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ATM PERFORMANCE EVALUATION USING FUZZY DEA METHODOLOGY

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Abstract - The service quality evaluation has been always a trend research topic. With the developing technology, and increasing data flow the performance evaluation of financial services gained importance. In general, these studies concentrate on efficiency of financial ratios of global banks or banking branches performance. In this study, we emphasize the importance of the effective management of Automated Teller Machines (ATMs), which is the 7/24 contact point of a bank with its customer and also potential customers. Therefore, we evaluate the performance of the ATMs employing Data Envelopment Analysis (DEA), due to the linguistic evaluation of the experts a fuzzy DEA model had to be exercised. Two fuzzy DEA models are applied to a case study, and results are compared.

Keywords - Performance Evaluation, Data Envelopment Analysis, Decision Making, Financial Services, Fuzzy Logic

I. INTRODUCTION

Even tough, the future of cash money became a debatable topic with the raise of electronic payment models, according to Federal Reserve Bank (Fed) the worldwide cash circulation continues to rise consistently [1]. Therefore, cash management tools and systems preserve their importance, and should be controlled, evaluated and improved continuously.Automated Teller Machines (ATMs), have a significant share on the total circulated cash. Basically ATM is a machine that utilized for alternative banking services such as withdrawals or deposits, balances inquiries and transfers, accessed by a debit card or by a QR code, and the transactions are processed electronically with smart computer information systems.

In the literature the studies concentrating on ATM management are quite popular. There are studies on the security of the ATMs [2]-[4], on the customer friendly interfaces [5],[6]. ATM deployment problem has been another focus area, the academics knowing that correct location selection would affect directly the customer need and satisfaction because of accessibility, employed different approaches such as geographic information systems, genetic algorithm and goal programing [7]-[10]. Most of the researchers addressed the dynamic demand environment of the ATMs, and tried to forecast ATM cash transactions in order to meet two conflicting objectives, namely; customer satisfaction which is consisted of meeting client demand and accurate inventory levels because the excess of money inside the machine is deprived of the interest. The methods that are employed to deal forecasting problem of ATM transactions are Genetic Algorithm, Artificial Neural Networks (ANN), regression or simulation techniques [11-15].Replenishment of the ATMs are another problem that arises. Inventory level control, routing of the armored vehicles and minimizing their total traveled distance has been subject of the literature with different techniques and objectives [16-19]. Evolution of shared ATM networks [20], the relationship between ATM networks and total cash usage [21], the role of ATMs on the bank profitability [22], the effects of the withdrawal limits on the ATM queue length [23] are some of the other ATM related problems.

Service performance evaluation is another highly investigated topic, when the existing literature reviewed on it for the financial sector including keyword “ATM” and “Performance Evaluation”we encountered only a limited number of articles. For this study, we took into account the studies that employed Data Envelopment Analysis (DEA) models for the financial services performance evaluation.

Barth and Staat (2005) analyzed the efficiency of a local German bank branches with a two stage DEA-bootstrap approach yielding to better results comparing to the traditional DEA model, which is sometimes incapable to well classify efficient and in efficient decision making units (DMUs). They classified parameters as discretionary; resources, profit and risk and as environmental which includes customer potential, branch characteristics and competitive environment [24].

Bergendahl (1998) applied DEA in order to measure efficiency of the Nordic banks of Denmark, Finland, Norway and Sweden. As inputs he employed cost of personnel, cost of material and expected cost of credit losses while as outputs used lending, deposits and gross revenues [25].

Damar (2006) estimated technical and scale efficiency of Turkish banks under the shared ATM network effects. He concluded that for small and medium size banks network structure is not beneficial for the efficiency [26].

Hemmati et al. (2013) employed DEA and TOPSIS for evaluating performance of the 16 Iranian banks. The inputs are number of issued cards, ATMs and POSs, while the two outputs are number of successful ATMs and POSs transactions [27].

Sherman (1995) presented resources used by bank branches as customer service (tellers), sales service (platform), manager, expenses, office (square feet). Summarized services provided as deposit, withdrawals, checks cashed, bank checks, night deposits, loans and new accounts. His application resulted with a \$6 million annual expense savings, the efficient branches are considered as benchmark units [28].

Wong et al. (2004) employed Evidential Reasoning (ER) approach to assess a hierarchy of multiple quantitative and qualitative attributes. They used results of the ER as inputs and outputs of the DEA. In their model there are four quantitative inputs; number of branches, number of ATMs, interest on instant savings and interest on 60 days' savings. Qualitative inputs are the expected utility values of customer service and banking environments. The three quantitative outputs are total asset size, total revenue and net income [29].

The rest of the paper is organized as follows. The second section gives the basic concept of the methodology and introduces two DEA models that are applied for this study, the third section is the application part and the final section is reserved for results and conclusion.

II. METHODOLOGY

2.1. Data Envelopment Analysis (DEA)

DEA, first proposed by Charnes, Cooper and Rhodes (CCR) (1978), is a non-parametric method identifying an efficiency frontier that is employedto measure the efficiency of Decision Making Units (DMUs) which is calculated as the maximum of a ratio weighted outputs to weighted inputs subject to the condition that the similar ratios for every DMU be less than or equal to unity [30]. The traditional and linearized form of the DEA model is as follows:

$$\max E_{j_0} = \sum_{r=1}^{s} u_r \, y_{rj_0}$$

subject to (1)

$$\sum_{i=1}^{m} v_i x_{ij_0} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, \quad \forall j,$$

$$u_r, v_i \ge \varepsilon, \quad \forall r, i.$$

Where E_{jo} is the efficiency score of the evaluated DMU, u_r is the weight assigned to output r, v_i is the weight assigned to input i, y_{rj} is the quantity of output r generated and x_{ij} is the amount of input i consumed by DMU j, respectively, and ε is a small positive scalar.

Classical DEA models mainly consider the inputs and outputs as crisp data. However, in real-life problems such as selection or performance evaluation, the decision makers confront with vagueness and uncertainty while evaluating and they tend to use linguistic terms. Within this context Fuzzy DEA, is an extension of DEA which incorporates imprecision in DEA [31]. There are many extensions of fuzzy DEA models such as the tolerance, the αlevel based, the fuzzy ranking and the possibility approachand Hatami-Marbini et al. (2011) reviewed and compared these models [32].

In this study we will employtwo differentαlevel based fuzzyDEA models. The first model is capable to integrate ordinal, cardinal and fuzzy DEA model at the same timeand contains two models namely optimistic and pessimistic [33], the latter one is a ranking model which deals with multiple effective solution composed from two model [34] that is commonly encountered classification problem in DEA. The generic model of the [33] is as follows:

Let $(E_{J_0})^U$ and $(E_{J_0})^L$ denote the upper and lower bounds of the α-cut of the membership function of the efficiency score for the evaluated DMU (j_0) the general optimistic scenario DEA model incorporating crisp and fuzzy data can be written as:

$$\max (E_{J_0})^U = \sum_{r \in C_R} u_r y_{rj_0} + \sum_{r \in F_R} u_r y_{rj_0 c} - \mu_r (y_{rj_0 c} - y_{rj_0 b})$$

subject to (2)

$$\sum_{i \in C_I} v_i x_{ij_0} + \sum_{i \in F_I} v_i x_{ij_0 a} + w_i (x_{ij_0 b} - x_{ij_0 a}) = 1$$

$$\sum_{r \in C_R} u_r y_{rj_0} + \sum_{r \in F_R} u_r y_{rj_0 c} - \mu_r (y_{rj_0 c} - y_{rj_0 b})$$
$$- \sum_{i \in C_I} v_i x_{ij_0} - \sum_{i \in F_I} v_i x_{ij_0 a} + w_i (x_{ij_0 b} - x_{ij_0 a}) \le 0$$

$$\sum_{r \in C_R} u_r y_{rj} + \sum_{r \in F_R} u_r y_{rja} + \mu_r (y_{rjb} - y_{rja})$$
$$- \sum_{i \in C_I} v_i x_{ij} - \sum_{i \in F_I} v_i x_{ijc} - w_i (x_{ijc} - x_{ijb}) \le 0 \quad j = 1,2...,n;\ j \ne j_0$$

$$\mu_r - u_r \le 0, r \in F_R, \quad w_i - v_i \le 0, i \in F_I$$

$$\mu_r \ge 0, r \in F_R, \quad w_i \ge 0, i \in F_I$$

$$u_r \ge \varepsilon \ge 0, r \in C_R, r \in F_R \quad v_i \ge \varepsilon \ge 0, i \in C_I, i \in F_I$$

where F_R and F_I respectively represent the subset of fuzzy outputs $(F_R \subseteq R)$ and the subset of fuzzy inputs $(F_I \subseteq I)$ where R denotes the set of outputs $(C_R \cup F_R = R)$ and I represents the set of inputs $(C_I \cup F_I = I)$ .The pessimistic model is quite similar to the previous one and interested reader may find it in the cited work. The ranking model [34] is as:

$\max E = \bar{y}_p$

subject to (3)

$\bar{x}_p = 1$

$\bar{y}_j - \bar{x}_j \leq 0$

$v(\alpha x_j^m + (1-\alpha)x_j^l) \leq \bar{x}_j \leq v(\alpha x_j^m + (1-\alpha)x_j^u)$

$u\ (\alpha y_j^m + (1-\alpha)y_j^l) \leq \bar{y}_j \leq u(\alpha y_j^m + (1-\alpha)y_j^u)$

$u, v \geq 0$

As a result of standard DEA models, efficient DMUs have an efficiency score equals to 1. Thus, it is not possible to rank these DMUs. The objective of performance evaluation and selection processes is to obtain a comparison among the units, so that the same score for more than one unit is not desirable. The following model enables to give a ranking for efficient DMUs:

$\min z = \theta$

subject to (4)

$$\theta(\alpha x_p^m + (1-\alpha)x_p^l) \geq \sum_{j=1}^{n} \lambda_j (\alpha x_j^m + (1-\alpha)x_j^u)$$

$$\alpha y_{rp}^m + (1-\alpha)y_{rp}^u) \leq \sum_{j=1}^{n} \lambda_j (\alpha y_{rj}^m + (1-\alpha)y_{rj}^l)$$

$\forall r, \lambda_j \geq 0 \quad \forall j.$

So far, we explained the DEA models that are employed in this study, the next section will be the application of these models in our ATM performance evaluation problem.

III. APPLICATION

In this study, we decided to apply the two models into the data set of the Muhammad et al. (2014). their study is about the performance evaluation of the ATMs, in order to do that they conducted a survey for Pakistani banks, reaching 100 clients and 6 representative banks. They identified factors that affect the ATM performance and using fuzzy TOPSIS they prioritized the criteria [35]. They showed as a further extension, use of the DEA models and compare of the results, which we are responding with this paper. The main difference will be that they ranked the criteria, however we will rank the alternatives, which is the main objective of DEA.

In the study, the main factorsof ATM performance evaluation are given as; User Friendly (C1), Neat and Clean Machine (C2),Adequate Number of ATMs (C3), Conveniently Located (C4), Correct and Clear Guidance Machine (C5),Flexibility (C6),24 Hour Service (C7),Availability of Cash (C8),Quick Operation (C9),Safe & Secure Machines (C10), Daily Cash Withdrawal Limit (C11),Other Facilities Availability (C12), Interbank Transfer (C13),Machines Breakdown (C14),Technological Updating (C15),Waiting Time (Queues) (C16),Awareness of Fee Charged (C17).

They used for the alternatives ratings the 1-10 scales fuzzy membership [36] in five classes; Very Poor (VP), Poor (P), Fair (F), Good (G) and Very Good (VG).

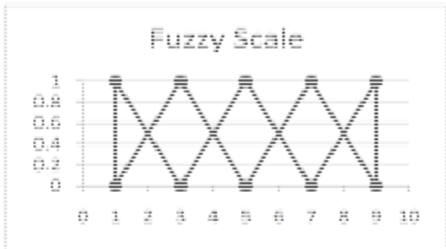

Fig.1. Employed Fuzzy Scale

The ratings of the six alternatives according to the 17 criteria are provided in the table below:

	A1	A2	A3	A4	A5	A6
C1	(7,9,9)	(7,9,9)	(7,9,9)	(1,3,5)	(5,7,9)	(7,9,9)
C2	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(7,9,9)	(1,3,5)
C3	(1,3,5)	(5,7,9)	(3,5,7)	(1,3,5)	(5,7,9)	(5,7,9)
C4	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)
C5	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
C6	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
C7	(1,3,5)	(1,3,5)	(3,5,7)	(1,3,5)	(5,7,9)	(1,3,5)
C8	(5,7,9)	(3,5,7)	(1,3,5)	(1,3,5)	(5,7,9)	(1,3,5)
C9	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)
C10	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)
C11	(5,7,9)	(5,7,9)	(5,7,9)	(1,3,5)	(5,7,9)	(1,3,5)
C12	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)
C13	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)
C14	(5,7,9)	(3,5,7)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)
C15	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)
C16	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(1,3,5)	(5,7,9)

C17	(3,5,7)	(5,7,9)	(7,9,9)	(5,7,9)	(3,5,7)	(7,9,9)

Table 1: Rating of the Alternatives

In the study, the criteria C1, C2, C3, C4, C14, and C16 are considered as cost criteria, and thus will be taken into account as inputs of our DEA model whereas C5, C6, C7, C8, C9, C10, C11, C12, C13, C15, and C17 are taken as benefit criteria and therefore will be the outputs of our DEA model. To sum up, we will build a model with six alternatives, six inputs and eleven outputs, from our experience in DEA, with the traditional DEA techniques, in this problem the efficiencies of each DMU would be “1”, effective. Therefore, the model will not do at all a classification and would be useless.

IV. RESULTS AND CONCLUSION

We solved the four given models above for α values between 0 and 1 with a step size of 0.1. When we applied the optimistic fuzzy DEA model given in (2), and the first ranking model given in (3), we observed that all the efficiency scores yielded to “1” as we expected. So we could not find any discrimination between ATM alternatives. Then we applied the pessimistic scenario to the same data set and we obtained the results given in the following table.

α	ATM1	ATM2	ATM3	ATM4	ATM5	ATM6
0	0.55	0.77	0.77	0.49	0.55	0.77
0.1	0.52	0.74	0.74	0.47	0.52	0.74
0.2	0.49	0.7	0.7	0.44	0.49	0.7
0.3	0.46	0.66	0.66	0.42	0.46	0.66
0.4	0.43	0.63	0.63	0.4	0.43	0.63
0.5	0.4	0.6	0.6	0.38	0.4	0.6
0.6	0.37	0.57	0.57	0.36	0.37	0.57
0.7	0.35	0.54	0.54	0.34	0.35	0.54
0.8	0.32	0.51	0.51	0.32	0.32	0.51
0.9	0.3	0.48	0.48	0.3	0.3	0.48
1	0.27	0.45	0.45	0.29	0.27	0.45

Table 2: Efficiency Score of the Alternatives by Pessimistic Model

As can be observed from the table also, when we apply the pessimistic model, we have the chance of the compare the DMUs for different αcut levels. For instance, ATM2, ATM3 and ATM6 perform better than the other three alternatives for each alpha level. The worst performances are shown by ATM1 and ATM5. In addition, while alpha is increasing we see that the efficiency values are decreasing also, this is due to the structure of mathematical model of the fuzzy DEA. The illustration of it is in the figure2.
Next, we employed the ranking model to the existing data set, and we obtained the following results.

α	ATM1	ATM2	ATM3	ATM4	ATM5	ATM6
0	13.15	5.4	5.05	14.33	11.53	13.9
0.1	9.66	4.55	4.25	10.37	8.5	10.35
0.2	7.29	3.85	3.59	7.72	6.38	7.86
0.3	5.6	3.26	3.04	5.86	4.89	6.01
0.4	4.35	2.77	2.59	4.51	3.81	4.65
0.5	3.41	2.35	2.21	3.5	3	3.63
0.6	2.69	1.99	1.88	2.73	2.39	2.84
0.7	2.11	1.69	1.61	2.14	1.91	2.21
0.8	1.66	1.43	1.37	1.67	1.54	1.71
0.9	1.3	1.2	1.17	1.3	1.24	1.31
1	1	1	1	1	1	1

Table 3: Efficiency Score of the Alternatives by Ranking Model

In the ranking model, we see a better discrimination comparing to the pessimistic scenario model, excluding the situation of$\alpha = 1$, when the model turns to a crisp DEA model. For example, for $\alpha = 0$, ATM4 perform best and ATM3 show the worst performance, similarly for $\alpha = 0.5$, the best performance belongs to the ATM6 and worst performance shown by ATM3. Like to the other model when the α parameter increases we see a decrease in the efficiency values. This is depicted also in the figure3. In order to compare the performances and test the correlations of this two models, we conducted Spearman's rank correlation test. We tested these correlations for three different alpha levels; for $\alpha = 0.3$ and $\alpha = 0.6$ we calculated the correlation as -0.65, and for $\alpha = 0.9$ the correlation became -0.57. This shows us that the fuzzy DEA models differ from each other, and the results of them would always be a question mark.

In this study, we employed the data set of an existing paper, and responded their further direction point. We employed four different DEA models of two studies. In the first models, we could not classify or rank the alternatives, however with the second models we had the chance of the rank the ATMs by their performance. However, when we compared the results by correlation tests, we observed inconsistency between results. Therefore, further research would focus to find most suitable models for the performance evaluation problem. An alternative further direction may be to apply different MCDM techniques, in order to rank the alternatives.

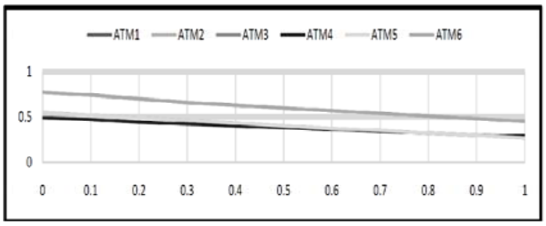

Fig.2.Efficiency Score of the Alternatives by Pessimistic Model

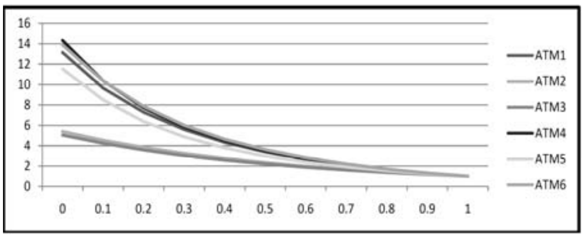

Fig.3.Efficiency Score of the Alternatives by Ranking Model

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