A Scheduling Model for Full Maintenance of Automated Teller Machines

Carlos Ilagan, Angelia Trinidad, John Lorenz Wee, Charlle Sy
Industrial Engineering Department
De La Salle University, Manila, Philippines
carlos_ilagan@dlsu.edu.ph, angelia_trinidad@dlsu.edu.ph, john_lorenz_wee@dlsu.edu.ph, charlle.sy@dlsu.edu.ph

Abstract

Strategies of financial institutions on cash replenishment and maintenance for a network of automated teller machines should be treated as a whole instead of independent of one another. Cash replenishment is a type of maintenance and having separate service providers conduct this type of maintenance adds costs and liabilities to the financial institutions. The optimal strategy to be employed focuses on the reduction of cash-related expenses, while maintaining the appropriate banknote-levels in each ATM; minimizing cash-dry instances on individual teller machines. With the increasing concern of financial institutions for customer satisfaction, the optimal strategy will also consider the amount of maintenance to be conducted for each ATM; minimizing downtime on individual teller machines. Factors such as daily service capacity, replenishment need, maintenance need, available time, travel time and service time are to be considered. The proposed model is able to solve situations where multiple machines are expected to breakdown on a certain day, as well as single replenishments spread throughout different days. Furthermore, the dynamic element of the scheduling problem enables the model to consider changes after new forecasts or behavior for replenishment or maintenance have been made for different teller machines, after the service schedule that had been initially made.

Keywords
Automated Teller Machine, Full Maintenance, Replenishment, Scheduling

1. Introduction

Retail financial services have continuously evolved at a great pace in the recent past. In this changing global financial services market, the role of a retail bank has continuously been redefined, specifically with respect to the provision of cash to a global society. Despite proposed movements to move into a cashless world, customers have continued to prefer cash as the method of payment in concluding their transactions (Adendorff and Kruger 2012). Given the situation, cash logistics or cash replenishment in automated teller machines (ATMs) has been a key operation that all retail banks have to deal with.

Cash logistics can be viewed as a supply chain with only one product involved: cash. The system deals with several factors and conditions; and financial institutions need to continuously adjust and operate under these constraints (Kurdel and Sebestyenova 2012). The resources that banks primarily use in cash logistics are the amounts of cash that are stored in ATMs, and the transportation teams that transfer cash through an ATM network. ATMs are usually stocked up with one up to four different types of banknotes or denominations, which are stored in containers called cassettes (Anholt and Vis 2012). ATMs allow customers to perform banking transactions such as withdrawing from one's account, conducting balance inquiries, transferring funds from one account to another, and conducting bill payments (Danlami and Mayowa 2014). The factors and conditions that banks operate under, on the other hand, are customer demand, calendar schedules, and machine breakdowns. Failure to determine a proper schedule for the replenishment of ATMs will lead to more costs that banks incur.

While amounts of cash being stored in ATMs contribute significantly to the cash logistics operations of a bank, financial institutions also need to consider ATM maintenance schedules; as the same amount of costs are used to transfer transportation teams from one machine to another. Considering cash replenishment as well as ATM maintenance schedules will not only avoid unnecessary costs in transportation, but also result to the minimization of downtime.

Mouton (2012) explains that factors such as the time of ATM usage, the location of the ATM itself, and its proximity among other ATMs are only some of the factors that contribute to the impact of a missed transaction on the performance on the ATM in customer service. In addition, a study conducted by Iberahim et al. (2016) mentions that reliability, as measured through consistency and dependability, should be given focus due to its significance in customers' satisfaction in ATM operations. Reliability in ATM systems is defined as having minimum errors and high uptime and cash backup (Adzmir et al. 2016).

The cash replenishment operation is key to take excess cash away, as well as supply cash to branches that are in need of more. A shortage situation becomes highly unacceptable for a branch because of the immediate customer perception that is involved. Bad service may result to ripple effects in the mind of a customer (Adendorff and Kruger 2012). Aside from the lack of cash in ATMs, the breakdown of automated teller machines is considered to be the primary reason for ATM downtime. Preventative maintenanceservice involves ATMs that regularly notify the server of equipment utilization data, which allows the server to gather and analyze preventative maintenance data. It is through equipment utilization that preventative steps before a breakdown actually occurs may be taken, which reduces the frequency of breakdowns of a teller machine. Financial institutions have extensively studied and resolved problems in cash replenishment since this is an aspect of banking operations that can easily be observed. Much data can be collected from each teller machine, given that the different transactions are constantly recorded (Sampang 2018). Given that cash withdrawals and deposits were the primary functions to be performed by customers, banks always made sure that cash inside teller machines were well-replenished. It was only in the last decade that personal services had been given more importance and is currently the primary differentiating factor for customer satisfaction. Therefore, the integration of both replenishment and maintenance creates a full maintenance model that will maximize automated teller machines' uptime.

Furthermore, the current practice in industry between banks and ATM manufacturers is a primary 5-year maintenance coverage for the machines that manufacturers supply. It is only after this coverage that banks need to provide continuous maintenance for the machines in its possession (Diebold 2013). Previous studies have only included cash replenishment in their researches since they worked under the assumption that cash replenishment is the only operation that banks want to consider (Sampang 2018). This, however should not be the case. To consider the benefit of third-party operators, as well as financial institutions who are operating teller machines that have succeeded the primary maintenance coverage, both the operations of cash replenishment and maintenance need to be included into one full maintenance model. Aside from ensuring the maximum availability of ATMs due to the increase in their reliability through proper scheduling, immediate and instant ATM maintenance procedures contribute to more business transactions within the day for both the bank and its clients. It offers more convenience for customers even outside the bank's area; in addition, availability of ATMs increases the bank's customer reach without having the need to open a new branch, given the increase in geographical location and 24/7 availability of a working ATM. No withdrawal and deposit slips are needed to be filled out, easing the transaction process on the customer's side. Unavailable ATMs, both off-site and on-site, may result to customers going to banks to make immediate and important transactions. This will result to massive amount of customers waiting in line to be served, causing irritation among customers. Also, given the inherent nature of ATMs to experience random and unpredictable breakdowns, a proper scheduling model will help address the reactive nature of the bank's maintenance procedures and promote a proactive means to solve such issues.

2. Model Formulation

A linear programming model was developed to determine the optimal maintenance schedule given a small network of automated teller machines positioned in different locations. The model considers assumptions regarding the operating hours of armored vehicles, proactive service constraints, service warranty constraints, and replenishment constraints. The model considers full maintenance, which considers both service maintenance and ATM replenishment. Table 1 presents the indices, parameters and decision variables used in the following model formulation.

Table 1: Indices, parameters and decision variables

Notation	Definition
i	Day
k	Automated Teller Machine Location
$SWARRANTY_k$	Amount of time ATM unit k is guaranteed to work continuously
$TRVLTIME_{kk'}$ $SERVTIME_{kl}$	Travel time from ATM unit k to k' Amount of time needed to service ATM unit k by armored vehicle l
$AVLTIME_l$	Available time of each armored vehicle to service units in one shift
$CURRAMT_{ik}$	Current amount of ATM unit k in day i
$DECAMT_{ik}$	Decrease in amount of ATM unit k in day i
$REPSS_k$	Replenishment safety stock level for each ATM unit k; Standard is set at 40% capacity
$REPCAP_k$	Replenishment maximum cap level for each ATM unit k; Standard is set at 90% capacity
$WORK_{ik}$	Binary variable; 1 if ATM unit k is working on day i, 0 otherwise
FIX_{ik}	Binary variable; 1 if ATM unit k is fixed (serviced) on day i, 0 otherwise
$POINT_{ikl}$	Sequence of ATM unit k in routing service on day i by armored vehicle
$SERV_{ikl}$	Binary variable; 1 if ATM unit k is serviced on day i, by armored vehicle
REP_{ikl}	Binary variable; 1 if ATM unit k is replenished on day i, by armored vehicle l
$ROUTE_{kk'i}$	Binary variable; 1 if route from ATM unit k to k' on day i is taken, 0 otherwise

The objective function of the model is to maximize the available ATMs in the network. This means acquiring the total machines that are working and are fixed for each time period. While maximizing availability, many other constraints are considered.

$$MAX\ Availability = \sum_i \sum_k (WORK_{ik} + FIX_{ik}) \tag{1}$$

The model constraints include the available time as defined in (2); it indicates the time a vehicle has to service ATM units together with the travel time it takes from unit to unit. Equation (3) introduces proactive service that dictates the machine will be serviced either the day before its expected breakdown, or on the day of its expected breakdown, while (4) indicates that the machine can only be serviced one of the two days. Equation (5) establishes a service warranty that indicates an ATM is expected to stay fixed after it is serviced, while (6) indicates that an ATM unit should only be classified as either fixed or working, and not both.

$$\sum_k \sum_l SERVTIME_{kl}\,(SERV_{ikl}) + \sum_k \sum_l TRVLTIME_{kk'}\,(ROUTE_{kk'l}) \le AVLTIME_l \tag{2}$$

$$1 - WORK_{ik} \le SERV_{i-1\,kl} + SERV_{ikl} \tag{3}$$

$$SERV_{i-1\,kl} + SERV_{ikl} \le 1 \tag{4}$$

$$SERV_{i-1\,kl} + SWARRANTY_k(1 - WORK_{i+1\,k}) = FIX_{ik} + FIX_{i+1\,k}\,(1 - WORK_{i+1\,k}) \tag{5}$$

$$FIX_{ik} + WORK_{ik} \le 1 \tag{6}$$

The current amount of each machine is indicated by (7); the decrease in the amount present in an ATM is deducted from the amount of the previous period. Equation (8) indicates that the money level inside the ATM should not be less than the safety stock. If the level is lower than the safety stock, then the replenishment is triggered for that ATM unit to be serviced on a specified time period. Equation (9) sets a limit on the replenishment capacity for each machine; the current amount should not surpass this level. Finally, the full maintenance constraint in (10) indicates that when an ATM is replenished, it is automatically serviced, as well; however when the ATM is serviced, it does not necessarily mean it is replenished.

$$CURRAMT_{i-1\,k} - DECAMT_{ik} = CURRAMT_{ik} \tag{7}$$

$$CURRAMT_{ik} \leq REPSS_k + M\,(1 - REP_{ikl}) \tag{8}$$

$$CURRAMT_{ik} \geq REPCAP_k - M\,(1 - REP_{ikl}) \tag{9}$$

$$REP_{ik} \leq SERV_{ik} \tag{10}$$

3. Model Validation

The model was validated using Microsoft Excel Solver. The discussed objective function and corresponding constraints were coded into the program. A Monte Carlo Simulation process was used to generate values with ranges based on ATM data, for the following model inputs:

1. Status of the ATM Unit - This is used to determine when there will be a need to service a machine given this occurrence of breakdowns considering that it needs to be proactive. The parameter is binary as it represents only if the machine is working (1) or if it is down (0).
2. Decrease in Cash Levels - To reflect the usage of the ATMs, daily cash withdrawals, in percentage, were generated for the decrease in cash levels. The ranges vary from 5 to 35% which was taken from interviews and data of banking institutes in Metro Manila.
3. Initial Cash Levels - Initial cash levels which were randomized from 50-100% were generated to use as inputs in the model, supported by the decrease in cash levels that was previously simulated.
4. Machine Location Coordinates - For routing purposes, location coordinates were generated. The scale used was 10x10, representing a general fixed scope for the full maintenance service.
   Distance and Travel Time between Machines (Based on Coordinates)
   - Based on the coordinates, the distance between machines and the cash center was computed. The travel time was computed based on the assumed speed of the vehicle that is 40 kph, in order to accommodate varying traffic conditions. The travel time will be used in determining how many and which machines can be accommodated in one period.
5. Service Time - Similar to travel time, service time was generated to determine how many and which machines can be accommodated in a day. The *randbetween* function was also used following a time range based on data from financial institutes in Metro Manila.

The model validation uses a Case-Study Approach with the simulated model inputs, with a system of twenty machines and seven days. The results are shown in Figure 1.

Full Maintenance Schedule							
ATM/Day	1	2	3	4	5	6	7
1	1	1	0	0	1	0	0
2	0	0	1	0	0	1	0
3	1	0	1	0	1	0	1
4	0	0	1	0	1	0	1
5	1	1	0	0	0	1	0
6	0	1	0	0	0	1	0
7	0	1	0	0	1	0	0
8	1	0	0	1	0	0	0
9	0	0	0	1	0	0	0
10	0	1	0	1	0	1	0
11	1	0	0	0	1	0	0
12	1	0	1	0	0	1	0
13	0	1	0	0	1	0	0
14	1	0	0	1	0	0	1
15	1	0	0	1	0	0	1
16	0	1	0	0	1	0	0
17	1	0	1	0	0	1	0
18	1	0	1	1	0	0	1
19	0	1	0	1	1	0	0
20	0	0	1	1	0	1	0

Figure 1. Full Maintenance Schedule

According to the Replenishment and Maintenance need of the ATMs, a Full Maintenance Schedule was formulated. It can be observed that ATMs are serviced at least once a week and up to four times in a week, depending on its usage and forecasted breakdown behavior.

Service Monitoring														
	1		2		3		4		5		6		7	
ATM\Day	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
1	1	1	0	1	0	1	0	1	0	1	1	1	1	1
2	1	1	1	1	1	1	0	1	0	1	0	1	1	1
3	0	1	1	1	0	1	0	1	1	1	0	1	0	1
4	1	1	1	1	1	1	0	1	1	1	0	1	1	1
5	0	1	1	1	0	1	0	1	1	1	1	1	1	1
6	0	1	0	1	0	1	1	1	1	1	1	1	1	1
7	1	1	0	1	0	1	1	1	0	1	0	1	0	1
8	0	1	1	1	1	1	0	1	1	1	1	1	1	1
9	0	1	1	1	1	1	1	1	0	1	1	1	1	1
10	0	1	0	1	1	1	1	1	1	1	0	1	1	1
11	0	1	1	1	0	1	1	1	0	1	0	1	0	1
12	0	1	0	1	1	1	1	1	0	1	1	1	0	1
13	0	0	1	1	1	1	1	1	1	1	0	1	0	1
14	1	1	0	1	1	1	0	1	1	1	1	1	0	1
15	1	1	1	1	0	1	0	1	0	1	1	1	1	1
16	0	0	1	1	1	1	1	1	0	1	0	1	0	1
17	1	1	0	1	0	1	1	1	0	1	0	1	1	1
18	0	0	0	1	0	1	0	1	1	1	1	1	1	1
19	0	0	1	1	0	1	1	1	1	1	1	1	1	1
20	0	0	1	1	0	1	1	1	0	1	0	1	1	1
TOTAL		15		20		20		20		20		20		20

Figure 2. ATM Status Monitoring

Following the resulting Full Maintenance Schedule, Figure 2 displays the status of each machine. The start column represents the forecasted behavior of the machine (1 for working and 0 for breakdown) and the end column represents the behavior of the machine after the service operations based on the formulated schedule. It can be observed that six out of seven days have 100% availability of machines, resulting from the practice of a a proactive maintenance schedule instead of a reactive one. The 75% availability on the first day, may be due to the dependency of the model to multiple days. Since it is the first day in the model and is not linked to any previous days, it serves as a warm up point for the proactive maintenance cycle.

4. Conclusions

A scheduling model for the full maintenance of automated teller machines considering a proactive approach was developed and proposed in this study. The model proposed considered assumptions for constraints regarding the operating hours of armored vehicles, proactive service, service warranty, and replenishment. The model considers full maintenance, which considers both service maintenance and ATM replenishment as it is essential for financial institutions to conduct their automated teller machine operations with regard to both of these aspects.

This study conducted a case study approach validation process that considered a number of ATMs being serviced by one armored vehicle through a fixed time period of one week. Considering different constraints, the model was able to determine a full maintenance schedule that indicates which ATMs to be serviced on different days.

Moving forward, factors such as the number of armored vehicles able to service the network of ATMs should be considered. Second, different routes from one ATM location to another ATM location will play a factor in the scheduling model. Considering traffic will affect the travel times of the armored vehicles, and therefore, will affect the amount of time left to service each machine. Furthermore, appropriate distribution functions should also be used for the determination of ATM service time, as well as decrease of ATM cash levels.

The following recommendations will be able to predict a more accurate behavior of the teller machines, and therefore, may also lead to a more accurate scheduling model for the full maintenance of automated teller machines.

References

Adendorff, S., and Kruger, P. S., A decision support model for the cash replenishment process in South Africa retail banking, *The South African Journal of Industrial Engineering,* vol. 11, no.2, pp. 17-27, 2012.

Danlami, M., and Mayowa, D., An empirical investigation of automated teller machines (ATMs) and customers' satisfaction in Nigeria: A case study of Ilorin, Kwara State. Faculty of Social Sciences, Kogi State University, Anyigba, P.M.B 1008, Anyigba; Kogi State, Nigeria. Retrieved from MPRA Paper No. 59757, 2014.

Diebold Nixdorf, Inc., First line Maintenance. Official document: Comprehensive services, 2013.

Iberahim, H., Mohd Taufik, N., Mohd Adzmir, A., and Saharuddin, H., Customer satisfaction on reliability and responsiveness of self-service technology for retail banking services, *Procedia Economics and Finance*, vol. 37, pp. 13-20, 2016.

Kurdel, P., and Sebestyenova, J. Modeling and optimization of ATM cash replenishment, *Latest Trends in Information Technology*, pp. 322-327, 2012.

Mouton, A. Development of an improvement ATM service level model, Built Environment and Information Technology: University of Pretoria, 2012.

Sampang, R. (2018, June 4). Personal Interview. (C. Ilagan, Interviewer).

Van Anholt, R., and Vis, I. Real-time performance measurement system for automated teller machines, *Proceedings of the 2012 Winter Simulation Conference*, Berlin, Germany, December 9-12, 2012

Biographies

Carlos Ilagan is currently an undergraduate student in the Department of Industrial Engineering student in De La Salle University- Manila, Philippines.

Angelia Trinidad is currently an undergraduate student in the Department of Industrial Engineering student in De La Salle University- Manila, Philippines.

John Lorenz Wee is currently an undergraduate student in the Department of Industrial Engineering student in De La Salle University- Manila, Philippines.

Charlle Sy is an Associate Professor in the Department of Industrial Engineering at De La Salle University, Manila, Philippines. She earned her B.S. and M.S. in Industrial Engineering from the same university. Meanwhile, she obtained her PhD in Industrial and Systems Engineering in the National University of Singapore, Singapore. She has published in Scopus-indexed journals and conference papers and had completed research projects in the energy, service and semiconductor industries. Her research interests include optimization under uncertainty, energy networks, supply chains, and system dynamics.