After the implementation, the bank can reduce its idle cash levels dramatically without hurting its customer service level (CSL).

Our article is organized as follows: First, a brief literature review is presented to provide a basic understanding of the cash supply chain optimization and the position of our approach.

Second, the background of the problem is presented. Third, the methodology implemented at the bank is provided. Fourth, the results of the implementation are presented. The article is concluded with the managerial implications of the study and suggestions for future research.

2. LITERATURE REVIEW

Although the inventory management literature is broad, applications of the models to cash management have been limited. The pioneering studies in the physical cash optimization literature are by Baumol (1952) and Tobin (1958). In their pioneering articles, Baumol and Tobin independently developed the economic model of the transaction demand for money. By assuming that cash inflows and outflows are stable and predictable, the researchers applied the economic order quantity model to establish a target cash balance. In the researchers' models, a trade-off between cash holding and interest-bearing assets is defined to determine the optimum level of cash availability.

To extend the economic model of transaction demand for money, Eppen & Fama (1968) defined a stochastic model and used linear programming techniques to study optimal operating policies. In the study, the authors defined transaction costs composed of both fixed and variable components. The researchers also defined the cash holding cost as an incentive to maintain a low cash balance and penalty costs for delays in meeting demands for cash.

The pioneering studies presented above are cash replenishment policy optimization studies, which benefit from the similarities between cash management problems and economic order quantity and periodic review policy problems. After these pioneering studies, the cash management literature is divided into two broad groups: cash replenishment policy optimization studies and cash demand forecasting studies. In one of the cash replenishment policy optimization studies, Simutis et. al. (2007) proposed a simulated annealing (SA) metaheuristic-based algorithm to estimate the cash load for each ATM to minimize the ATMs' maintenance cost function. The researchers considered three primary costs: the cost of cash, the cost of cash uploading and the cost of daily services. Castro (2009) used a stationary discrete probability distribution to define the cash demand as stochastic and later solved the problem with mixed integer linear programming (MIP) techniques. Baker, Jayaraman, & Ashley (2012) proposed an adaptive data-driven policy to determine the optimal time series forecaster and the best-fitting weekly forecast error distribution. In the proposed model, the optimal cash inventory level and the time between orders are obtained via an optimization module, which uses the rolling horizon time series forecasts of cash withdrawals. Ekinci, Lu, & Duman (2015) integrated the results of their forecasts with a cash replenishment optimization model to determine the amount of cash and trucking logistics schedules necessary for replenishing cash in all of the ATMs. Agoston, Benedek, & Gilanyi (2016) defined the cash management problem as a single problem by incorporating the cash optimization problem of the bank into the cash optimization problem of the CIT firms. To reduce the overall cash management costs, including transportation costs and interest costs, the researchers defined a joint optimization model using contractual prices between banks and the CIT firms. The researchers subsequently applied their model to the ATM network of a Hungarian Commercial Bank.

In a cash demand forecasting study, Bretnall, Crowder, & Hand (2010) proposed density forecasts for predicting the daily amounts withdrawn from 190 ATMs in the United Kingdom. The authors explored three different models for the network: linear, autoregressive and structural time series. The authors subsequently constructed Markov–switching models and concluded that Markov–switching models are preferable. Teddy and Ng (2011) used cerebellar associative memory networks to produce forecasts for ATM cash demands. The authors also performed benchmark studies to evaluate the performance of the model compared with conventional global learning computational intelligence and regression models. Venkatesh et al. (2014) used neural networks to predict the cash demands of ATMs. The authors advocated that ATMs with similar weekday cash demand patterns generated better results than individual ATM forecasts. Ekinci et al. (2015) grouped ATMs in nearby locations into clusters and generated forecasts for the clusters. The researchers also studied location variables to improve the forecasting model quality. In a recent study, Lazaro, Jimenez, & Takeda (2018) used machine learning to forecast cash demands for each of the branches, taking into account past demands and calendar effects.

Authors forward demand predictions to an optimization model, whose outputs are cash transports that each branch should request. Although both forecasting techniques and cash replenishment policy optimization models are required to optimize the physical cash in a bank's network, there are a limited number of papers that integrate these two types of models. To the best of our knowledge, there are only five studies that integrate cash demand forecasts into the replenishment policy optimization problem: (Simutis, Dilijonas, Bastina, Friman, & Drobinov, 2007), (Baker, Jayaraman, & Ashley, 2013), (Osorio & Toro, 2012), (Ekinci, Lu, & Duman, 2015) and (Lazaro, Jimenez, & Takeda, 2018). Regarding real-world scenarios, the literature is notably limited. Although there are certain models, such as (Ekinci, Lu, & Duman, 2015), (Agoston, Benedek, & Gilanyi, 2016), (Lazaro, Jimenez, & Takeda, 2018) and (Osorio & Toro, 2012), that test the applicability of the model on a real network of an existing bank with the historical data, they do not present the actual results of the application of the models. For example, Lazaro, Jimenez, & Takeda (2018) used four years of branch level historical data from a national bank on a daily basis. The data includes cash levels, demands and transportations requested. By using the data from the bank, the authors try to test the applicability of the model and analyze the potential savings if the model have been applied to. However, the model has never been applied by any financial institution. To the best of our knowledge, there is only one paper (Baker, Jayaraman, & Ashley, 2013) in the literature that presents real-world case studies in addition to application of the models to a real bank network. Baker, Jayaraman, & Ashley (2013) developed their integrated cash management optimization model specifically for a large financial institution that manages several ATMs in the western United States. The researchers presented the results of the application of the model to the bank’s ATM network as well as the cost reduction that the model helped the bank achieve.

The vast majority of the papers regarding cash management optimization strive to optimize the cash in an ATM network. However, management of the cash level at the branches and the cash transfers between central locations and branches also play an important role in cash management of financial institutions. Nevertheless, our literature review revealed that there are only two studies that includes branch cash optimization: (Lazaro, Jimenez, & Takeda, 2018), (Osorio & Toro, 2012). Osorio & Toro (2012) built a multi-objective MIP model to determine optimal decisions regarding cash inventory and transportation by balancing the cost of service and the availability of cash for final users. The authors used neural networks to forecast the demand and historical simulations to explain the service level and stock-out costs. The model was later applied to optimize the cash network of a Colombian financial institution that had 85 offices, including branches and several ATMs.

According to our literature review, joint cash forecasting and cash inventory optimization models are limited. Regarding real-life scenarios, current literature is notably limited, there is only one model which is applied to the cash network of a real financial institution. Besides, none of the studies includes recycling ability in their models. The model presented here is the first integrated model which has been applied to both ATM and branch network of a financial institution. The principal contribution of this paper is the presentation of real world application results of the integrated model . By applying the model to branches, the paper will also contribute to the literature, as branch-level optimization is very rare in the literature. As an additional important contribution to the literature, the applied model is the first to include the recycling feature of ATMs.

3. PROBLEM DEFINITION

Kuveyt Turk Bank is a mid-sized bank that operates primarily in Turkey. Owing to its financial success in the last ten years, the bank has tripled the number of branches and ATMs within its network and the bank also had plan of increasing the number of ATMs in the network. At the beginning of 2015, before forecasting and optimization models were implemented, the bank had 307 branches and 378 ATM machines, including recycling featured machines.

As the only bank with a research and development (R&D) center acknowledged and supported by the Ministry of Science, Industry and Technology of Turkey, Kuveyt Turk is known for effectively utilizing technology in its operations and for being innovative in its products and services. However, the bank had no experience in using forecasting or optimization techniques in the management of cash transfers to branches or ATMs. The bank believed that there were such a high number of seasonal indices that play a critical role in cash requirements, such as the day of the month, the day of the week and religious holidays, that it was nearly impossible to forecast cash requirements effectively. However, in July 2014, the bank conducted a preliminary study regarding the total idle money at its Istanbul branches and ATMs and its total cash operations costs to compare these figures with the industry averages (Table 1).

Table 1: Basic Summary Statistics Regarding Kuveyt Turk Istanbul's Branches And Atms Before The Optimization Of Cash Supply Chain

# of branches in Istanbul	# of ATMs and XTMs	Average idle money rate at branches (%)[1]	Average money held at ATMs (TL)	Average money rate at ATMs (%)[2]	Cash transfer costs (TL per cash point)
133	378	6.68 %	102,894	1.74 %	7,699

[1] Calculated as the ratio of the average amount of idle money to the average total amount of current accounts at the branch (only for Istanbul branches).
[2] Calculated as the ratio of the total money held in ATMs to the total amount of current accounts.

The results demonstrated that the average amount of idle money retained at the branches was considerably greater than the industry average (estimated to be less than 3 %), and the total amount of idle money retained in ATMs was also much greater than the industry average (estimated to be less than 1 %). Moreover, the total cash transfer and operational costs were greater than the industry averages. It was thus concluded that the physical cash management operations were ineffective in terms of both performance metrics.

There were many reasons behind the ineffective cash management at the bank. The first major reason was the decentralized cash management approach. At that time, all cash points made their own decisions about their cash requirements. As a result of the lack of a cash optimization approach at the decentralized points, the cash points tended to maintain high levels of cash. Another major reason was the lack of a forecasting or optimization tool to utilize in the decision-making process. To centralize the cash management operations, the cash management center required a tool to estimate the daily cash requirements of each cash points.

After analyzing the results of the preliminary analysis, which made the inefficiency in the cash operations obvious, a proof-of-concept (POC) study was conducted by Kuveyt Turk and P1M1 experts on 20 randomly selected cash points to quantify the potential benefits of utilizing an integrated cash forecasting and optimization tool. The results of the POC study indicated that the model could reduce the annual total CIT costs for the points in the study from 7,699 Turkish Lira (TL) to 4,691 TL (a 39.85 % decrease). The total amount of idle cash at cash points in the study could also be reduced by 29.02 %. The POC study also demonstrated that the bank could save approximately 1.5 million TL, even if the idle cash to current account level was only reduced from 6.68 % to 5 % (still much greater than the 3 % industry average) and the CIT costs were reduced only by 10 %. These savings could be as much as 4.5 million TL if all of the potential savings in the POC could be realized at all cash points in the network. In the POC study, it was assumed that the cost of idle cash was annually 10 %, because the interest rate on the market was approximately 10 %. After the preliminary study and the POC studies, the bank decided to utilize integrated model to forecast cash requirements for each cash point (branches and ATMs, including - both ATMs with the recycling feature and those without) and optimize cash transfers among all cash points.

4. SOLUTION APPROACH / MODEL DEFINITION

In this section of the article, the model applied to the bank network is presented. First, the methodology adopted to integrate forecasting and optimization modules is explained. Then, the applied model is conceptually defined.

The solution approach presented in this paper and implemented to solve the real-world problem of the bank consists of two phases: forecasting and planning (i.e., optimization). Figure 1 summarizes the methodology. In the forecasting phase of the methodology, a machine-learning approach is implemented to predict customers' cash transactions, at both ATMs and branches. The methodology considers calendar patterns, such as the day of the week, the month of the year, predefined holidays, automatic date realignment for moving holidays and salary payment periods. In the forecasting model, many seasonal indices are utilized to predict cash requirements. Seasonal indices play a critical role in cash requirements. For example, customers withdraw more money from ATMs in shopping malls during the weekend, and most ATMs have a very large withdrawal rate during the salary payment periods. These "special" days are introduced into the forecasting process to include the effects of the characteristics of these day in the prediction if there are any such days during the forecast period. For example, if a company makes salary payments on the same date, such as the 15th of each month, the model is easily adjusted to include the same effect for the 15th of each month in the future. The indices included, but were not limited to, the following:

- ❖ day of the week,
- ❖ day of the month,
- ❖ proximity to the city center,
- ❖ proximity to salary recipients,
- ❖ Whether the day was within the holy month of Ramadan,
- ❖ closeness to holidays and
- ❖ distance between two cash points.

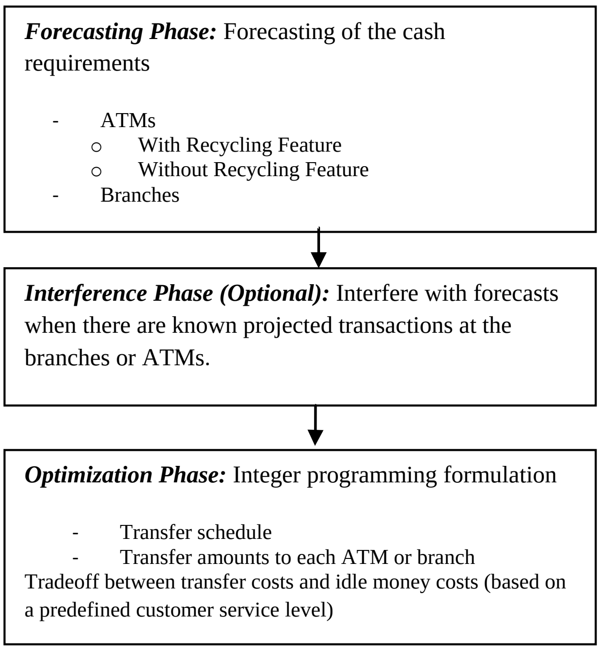

Figure 1: Joint Cash Management and Optimization Model

After the forecasting phase is complete, the user can interfere with the forecasting results before moving on to the planning phase (called the interference phase). This optional step is important in case there is an unusual event that could change customer habits and lead to an increase or decrease in the forecasted customer transactions, particularly at the branch level, where there may be planned cash deposits or cash withdrawals for the upcoming days. These transactions must also be considered in this step.

In the optimization phase of the model, an integer programming formulation is constructed to obtain the optimum transfer schedule for ATMs and branches. The main objective of the model may be defined as the minimization of total cost, which includes two components: transfer costs and the penalty fee for maintaining idle cash. When transferring money to or from the ATMs or branches, there is a cost associated with the transfer. That cost is defined as the transfer cost. The interest rate is also defined to represent the cost of idle money. The cost of idle money can be considered as opportunity cost because the idle cash could be used for investment purposes. A daily interest rate is defined to calculate the opportunity cost. To minimize the total costs, the objectives below are to be achieved:

- ❖ Forecast customers' cash transactions as accurately as possible.
- ❖ Minimize transfer costs.
- ❖ Minimize the amount of idle cash in the ATM machines and branches.
- ❖ Minimize the number of cash–outs to increase customer satisfaction.

Since the goals of minimization of the total cost, and minimization of the probability of cash-out are conflicting, the multi-objective nature of the model is overcome by using the probability of cash–out as a constraint in the model. The current probabilities of availability of cash amounts at each ATM and branch (i.e., the service level) are determined based on historical data, and the model is set to guarantee the same level of cash availability.

Variables defined in the model are as follows:

- ❖ The total amount of money withdrawn and deposited by customers at each ATM and branch must be forecasted within the forecasting module.
- ❖ Depending on the forecasted cash requirement, desired service level and tradeoff between cash transfer costs and idle cash costs, the total amount of money that needs to be retained at each ATM and branch is calculated.
- ❖ The total amount of money to be transferred to and from each ATM is determined.
- ❖ The total amount of money to be transferred to and from each branch is determined. The projected cash deposits and withdrawals, if there are any, are also considered for branches.

To maintain an operationally efficient and balanced model and to guarantee the desired service levels at branches and ATMs, the following constraints are included in the model:

- ❖ Cassette capacity constraints: The amounts of money in both the deposit and withdrawal cassettes must be within the limits.
- ❖ ATM cassette balance constraints: The available money in each cassette must equal the difference between the amount of money entering the cassette and the amount of money leaving the cassette at each ATM.
- ❖ Branch vault balance constraints: The available money at each branch must be equal to the difference between the amount of money physically entering the branch and

the amount of money physically leaving the branch.

- ❖ Availability and transportation constraint: Whether to conduct or halt transportation must be decided, and the days on which transportation has occurred are tracked.
- ❖ Service level constraint: The model is set to guarantee the same level of cash availability at each ATM and branch.
- ❖ Transfer days: The days on which transfers can be performed are also predefined within the model.

Since the actual cash withdrawals from branches and ATMs fluctuate, the bank should hold more than the mean of the forecasted amount to prevent cash-outs. This extra amount of money is equal to the critical cash limit, which is calculated for each branch and ATM according to its historical transactions. While analyzing the historical data for each ATM and branch, the current service level, i.e., the probability of availability of cash in stocks, is calculated. A set of constraints are defined to guarantee the same service level to customers at each cash point.

The forecasting and optimization models are run every day for a predetermined planning horizon. Although the decision is made for only the first day of the planning horizon, the planning horizon is defined as 10 days by default. Although the planning horizon is longer than 1 day, the model is run on each day, and new data are observed; this approach is used for future forecasting. The results are input into the optimization model to determine the required cash levels for each branch and ATM.

The model excludes the insurance cost, the route optimization for cash transfers and aggregation of ATMs or branches. Therefore, the locations of ATMs and branches are not defined in this model.

5. RESULTS AND DISCUSSION

Before the model was applied, a preliminary study was conducted to determine the current service level (the likelihood of cash availability) at all cash points and to identify the seasonal indices that influence the cash requirements at all cash points. In the preliminary study, two years' cash requirements and cash transfer data for the bank's ATMs and branches were analyzed. Over a hundred potential indices were analyzed during this preliminary study phase to identify whether these indices have any influence on the cash requirements.

After the preliminary study, the integrated model was piloted at 40 ATMs in October 2015. Next, the implementation of the model was extended to the remaining ATMs in the network at the beginning of 2016. Thereafter, the model was implemented at 37 branches in Istanbul in February 2016. Finally, the implementation of the model was extended to all Istanbul branches (133 branches) in the network in April 2016. Upon implementation of the model in the bank's network, the results were analyzed to measure the following performance factors: the accuracy of the forecasts, how the implementation influenced the number of cash-outs (service level), the idle cash levels at both ATMs and branches, the CIT costs and, ultimately, the total cost savings to the cash network.

In the cash requirements forecasting literature, the mean absolute percent error (MAPE) is generally used as the primary performance measure, ranging between 20 % and 45 % (Ekinci, Lu, & Duman, 2015). After the model was implemented in the network, the six months' forecast and the actual cash requirements data for the ATMs in the network (330 ATMs at the time) were compared and analyzed. The forecast accuracy for the branches was not considered, as the number of branches is limited, and the model still remains in the pilot phase at the branches. The analysis of the ATM data indicated that the MAPE for the model for the period analyzed is 26.44 % (Table 2). Considering the number of ATMs in the network and the difficulty of estimating cash requirements at ATMs due to the changing nature of holidays, weekdays and religious holidays, the accuracy of the estimates is very high compared with the MAPE values in the literature. In the current literature, the MAPE values are generally calculated by retrospectively applying the developed models to historical data since implementation of the models to real world scenarios is very limited. Because the developed models represent the changes in the historical data more effectively, the MAPE values tend to be greater when the models are implemented in real-world situations. However, in our study, the error value is similar to the lowest MAPE value in the literature. In other words, the MAPE value indicates that the model is capable of successfully forecasting the cash requirements. The results also demonstrate that MAPE did not substantially change through the months during the analysis period.

Table 2: MAPE Values For Atms In The Network During The Months Of Jan 2016 Through Jun 2016

Month	MAPE (%)
Month I	26.23
Month II	25.29
Month III	27.62
Month IV	26.89
Month V	26.98
Month VI	25.44
Average	**26.44**

Below, how the MAPE values change between recycling and non-recycling ATMs is presented (Table 3). As seen, the model can estimate the cash requirements for both recycling ATMs and non-recycling ATMs successfully. There is, also, no substantial change between the MAPE values between recycling and non-recycling ATMs. In order forecasting module to estimate the cash requirements for recycling machines, those machines have been identified in the model and the cash requirements for those machines are defined as the difference between cash deposits and cash withdrawals.

Table 3: MAPE Values For Atms In The Network By ATM Type (Recycling And Non-Recycling)

ATM Type	MAPE (%)
Without recycling feature	26.44 %
With recycling feature	26.41 %
Average	**26.44%**

Cash availability at cash points is one of the major measures that banks need to manage and control. Therefore, in any study that has the potential to impact cash availability at cash points, the service level (defined as the percent rate of meeting all the cash requests for a specific day) needs to be checked and analyzed. To explore how the cash availability is influenced after the implementation of the model, service level data regarding 169 of the bank's ATMs are explored. To monitor the availability of cash levels at the ATMs, the bank assumes that when the cash level decreases to less than a certain value (1,000 TL in this case), a cash-out occurs. The bank retained a record of the cash-outs at the 169 ATMs before and after the implementation. The table below presents the monthly changes in the number of cash-out incidents.

Table 4: Monthly Average Number Of Cash-Out Incidents (Before And After The Implementation)

	Monthly Average Number of Cash-out Incidents (per ATM)							7 Months Average
	Jan	Feb	Mar	Apr	May	Jun	Jul	
Before the implementation (Jan 2015 to Jul 2015)	7.09	7.04	7.96	8.18	7.38	8.33	8.47	7.78
After the implementation (Jan 2016 to Jul 2016)	8.07	7.22	2.65	9,43	9.62	9.10	8.12	7.71

As the results illustrate, the implementation of the integrated forecasting and optimization tool did not negatively impact the service level for the ATMs. There was actually a slight improvement in the average number of cash-out incidents (a decrease from 7.78 to 7.71).

Another performance measurement is the idle cash levels at both branches and ATMs.

This level can also be used to quantify the savings to the bank's cash operations. Table 5 presents the average idle cash levels and the cash level-to-total current accounts ratios from January 2015 to July 2016 at the Istanbul branches.

Table 5: Change In Total Idle Cash Levels At Istanbul Branches (Before And After The Implementation)

Month	Year	Average idle cash amount (million TL)	Total amount of current accounts (million TL)	Idle cash / Total current accounts ratio (%)
Jan	2015	114.4	3,134.8	3.65 %
Feb	2015	131.8	3,315.3	3.98 %
Mar	2015	136.1	3,458.9	3.94 %
Apr	2015	141.8	3,658.8	3.87 %
May	2015	147.0	3,871.3	3.80 %
Jun	2015	145.7	4,363.4	3.34 %
Jul	2015	147.4	4,196.6	3.51 %
Aug	2015	158.3	4,393.0	3.60 %
Sep	2015	171.4	4,687.9	3.66 %
Oct	2015	157.8	4,746.6	3.32 %
Nov	2015	154.8	4,804.6	3.22 %
Dec	2015	148.5	4,675.2	3.18 %
Jan	2016	146.7	4,895.8	3.00 %
Feb	2016	140.0	4,938.5	2.84 %
Mar	2016	131.7	4,938.0	2.67 %
Apr	2016	128.8	4,929.1	2.61 %
May	2016	144,6	5,231.9	2.76 %
Jun	2016	138.6	5,197.8	2.67 %
Jul	2016	148.9	5,216.0	2.86 %
Average from Jan 2015 to Jan 2016 (before implementation)		146.3	**4,169.4**	**3.54 %**
Average from April 2016 to July 2016 (after implementation)		140.2	**5,143.7**	**2.73 %**
Idle Cash Reduction Rate (%)				**22.88 %**
Savings on Current Accounts (Million TL)				**44.6**

Given that the model was deployed at the Istanbul branches throughout February and March 2016, comparing the average idle cash levels from January 2015 to January 2016 (before the implementation) with the average idle cash level from March 2016 to July 2016 would be wise. As the table illustrates, the application of the integrated model helped the bank reduce idle money levels at Istanbul branches by 22.88 %. Since the average interest rate on the market is approximately 10 %, the total savings can be calculated by multiplying the total reduction in idle cash level by 10 %; the bank has an opportunity to transfer that amount of money to its treasury to be utilized for other purposes. This finding means that the implementation helped the bank save approximately 4.46 million TL at the Istanbul branches alone.

Table 6: Change In Total Idle Cash Level At Atms (Before And After The Implementation)

Month	Year	# of ATMs in the Network	Average Idle Cash per ATM (1,000 TL)	Total Idle Cash at ATMs (1,000 TL)	Total Idle Cash If Not Optimized (Projected-1,000 TL)	Cash Savings (1,000 TL)
Jan	2015	378	102.9	38,893.9		
Feb	2015	391	99.2	38,788.7		
Mar	2015	394	102.2	40,282.7		
Apr	2015	395	126.3	49,891.8		
May	2015	399	101.2	40,369.4		
Jun	2015	400	101.4	40,540.0		
Jul	2015	404	105.0	42,411.6		
Average from Jan to Jul 2015			*104.9*	*41,596.9*		
Aug	2015	411	99.1	40,743.3		
Sep	2015	415	104.7	43,448.3		
Oct	2015	426	107.1	45,651.1		
Nov	2015	514	84.1	43,252.0	53,925.9	10,673.8
Dec	2015	535	90.0	48,131.1	56,129.1	7,997.9
Jan	2016	555	85.6	47,583.7	58,332.3	10,748.6
Feb	2016	561	70.8	40,853.6	60,535.5	19,681.9
Mar	2016	563	67.5	40,353.6	62,738.7	22,385.0
Apr	2016	571	75.6	43,183.2	59,906.0	16,722.7
May	2016	574	79.5	45,653.1	60,220.7	14,567.6
Jun	2016	575	85.9	49,363.8	60,325.6	10,961.8
Jul	2016	583	102.5	59,777.4	61,164.9	1,387.6
Average from Jan to Jul 2016			*81.1*	*46,681.2*		
Average Savings on the Idle Cash Level at ATMs						**12,791.9**

Table 6 presents the average idle cash levels at ATMs from January 2015 to July 2016. The table reveals that the average amount of cash retained at ATMs was 104,914 TL before the implementation of the optimization model in November 2015. However, the average amount of cash per ATM was reduced by 22.2 % to 81,059 TL after the implementation. The savings in July 2016 were minimal due to a week-long holiday in that month. The projected amount of total idle cash level in the 6th column was calculated by multiplying the average cash level per ATM by the number of ATMs in the network. From Jan 2015 thru Jul 2018 the bank increased the number of ATMs within the network by around 55% due to rapid expansion of both branch network and ATM network. Ultimately, the results indicate that the idle cash level in the ATM network was reduced by approximately 12.8 million TL on average. As the cost of idle cash on the financial markets is approximately 10 %, it is clear that the implementation of the model in the ATM network helped the bank reduce its opportunity cost by approximately 1.28 million TL annually. Thus, the total annual benefit of the reduced cash levels at the ATMs and the Istanbul branches reached as much as 5.74 million TL, which is equivalent to approximately 1.5 % of the total profits of the bank in 2015.

The reduction in idle cash levels stems from the following:

- Utilization of a powerful forecasting tool for the cash requirements;
- Optimization of the cash levels at the ATMs and branches by considering the expected CSL, operational costs and opportunity cost of idle cash;
- Effective and close monitoring of cash forecasts;
- Centralized cash management system at the bank.

Next, the CIT costs need to be analyzed to understand how they were influenced by the implementation of the model at the bank. Table 7 presents how the total CIT costs changed from January 2015 to July 2016 after the implementation of the integrated cash requirement forecasting and optimization model. The figures represent only part of the data, as the available data are only for the parts of the country in which a single CIT transportation company operates.

Table 7: CIT Cost Change From 2015 (Before The Implementation) To 2016 (After The Implementation)

Average Monthly Total CIT Costs (TL)		Number of Cash Points		Average Monthly CIT Costs (per Cash Points - TL)	
2015	2016	2015	2016	2015	2016
200.534	230.741	362	448	554	515

The results reveal that there was an improvement in CIT costs, albeit not a very significant one. The decrease in the average CIT costs per cash point was approximately 7.5 %, which is considerably less than the expected rate in the POC studies. There are several reasons for this finding. First, most of the bank's cash points are located outside Istanbul. In places outside Istanbul, the ATMs and branches are generally found at the same locations. Since the model has not been implemented at branches outside Istanbul to date, the availability of consolidated transportation remains limited. In addition, the bank continues to transfer to each cash point on most days. These reasons are believed to have prevented the CIT costs from decreasing as much as expected. However, once the model is implemented at branches outside Istanbul, the CIT costs are expected to decrease dramatically.

In summary, the results demonstrated that the accuracy of these forecasts is very high compared to similar studies in the literature, and the model substantially reduced the cash levels at both branches and ATMs without hurting the CSL. In addition, the implementation helped the bank slightly reduce its operational CIT costs. Traditionally, these two measures appear to conflict in cash supply chain models.

6. CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The objective of the study presented in this paper is to minimize the idle cash levels at branches and ATMs without decreasing CSL by providing the correct amount of cash at the correct place with the help of the integrated cash forecasting and cash inventory optimization tool. This study is one of the few real-world applications of cash optimization models presented in the literature. The proposed model was implemented in the cash network of a mid-sized bank in Turkey. The study demonstrates that the integrated models play a critical role in the optimization of cash operations, and the model is easy to implement in both ATM and branch networks. The results indicate that the proposed integrated model dramatically reduces the idle cash levels at both branches and ATMs for the bank.

To the best of our knowledge, the model is the first integrated model in the literature to be implemented for both ATMs and branches concurrently. Although the application of branch-level cash optimization models is very rare in the literature, the results are remarkable, and the decrease in idle cash levels at the branches is very high. This finding indicates the potential of branch-level cash optimization studies. The results revealed that the implementation of the model needs to be aligned with the appropriate processes and authority levels to be as effective as possible.

A deliberate analysis of the estimates revealed that utilization of seasonal indices plays a critical role in forecasting the cash requirements of a bank. More than one hundred seasonal indices are tested in the forecasting module to increase the accuracy of the estimates. Considering the number of ATMs in the network and the difficulty of estimating the cash requirements at each ATM owing to the changing nature of holidays, weekdays and religious holidays, the accuracy of the estimates (an MAPE value of approximately 26 %) is very high compared with the MAPE values presented in the literature. Given that the MAPE values in the literature are generally acquired by retrospectively applying models to historical data, the accuracy of the estimates in our study is very precise.

As previously noted, the model is the first in the literature to include the recycling feature of ATMs. The results demonstrated that by including deliberate seasonal indices and identifying recycling ATMs in the forecasting model, joint models can capture the cash requirements of recycling ATMs. Thus, the accuracy of the estimates (MAPE) does not substantially differ between recycling ATMs and non-recycling ATMs.

Another major finding of the study is that the implementation helped the bank reduce both the idle cash levels and the operational (CIT) costs. Traditionally, these two measures appear to conflict in cash supply chain models.

One of the limitations of the model is related to the predefined CSL defined in the model. Including CSL with a penalty factor as a decision variable would provide a means to optimize the desired CSL. Thus, researchers could investigate the changes in the total cost of cash operations associated with changing CSL at various cash points.

To enhance the developed model, it can be integrated with vehicle routing and optimization models. Vehicle routing, transportation and cash replenishment decisions may be made in a coordinated and optimized manner. To the best of our knowledge, there is no study in the current literature that includes both a vehicle routing model and a cash optimization model concurrently. Joint decisions would increase the effectiveness of the cash supply chains.

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