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# A framework for evaluating the performance of automated teller machine in banking industries: A queuing model-cum-TOPSIS approach

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A B S T R A C T

The improvement in the provision of banking services to customers enhances bank's performance (profitability and productivity) and the amounts of dividend declared to shareholders as well as bank's competitiveness. One means of fast tracking the service time for bank customers is through the use of self-servicing machines, such as automated teller machine (ATM). Total service cost, expected waiting time in queue, ATM utilization and percentage of customer loss are some of the performance indices that are used to evaluate the service rendered by a bank's ATM. This study proposes a framework for evaluating the performance of ATM by integrating queuing model and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methodology. Applicability of the framework was tested using practical data obtained from four banks in Nigeria. It was observed that the average ATM usage in the study area was less than 50%. The TOPSIS results identified Bank A as the best ranked bank. In addition, the results obtained revealed that banks with two ATM were ranked higher than banks with more than two ATM.



## 1. Introduction

The introduction of self-servicing machine known as Automated Teller Machine (ATM) has helped banks in transferring part of the control of cash withdrawal and money transfer to their customers during working and off-working periods. This has improved the interrelationships between bank and their customers. Apart from the ability of banks to provide this banking service through the use of ATM at off-working periods, the provision of ATM at strategic locations has helped in reducing the number of customers in banking halls (Dilijonas et al., 2009; Olatokun & Igbinedion, 2009; Asabere et al., 2012). Other benefits of ATM are: transfer of funds, payment of bills, display of promotional messages and purchase of Global Systems for Mobile (GSM) communication credits (Asikaogu & Mbegbu, 2012; Adeoti, 2011). These services are provided using modern Information and Communication Technology (ICT) facilities.

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The reduction of customers at banking halls has aided banks in reducing the number of tellers at the banking halls. This has led to the reduction of workforce cost on the part of management, while for customers, the stress of going to banking hall to queue for financial transactions has been reduced considerably (Awodele & Akanni, 2012). The probability of customers to use the ATM is influenced by the number of withdraw per period and the time spent at the ATM point (Sowunmi et al., 2014). The problem of low service rate of ATM which causes queue at ATM locations is a major determinant of the ATM usage. Surcharges and the features of an ATM do not always affect the use of the ATM significantly (Asikaogu & Mbegbu, 2012).

The type of ICT (ATM banking, internet banking, credit card transactions and mobile device banking) used by banks affects their service delivery rate, customers' retention and market penetration (Surjadjaja et al., 2003; Asabere et al., 2012). Low service rate affects the number of transaction made at any particular time. This has led to customers wanting to use banks with good ATM services. The low service rate of ATM is usually attributed to network failure, operating system of ATM and interconnectivity problems among banks (Jegede, 2014).

The problem of customers being robbed or their personal identification numbers (PIN) memorised by fraudster when handled carelessly are other challenges of ATM usage. The activities of fraudsters have resulted in financial losses for banks and customers (Awodele, & Akanni, 2012). These problems are common in areas where the arrival rate of ATM users is high (Olatokun & Igbinedion, 2009). However, the benefits of using ATM supersede these challenges and its usage continues to spread to areas where it is not currently in use. The satisfaction level which customers derived from ATM usage is affected by the duration spent at queue (Odusina, 2014). The quality of service provided by the ATM serves as a mean of improving bank's competitiveness. It also enhances the relationships between the banks and their customers (McAndrews, 2003). Although, the service rate of teller in banking halls could be more than that of ATM. There is still need to study ATM service rate as it affects customer's waiting time (Laderman, 1990). This will help in determining the actual number of ATM required for a given location. Literature search showed that the application of queuing theory for ATM serve rate analysis is sparse. Also, the analysis of how to rank the performance of ATM among banks appears to under reported in the literature to the best of our knowledge. A study that bridges the above knowledge gaps will improve the analysis of ATM performance for informed decision making. These knowledge gaps motivated the need for this study.

The aim of this study was to rank bank ATM service based on selected performance indices. This was achieved by the proposed a framework which integrates queuing model and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methodology. The queuing model was used to determine the value of bank's ATM performance, while the TOPSIS was used to rank of bank's performance based on the queuing model results.

## 2. Methodology

The following notations are used to present the various performance indices used in the proposed queuing-TOPSIS framework.

| | |
|---|---|
| $\lambda_n$ | arrival rate of customers in a system |
| $\mu_n$ | service rate of customer in a system |
| C | number of available servers. |
| $P_n$ | steady-state probability of customers in a system |
| $P_o$ | probability of first person in a system |
| $\rho$ | utilisation factor |

| | |
|---|---|
| $c_w$ | amount allocated for waiting in hour |
| $c_f$ | amount allocated for servicing ATM per day |
| $c_r$ | amount allocated for redundancy of ATM per day |
| *FIFO* | first in, first out (queuing discipline) |
| $F_{cm}$ | service cost |
| $L_s$ | expected number of customers in a system |
| $L_q$ | expected number of customers in a queue |
| $R_{cm}$ | redundant cost |
| $R$ | expected number of idle servers |
| $T_c$ | total costs |
| *TRW* | total profit lost |
| $U(Rho/c)$ | facility utilisation |
| $\lambda_{eff}$ | lambda effective which is equal to λ in multiple server model |
| M/MC: FIFO | arrival rate/ departure rate/number of services: queue discipline/system limit (infinity)/source (infinity) |
| $W_s$ | expected waiting time in a system |
| $W_q$ | expected waiting time in a queue |
| $W_{cw}$ | waiting cost |
| $N_m$ | mean number of customers in the system |

*2.1 Conceptual framework*

The framework that is proposed for ATM performance ranking is based on the evaluation of the ATM performance using queuing model and TOPSIS methodology (Fig. 1).

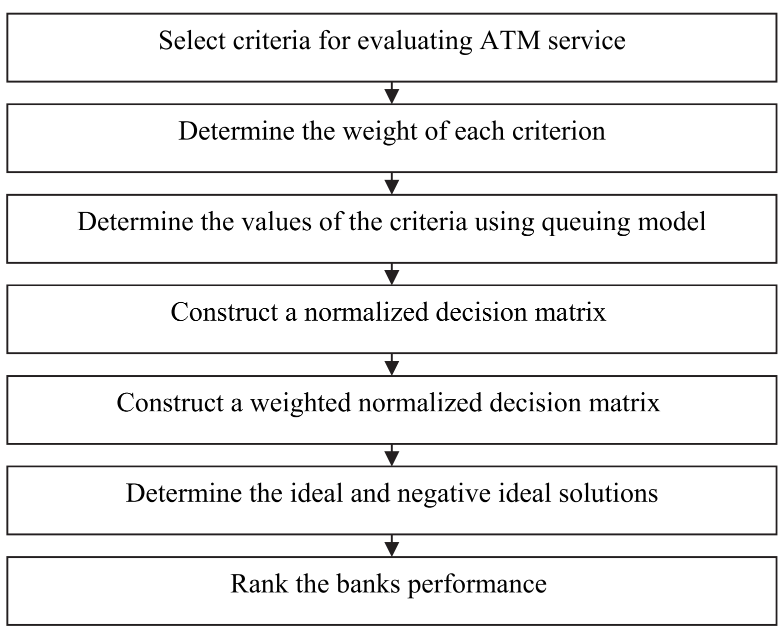


**Fig. 1.** Conceptual framework for bank's ATM service ranking

*2.2 Queuing Model for Self-Service Machine*

In self-service machines (ATM), the queuing model assumes multi-server concept in which arrival and service rates follow a Poisson distribution pattern with finite parallel servers. But they have infinite system and source (Taha, 2007). The main inputs to the proposed framework are arrival rate (λ) and service rate (μ) of customers to be served. The outputs are performance indices such as customers waiting time in a queue ($W_q$) and in system ($W_s$), length of a queue ($L_q$) and system ($L_s$), percentage of ATM utilisation and probability of *n* customers in a system.

The service discipline of the ATM is considered as first-come, first-served (FCFS) which is expressed as a (M/M/c): (FCFS∞/∞) model from which the other factors are determined (Taha, 2007). The service rate of *n* customers in the system is expressed as Eq. (1). The expression for ATM utilisation is given by Eq. (2).

$$\mu_n = \begin{cases} n\mu & n < 0 \\ c\mu & n \geq c \end{cases} \quad \forall n \tag{1}$$

$$\rho = \frac{\lambda}{\mu} \tag{2}$$

The steady-state probability of *n* customers in a system is expressed as Eq. (3), while the sum of all the steady-state probability is given by Eq. (4a) and Eq. (4b).

$$P_n = \begin{cases} \dfrac{\lambda^n}{n!\,\mu^n} P_o & n > c \\ \dfrac{\lambda^n}{c!\,c^{n-c}} P_o & n \geq c \end{cases} \quad \forall n \tag{3}$$

$$\sum_{n=0}^{\infty} P_n = \sum_{n=0}^{c-1} \frac{\rho^n}{n!} P_o \tag{4a}$$

$$\sum_{n=0}^{\infty} P_n = \sum_{n=0}^{\infty} \frac{\rho^n}{c!\,C^{n-c}} P_o \tag{4b}$$

By combining Eq. (4a) and Eq. (4b), and separating variables, the value of $P_o$ is expressed as Eq. (5).

$$p_0 = \frac{\sum_{n=0}^{\infty} p_n}{\left( \sum_{n=0}^{c-1} \frac{\rho^n}{n!} + \sum_{n=c}^{\infty} \frac{\rho^n}{c!\,c^{n-c}} \right)} \tag{5}$$

$$\sum_{n=0}^{\infty} P_n = 1 \tag{6}$$

$$\frac{\rho}{c} < 1 \tag{7}$$

The sum of all probability is equal to 1 (6). By considering Eq. (7), Eq. (5) is simplified as Eq. (8).

$$P_o = \left( \sum_{n=0}^{c-1} \frac{\rho^n}{n!} + \frac{\rho^n}{c!} \left( \frac{1}{1-\rho/c} \right) \right)^{-1} . \tag{8}$$

When $P_o$ is determined, the expected number of customers in a queue (Lq) is given by Eq. (9). The expected number of customer in a system (Ls) is expressed as Eq. (10), while the expected waiting time of customers in a queue (Wq) is expressed as Eq. (11). Eq. (12) is used to determine the expected waiting time of customers in a system. The percentage utilisation of ATM (*U*) is given by Eq. (13), while the percentage of customers' loss (*L*) is expressed as Eq. (14).

$$L_q = \frac{\rho^{c-1}}{(c-1)!(c-\rho)^2} P_0 , \tag{9}$$

$$L_s = L_q + \rho , \tag{10}$$

$$W_q = \frac{L_q}{\lambda} , \tag{11}$$

$$W_s = W_q + \frac{1}{\mu} , \tag{12}$$

$$U = \frac{100\lambda}{c\mu} , \tag{13}$$

$$L = P_o \lambda , \tag{14}$$

where $c$ is the number of services.

The service provided by a machine is considered as automatic and the service duration is assumed to be constant. Under these conditions, the service-time distribution has a variance of zero (Blanchard & Fabrycky, 2010). For the ATM case, the service duration is constant as the number of customers tends towards 30 and above. The mean number of customers in the system is expressed as Eq. (15), while the mean waiting time of ATM is given by Eq. (16).

$$n_m = \frac{\left(\lambda/\mu\right)^2}{2\left(1-\left(\lambda/\mu\right)\right)} + \frac{\lambda}{\mu} , \tag{15}$$

$$W_m = \frac{\lambda/\mu}{2\mu\left(1-\lambda/\mu\right)} + \frac{1}{\mu} . \tag{16}$$

The expected waiting cost per period is the product of waiting per unit per period and the mean number of units in the system (17). The expected facility cost per period is the product of the cost of servicing one unit and the service rate in units per period (18).

$$W_{cm} = C_w \left( \frac{\left(\lambda/\mu\right)^2}{2\left(1-\left(\lambda/\mu\right)\right)} + \lambda/\mu \right) , \tag{17}$$

$$F_{cm} = C_f \mu . \tag{18}$$

The expected total system cost per period is the sum of the expected waiting cost per period and the expected facility cost per period (Blanchard & Fabrycky, 2010) and it is expressed as Eq. (19).

$$T_{cm} = C_w \left( \frac{\left( \lambda / \mu \right)^2}{2\left(1 - \left( \lambda / \mu \right)\right)} + \lambda / \mu \right) + C_f \mu . \quad (19)$$

*2.3 TOPSIS*

The use of single performance index in evaluating the performance of a system tends to bias the judgement of decision makers. This problem becomes more obvious when such performance index computation involves the interaction among several parameters. To address the shortcomings of using single performance index, different multi-criteria modelling approaches have been proposed. Some of these are SAW (Hwang & Yoon, 1981), PROMETHEE (Brans et al., 1984). TOPSIS (Hwang & Yoon, 1981, 1994), AHP (Saaty, 1988) and ELECTRE (Roy, 1968, 1991). They seek to generate single values for each option for a course of action. This study selects TOPSIS because of its ease to understand and apply when compared with AHP and ELECTRE. TOPSIS makes use of proportional distance of each option negative idea and ideal solution in generating the rank for each option. The implementation of TOPSIS involves the following procedure (Jadidi et al., 2008; Afkham et al., 2012; Bhutia & Phipon, 2012):

(i.) Normalisation of the various performance indices in a decision matrix (20)

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{n} f_{ij}^{\,2}}} \qquad \forall (i, j) \quad (20)$$

(ii.) Design of a weighted normalized decision matrix by multiplying the normalized decision matrix with weight vectors (21).

$$V_{ij} = w_i r_{ij} \qquad \forall (i, j) \quad (21)$$

where $w_i$ is weight assigned to performance index $i$.

(iii.) Determination of the ideal (22) and negative ideal (23) solutions for each of the performance index using information contained in the weighted normalized decision matrix. The value of ideal solution depends on the preferred direction of each performance index.

$$A^{+} = \{v_1^{+}, \cdots, v_i^{+}\} = \left\{ \left( \max v_{ij} \middle| i \in I' \right), \left( \min_j v_{ij} \middle| i \in I'' \right), \right\} \quad (22)$$

$$A^{-} = \{v_1^{-}, \cdots, v_i^{-}\} = \left\{ \left( \min v_{ij} \middle| i \in I' \right), \left( \max_j v_{ij} \middle| i \in I'' \right), \right\} \quad (23)$$

where $I'$ is the maximum performance index value, and $I''$ is the minimum performance index value.

(iv.) Determination of the distance of each bank performance indices from ideal (24) and negative ideal solutions (25).

$$D_j^+ = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^+\right)^2} \qquad \forall j \tag{24}$$

$$D_j^- = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^-\right)^2} \qquad \forall j \tag{25}$$

(v.) Calculation of the rank of each bank using the proportional distance of each bank to its negative ideal solution (26).

$$R_j = \frac{D_j^-}{D_j^+ + D_j^-} \quad \forall j \tag{26}$$

## 3. Model Implementation and Discussion of Results

The proposed framework applicability was demonstrated using a case study drawn from four banks located in Ibadan, Nigeria. The choice of the case study was based on concentration of banks in the study area (Anyaeche et al., 2015). During the study, it was observed that congestion in queuing system takes place during two peak periods. The peak periods were between morning (8.00 a.m. to 11.00 a.m.) and evening (4.00 p.m. to 7.00 p.m.) periods. Data was collected also at night periods. The study hour was between 8.00 a.m. to 11.00 a.m. in the morning, 12.00 p.m. to 3.00 p.m. in the afternoon and 4.00 p.m. to 7.00 p.m. in the evening. Information on the arrival rate, service rate and queue length were collected at 1 hr interval for 30 days. Based on the analysis of the information obtained, different values of $\lambda$ and $\mu$ were determined for different days (Table 1).

**Table 1**
The arrival and service rates of each of the banks

| | Bank A | | Bank B | | Bank C | | Bank D | |
|---|---|---|---|---|---|---|---|---|
| **Days** | $\lambda$ | $\mu$ | $\lambda$ | $\mu$ | $\lambda$ | $\mu$ | $\lambda$ | $\mu$ |
| 1 | 9 | 10 | 42 | 51 | 40 | 44 | 51 | 78 |
| 2 | 7 | 10 | 41 | 53 | 36 | 48 | 54 | 73 |
| 3 | 14 | 18 | 42 | 56 | 36 | 47 | 55 | 73 |
| 4 | 13 | 13 | 45 | 59 | 39 | 51 | 56 | 75 |
| 5 | 14 | 12 | 48 | 57 | 39 | 47 | 52 | 68 |
| 6 | 16 | 15 | 44 | 51 | 40 | 48 | 59 | 67 |
| 7 | 15 | 14 | 49 | 56 | 38 | 47 | 59 | 75 |
| 8 | 11 | 13 | 42 | 58 | 38 | 47 | 57 | 76 |
| 9 | 8 | 16 | 43 | 51 | 38 | 49 | 61 | 70 |
| 10 | 16 | 18 | 50 | 55 | 43 | 45 | 53 | 66 |
| 11 | 14 | 11 | 43 | 57 | 40 | 50 | 61 | 72 |
| 12 | 11 | 13 | 48 | 54 | 36 | 45 | 52 | 79 |
| 13 | 16 | 16 | 48 | 50 | 37 | 46 | 60 | 68 |
| 14 | 15 | 18 | 47 | 58 | 35 | 48 | 55 | 74 |
| 15 | 8 | 16 | 42 | 59 | 39 | 45 | 58 | 66 |
| 16 | 10 | 17 | 44 | 53 | 37 | 46 | 58 | 79 |
| 17 | 12 | 17 | 46 | 59 | 42 | 43 | 54 | 76 |
| 18 | 12 | 17 | 42 | 52 | 36 | 44 | 61 | 72 |
| 19 | 14 | 10 | 46 | 53 | 42 | 50 | 53 | 78 |
| 20 | 15 | 15 | 47 | 55 | 36 | 52 | 60 | 68 |
| 21 | 10 | 14 | 45 | 51 | 37 | 51 | 55 | 70 |
| 22 | 16 | 19 | 42 | 56 | 42 | 47 | 57 | 72 |
| 23 | 8 | 16 | 43 | 50 | 43 | 44 | 55 | 65 |
| 24 | 7 | 15 | 48 | 55 | 36 | 44 | 51 | 65 |
| 25 | 9 | 17 | 47 | 58 | 38 | 51 | 58 | 75 |
| 26 | 15 | 14 | 42 | 60 | 38 | 48 | 53 | 73 |
| 27 | 13 | 17 | 49 | 51 | 41 | 43 | 54 | 76 |
| 28 | 11 | 12 | 46 | 54 | 39 | 47 | 57 | 76 |
| 29 | 10 | 18 | 41 | 54 | 38 | 48 | 55 | 68 |
| 30 | 9 | 13 | 48 | 53 | 41 | 45 | 54 | 80 |

Based on the information in Table 1, the average values for Ls, Wq, Ws, loss, utilization and total cost for each of the banks were estimated (Table 2).

**Table 2**

Decision matrix of the study

| Banks | Ls | Wq (hr) | Ws (hr) | Loss | Utilisation (%) | Total cost (₦) |
|---|---|---|---|---|---|---|
| A | 1.2278 | 0.0298 | 0.0999 | 0.4245 | 41.3935 | 61528.71 |
| B | 0.8479 | 0.0005 | 0.0189 | 0.3341 | 27.5605 | 228849.10 |
| C | 1.1799 | 0.0090 | 0.0304 | 0.4361 | 41.3238 | 199144.70 |
| D | 0.7744 | $9.6800 \times 10^{-6}$ | 0.0139 | 0.2824 | 19.3467 | 302847.30 |

By using Eq. (20), the normalized decision matrix for the banks was generated (Table 3). The weighted normalized decision matrix in Table 4 was obtained based on Eq. (21). The weight ($w_i$) for each of the performance indices was 0.1667.

**Table 3**

Normalised decision matrix of the study

| Banks | Ls | Wq (hr) | Ws (hr) | loss | Utilisation (%) | Total cost (₦) |
|---|---|---|---|---|---|---|
| A | 0.5978 | 0.9574 | 0.9336 | 0.5664 | 0.6133 | 0.1420 |
| B | 0.4128 | 0.0149 | 0.1763 | 0.4458 | 0.4084 | 0.5285 |
| C | 0.5745 | 0.2886 | 0.2837 | 0.5818 | 0.6123 | 0.4600 |
| D | 0.3771 | 0.0003 | 0.1297 | 0.3768 | 0.2867 | 0.6993 |

**Table 4**

Normalised weighted decision matrix of the study

| Banks | Ls | Wq (hr) | Ws (hr) | loss | Utilisation (%) | Total cost (₦) |
|---|---|---|---|---|---|---|
| A | 0.0997 | 0.1596 | 0.1556 | 0.0944 | 0.1022 | 0.0237 |
| B | 0.0688 | 0.0025 | 0.0294 | 0.0743 | 0.0681 | 0.0881 |
| C | 0.0958 | 0.0481 | 0.0473 | 0.0970 | 0.1021 | 0.0767 |
| D | 0.0629 | $5.1800 \times 10^{-5}$ | 0.0216 | 0.0628 | 0.0478 | 0.1166 |

Performance indices *Ls, Wq, Ws*, loss and total cost were considered as performance indices whose minimum values were desired. ATM utilization was considered as a performance index whose maximum value was desired. Based on these explanations of the performance indices directions, the ideal and negative solutions for each of the performance indices were calculated (Table 5).

**Table 5**

Ideal and negative ideal solutions

| Solutions | Ls | Wq (hr) | Ws (hr) | Loss | Utilisation (%) | Total cost (₦) |
|---|---|---|---|---|---|---|
| Ideal | 0.0629 | $5.1824 \times 10^{-5}$ | 0.0216 | 0.0628 | 0.1022 | 0.0237 |
| Negative ideal | 0.0997 | 0.1596 | 0.1556 | 0.0970 | 0.0478 | 0.1167 |

Based on the information in Tables 4 and 5, the distances of the ideal and negative ideal solutions were estimated (Table 6).

**Table 6**

Distances of each bank solution from the ideal and negative solutions

| Solutions | Bank A | Bank B | Bank C | Bank D |
|---|---|---|---|---|
| Ideal | 0.2185 | 0.0340 | 0.0990 | 0.0990 |
| Negative ideal | 0.0981 | 0.0723 | 0.0526 | 0.2185 |

From the information in Table 6 and Eq. (26), Bank A (0.6901) was ranked first among the four banks based on the six performance indices that were considered. Thus, it is suffice to say that the number of ATM in Bank A should be retained. The second ranked bank was Bank C (0.6533), it has the second highest ATM utilization value and total cost of retaining ATM. Bank B (0.3201) was the third ranked bank. Bank D (0.3118) was the last ranked bank. Although, Bank D had the lowest value of the expected waiting time of customers, there is the need for the management to reduce the number of ATM. This will help in improving their ATM utilization value. Based on the results, it can be deduced that banks in the study areas should not use more than three ATM in a location. This suggestion is subject to periodic review using the proposed framework.

## 4. Conclusions

An empirical study on performance ranking of ATM used by banks was presented in this paper. This was achieved using an integrated queuing-TOPSIS framework. The framework considered ATM utilization, percentage of customers' loss, total cost of service and expected length of customers in a queuing system, as well as the expected waiting time of customers in a queuing system and expected waiting time of customers in a queue as performance indices. The results obtained revealed that Bank A was the highest ranked bank, while Bank D was the least ranked bank. The results obtained showed that two banks had ATM utilization values of above 50%, while the other two banks had ATM utilization values of less than 50%. The average ATM usage in the study area was about 48.02%. Based on these results obtained, banks in the study areas should install one or two ATM at each location. To improve on the utilization of ATM, a study using benefits-cost analysis could be considered as a further study.

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