COMPARISON OF SMARTPHONES USING DATA ENVELOPMENT ANALYSIS

ADLI MUSTAFA, TAN LEAN PEAW

School of Mathematical Science, Universiti Sains Malaysia,11800 USM Penang, Malaysia.
adli@cs.usm.my

School of Mathematical Science, Universiti Sains Malaysia,11800 USM Penang, Malaysia.
tlpeaw@yahoo.com

Abstract: In today's digital era, competition for smart gadgets is often fierce. The last few years have witnessed the emergence of smartphones with each manufacturer trying to out do its competitor in terms of attractive features. It is therefore crucial for potential buyers to do products comparison before deciding on a smart phone brand. In this paper, we present the findings of a study that compared 25 smartphones using Data Envelopment Analysis (DEA). Smartphone features such as dimensions, weight, performance, total memory, messaging, colour resolution, network capabilities and other added features were treated as outputs whereas retail price was the input. These output-input data were taken from a local consumer magazine and modified accordingly for analysis. The results were presented as the single efficiency score. The study also recommended the reduction of retail prices of those inefficient smartphones.

Keywords: Products comparison, data envelopment analysis.

1. Introduction

In the last few years various models of smartphone had filled the market because of high demand from consumers of different ages. Smart consumers will do products comparison before deciding to purchase a smartphone which meets their needs and budgets.

From manufacturers' point of view, products comparison can provide useful feedback in order to understand the advantages and shortcomings of their products and also their competitors'. Such feedback may lead to further improvement on a product in the long run to enable them to survive in this competitive market. However, comparison charts or data that is usually provided by manufacturers, mass media or experts are always manipulated for their own advantage. Most of the manufacturers only emphasize on certain attributes of smartphone which are more advantageous to their product and data are positively presented to promote their product. This might mislead or confuse the consumers in their decision making on the purchase of smartphones.

A potential buyer will compare smartphone models and their attributes from different brands before purchase. However, attributes being considered vary from each potential buyer. Some may only consider the price of a smartphone, whilst some may focus on the functions such as colour display, size, design, brand and etc.

"It has a long talk time; the ring tone is very loud; it's very bulky; the displayed screen looks fade under the sun; the photo taken by the smartphone is not so sharp; operating system's loading is a bit slow..." These are layman's words often heard while evaluating a smartphone. However a potential buyer will finally ask, "Among these smartphones, which one for me is the best buy!". In the circumstance where the decision is complicated and involved many attributes, human choice maybe unacceptably poor (Doyle and Green, 1994). Therefore we propose a more technical approach in helping potential buyers to compare smartphones with multi-attributes by introducing a non-parametric approach called Data Envelopment Analysis (DEA).

By adopting DEA as a comparison tool, most of the attributes in a smartphone are adopted as variables in the comparison. The input considered certainly is the price that a potential buyer needs to pay for. Other variables which consists of dimensions, weights, standby time, talk time, memory, Read Only Memory (ROM), availability of expansion slot, Infrared, Bluetooth, WiFi, GPRS, WAP, Java application, MP3, types of messaging, resolution of digital camera, screen resolution and colour displayed are smartphone's outputs. The result of the analysis will be displayed as a single efficiency score for each smartphone. These efficiency scores certainly will help a potential buyer to make a purchase decision more easily.

In the next section, discussion is on the DEA methodology. Previous work on the use of DEA for product comparison is described in Section 3 and Section 4 discusses the data preparation and modification for our DEA model. Results and discussion of smartphones comparison are presented in Section 5. Final section is the conclusion of this paper.

2. Methodology

Data Envelopment Analysis (DEA) is a non-parametric approach to relatively evaluate the performance of a homogeneous set entities refer as Decision Making Units (DMU) in the presence of multiple weighted inputs and multiple weighted outputs. It was first initiated by Charnes, Cooper and Rhodes (CCR) (Charnes *et al.* 1978) with the objective of maximizing the efficiency value of a tested DMU from among a reference set of entities. Weights of individual inputs and outputs are varied from each DMU in order to give the best combination of multiple weighted inputs and multiple weighted outputs for the purpose of maximizing the efficiency value of DMUs. An efficient frontier is to be identified among the comparison set of DMUs. DMUs will have 100% efficiency if they are on the frontier. A benchmark set of efficient units will be provided by DEA as well as a conclusion for an efficiency score for each of the inefficient DMUs.

CCR model is applied in our smartphones comparison. Twenty-five models of smartphone from various brands that are available in the local market, which are defined as DMUs, are evaluated. The dimensions, weights, standby time, talk time, memory, ROM, availability of expansion slot, Infrared, Bluetooth, WiFi, GPRS, WAP, Java application, MP3, types of messaging, resolution of digital camera, screen resolution and colour displayed will be the output variables and price will become the only input variable.

Measurement of the efficiency for a particular DMU is defined as the ratio of weighted sum of its output (virtual output) to weighted sum of its input (virtual input). It is also defined as the efficiency score of the DMU. In another way of expression, a DMU which labeled as j consumes inputs' vector $X_j = \{x_{ij}\}$ $(i = 1,\ldots,m)$ will produce outputs vector $Y_j = \{y_{rj}\}$ $(r = 1,\ldots,t)$. Thus, the formation of a fractional programming model (also known as CCR model) (Charnes *et al.* 1978) which represents the efficiency score, h_0 of the particular DMU j_0 can be expressed as follow:

Fractional Programming Model:

$$\text{Max } h_0 = \frac{\sum_{r=1}^{t} u_r y_{rj_0}}{\sum_{i=1}^{m} v_i x_{ij_0}} \tag{1}$$

$$\text{Subject to } \frac{\sum_{r=1}^{t} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \;, j = 1,\ldots\ldots,n \tag{2}$$

$$u_r \geq 0 \;, r = 1,\ldots\ldots,t$$

$$v_i \geq 0 \;, i = 1,\ldots\ldots,m$$

where h_0 = efficiency score for DMU o, y_{rj} = amount of output r for DMU j, x_{ij} = amount of input i for DMU j, u_r = weight attached to output r, v_i = weight attached to input i, n = number of DMUs, t = number of outputs, m = number of inputs.

However, CCR model which is stated in fractional programming model has been converted to linear programming model due to its infinite number of optimal solution (u^*, v^*). In the linear programming model which also a primal model, two constraints are transformed from the fractional programming model. The first constraint (4) obtained by normalizing the denominator of the objective function in fractional programming model to one. An algebraic manipulation of the constraint in the fractional programming model has formed the second constraint (5) in the linear programming model. This linear programming form is commonly adopted in the formulation of CCR model including the development of DEA software that has simplified the mathematical calculation for DEA. The following formula represented the converted linear programming model.

Primal Model:

$$\text{Max } h_0 = \sum_{r=1}^{t} u_r y_{rj_0} \tag{3}$$

$$\text{Subject to } \sum_{i=1}^{m} v_i x_{ij_0} = 1 \tag{4}$$

$$\sum_{r=1}^{t} u_r y_{rj_0} - \sum_{i=1}^{m} v_i x_{ij_0} \leq 0 \text{ , } j = 1, \ldots\ldots, n \tag{5}$$

$$u_r \geq 0 \text{ , } r = 1, \ldots., t$$

$$v_i \geq 0 \text{ , } i = 1, \ldots., m$$

Although the calculation of the efficiency score of DMU can be done easily with one simple click, each calculation of DMU (efficiency score) needs to satisfy the $n + m + t + 1$ (number of DMUs + number of inputs + number of outputs + one) constraints. Thus, it has lead to the development of the dual model as below where number of constraints which need to be satisfied reduced to $m + t$ (number of inputs + number of outputs). Therefore, efficiency of the computer calculation has improved in comparison to the primal model.

Dual Model:

$$\text{Min } \theta_{j_0}$$

$$\text{Subject to } \sum_{j} \lambda_r y_{rj} \geq y_{rj_0} \quad r = 1, \ldots\ldots\ldots, t$$

$$\theta_{j_0} x_{ij_0} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0 \quad i = 1, \ldots\ldots, m$$

$$\lambda_j \geq 0$$

$$\theta \text{ } \textit{unconstrained}$$

In Dual model:
An efficient DMU:

- All dual variables are equal to zero.
- θ_{j_0} and λ are equal to one.

An inefficient DMU:

- θ_{j_0} is equal to the ratio solution of primal model which is less than 1.
- The inefficient DMU will have positive λ values for a set of other DMUs.
- The remaining variables λ, if positive, will be multiplied to the j_0's inputs and outputs in order to compute the composite efficient DMU, pseudo-DMU.

In a simple illustrative example, we compare five smartphones (DMUs) using one input and two outputs factors. The only input is the price (RM) while first output (O1) and second output (O2) are memory (Mb) and ROM (Mb) respectively. We assign the ratio of O1/I and O2/I as the coordinate value in Fig.1. O1/I is represented on horizontal axis *(X)* and O2/I is represented along the vertical axis *(Y)*. Table 1 shows that smartphone A has a greater ratio compared to smartphone B. It means that smartphone A is offering a greater memory (Mb) and ROM (Mb) compared to smartphone B. With both smartphone B and smartphone D offering the same price (RM), smartphone D is offering a lower ROM (Mb) compared to smartphone B where smartphone B's ROM is 1.1 times greater than smartphone D. On the other hand, a greater memory (Mb) which is 1.3 times greater than smartphone B is offered by smartphone D. As presented in Fig.1, the line CAD (smartphone C, smartphone A and smartphone D) has formed the efficiency frontier. Smartphone E and B are not on the efficiency frontier and thus are evaluated as inefficient. A pseudo-smartphone B' is formed by calculating the coordinates of the intersection line AD and OB'. A pseudo-smartphone B' is referred as an virtual efficient DMU B after output augmentation from smartphone B. Smartphone A and smartphone D are the benchmark set for smartphone B or in other words, smartphone A and smartphone D are the peer group of smartphone B. It means that smartphone A and smartphone D are efficient frontiers with which smartphone B is compared to. Smartphone C and smartphone A become peer group of smartphone E.

Table 1

	O_1/I	O_2/I	Price (RM)	RAM (Mb)	ROM (Mb)
Smartphone A	22	11	3000	66	33
Smartphone B	20	5	2000	40	10
Smartphone C	14	16	1500	21	24
Smartphone D	26	4.5	2000	52	9
Smartphone E	18	12	2000	32	24
Smartphone B'	24.93	6.23			

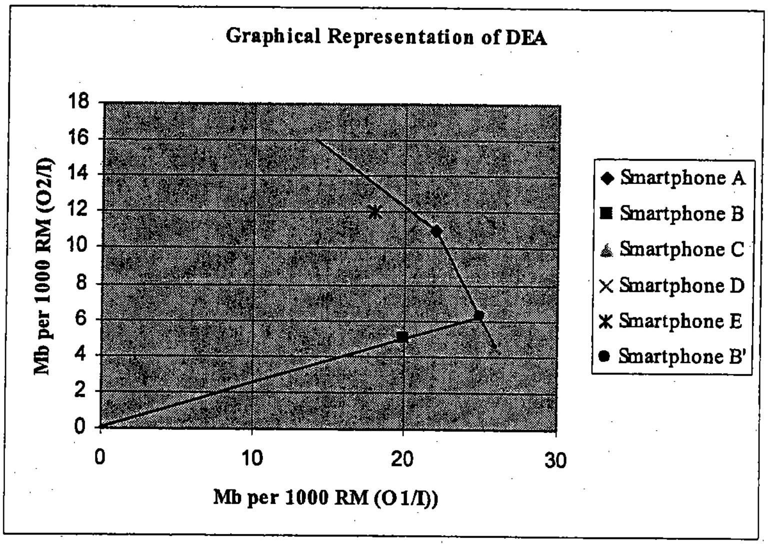

Figure 1

3. DEA Model for Product Comparison

DEA has been used by worldwide decision-makers to solve problems in many areas and DEA applications have been reported widely in journals (Gattoufi *et al.* 2004a; 2004b; Seiford, 1997).

Application of DEA in product comparison can be traced back to a publication by Doyle and Green (1991). The article compared 37 computer printers featured in a computer magazine BYTE. Two dozens features have been reduced into seven outputs and a single input by inspecting the correlation matrix of all measures which correlated with all other features. Peer group has been identified as a benchmark for each inefficient computer printers. In Doyle and Green (1994), they have commented on the usefulness of the complicated multiple regression's application in investigating the relationship between the price of a computer and its performance. Multiple regression has been applied in evaluating the efficiency of a computer from various perspectives and angles in some of the previous study. However, the multiple regression analysis is only useful for certain group of people. Therefore the authors proposed a method based on linear programming, DEA, to determine the performance of the computer which is more accepted by the public where only efficiency scores are displayed. In the final stage of the evaluation, an average cross-efficiencies method has been applied in selecting the most efficient among the efficient (best of the best).

In Papahristodoulou (1997), car efficiency has been evaluated via DEA method with the economic and technical data taken from German car magazine *Auto Motor and Sport*. Various models of car from different manufacturers have been evaluated. Papahristodoulou has classified the car models in three different groups based on the engine performance. Four economic variables and ten technical variables have been used in evaluating the performance of 121 car models. For Italian car market, Storto (1997) has segmented the car's engine capacity lower than 1000cc and between 1000cc and 1250cc. Thirteen output variables and two input variables which are major factors have been identified in the DEA implementation. Measures for some of the variables are obtained as a mean value of different operative conditions. Geometric mean is used for objectively measured (ordinal) factors and arithmetic mean is used for subjectively measured (cardinal) factors. Twenty-nine cars have been selected as DMU in the DEA analysis. Data on the variables are normalized. Principal Component Analysis is performed to identify correlation among the output variables. Output variables with strong correlation are excluded in the DEA analysis and the results are compared and discussed with the DEA analysis which included all output variables. Finally, cross-efficiency has been applied and compared with the efficiency score in DEA analysis. In McMullen and Tarasewich (2000), comparison of notebook personal computers is done by categorizing ten attributes into four different groups. Data set have been standardized and rescaled. Weighting restriction has been applied to the data in order to reflect a better result. Sensitivity analysis has been applied right after the DEA computation in order to find out the robustness of each efficient notebook.

4. Data Preparation and Modification

In this study, data on the attributes of smartphones is taken from a local magazine *Mobile World May 2005 edition*. The attributes provided by the magazine including price (RM), dimensions (mm^3), weights (gram), standby time (hrs), talk time (mins), memory (MB), ROM (MB), expansion slot, Infrared, Bluetooth, WiFi, GPRS, WAP, Java application, MP3, types of messaging, resolution of digital camera (megapixels), screen resolution (pixels) and colour displayed.

Quantitative data and qualitative data are both used in this smartphones comparison. Quantitative data are price, dimensions, weights, standby time, talk time, memory, ROM, resolution of digital camera and screen resolution of a smartphone, while qualitative data are the availability of expansion slot, Infrared, Bluetooth, WiFi, GPRS, WAP, Java application, MP3, types of messaging and the types of colour displayed (see Table 2).

Before we start to compile the data, modification of the data is needed in order to use the DEA's formula. A bulky (dimension) and heavy (weight) smartphone which indicate bigger values of dimension and weight will become a concern for a potential buyer (Talluri and Yoon, 2000). Since smaller value of dimension and weight indicate a smaller and lighter smartphone, therefore we inversed the weight and dimension data values. The reason is weight and dimension for smartphone are a part of the outputs which also become a part of the numerator in DEA's formula. In DEA, a large output value is considered to be better than a small value (Talluri and Yoon, 2000). By inversing the two outputs, any increase of these weight and dimension will bring to the decrease of the data values.

Modification by setting the minimum score for qualitative data as zero is to limit these data from having a negative value. Zero score will be given if the attribute (Infrared, Bluetooth, WiFi, Java application and MP3) is not available while score of one will be given if the attribute is available. Availability of expansion slot and types of messaging are rated by setting zero score if the attribute is not available while score of one will be given if only one type of expansion slot/messaging is available. Value of the score will be increased by one for every additional type of expansion slot/messaging which is available in a smartphone. Score for GPRS, WAP and types of colour screen displayed is obtained by ranked the output with zero score if GPRS, WAP and colour displayed is not available. GPRS, WAP and colour displayed will be given a score of one if the attribute is ranked in higher level. For example, no colour screen displayed (monochrome displayed) received zero score, 4096 colour screen displayed received score of one, 65000 colour screen displayed received score of two while 262000 colour screen displayed received score of three. This method of handling qualitative data has been adopted by McMullen and Tarasewich (2000), McMullen and Powers (2000) and McMullen and Strong (1998).

Data from 19 attributes which are different in units (MB,gram,...) and properties (cardinal/ordinal) are standardized. Standardized data are rescaled by adding a constant. The main reason we standardized the data was to enable the unification among the 19 attributes in order to reduce into eight major categories. Rescaling the standardized data enable the data to attain positive value for computation purpose (McMullen and Powers, 2000; McMullen and Tarasewich, 2000).

Table 2: Classification of 19 smartphone attributes into 8 major groups

Major Categaries of Smartphone Attributes	Smartphone Attributes	Variable Type
PRICE		
Input01	Price (RM)	Quantitative
SIZE		
Output01	Dimension (mm)	Quantitative
Output02	Weight (gm)	Quantitative
PERFORMANCE		
Output03	Standby Time (hrs)	Quantitative
Output04	Talk Time (min)	Quantitative
TOTAL MEMORY		
Output05	Memory (MB)	Quantitative
Output06	ROM (MB)	Quantitative
CONNECTIVITY		
Output07	Expansion	**Qualitative**
Output08	IrDA	**Qualitative**
Output09	Bluetooth	**Qualitative**
Output10	WiFi	**Qualitative**
Output11	GPRS	**Qualitative**
Output12	WAP	**Qualitative**
FEATURES		
Output13	Java Application	**Qualitative**
Output14	MP3	**Qualitative**
Output15	Digital Camera (mp)	Quantitative
MESSAGING		
Output16	Messaging	**Qualitative**
SCREEN		
Output17	Resolution (pixels)	Quantitative
Output18	Colour Displayed	**Qualitative**

Among the 19 attributes, only price (RM) is identified as input variable for DEA computation. The 18 output variables are classified into seven major categories as in Table 2 which included the category: size, performance, total memory, connectivity, features, messaging and screen. Dimensions and weights are classified into size category while standby time and talk time are classified into performance category. Memory and ROM are grouped in total memory category while connectivity category consists the availability of expansion slot, Infrared, Bluetooth, GPRS, WAP, WiFi. Availability of Java application, MP3 and resolution of digital camera are in features category. Screen resolution and colour displayed are grouped in screen category while messaging category consists types of messaging.

An assumption had been made that output variables make equal contributions in each category in our study (McMullen and Tarasewich. 2000). Therefore, data value for each output categories is the mean value of the attributes included in each category. For example, mean value of the standardized and rescaled data for the attribute dimensions and weights become the data value for size category. Therefore, we will have only seven groups of attribute (size, performance, total memory, connectivity, features, messaging and screen) as output variables and one single input variable (price) as shown in Table 2.

5. Result and Discussion

Table 3: Efficiency Scores for 25 DMUs

	DMU	Score	Benchmarks
17	O2 Xphone	**100.00%**	**17**
18	Palmone Tungsten W	**100.00%**	**12**
21	Siemens SX1	**100.00%**	**15**
25	Zircon Wizard c33	**100.00%**	**4**
9	Nokia 6260	94.36%	17 21
2	Axia A108	93.59%	17 18 25
6	Motorola A768i	92.78%	17 18 21 25
3	Dallab DP-900	92.45%	17 18
11	Nokia 6670	89.61%	21
23	Xplore G88	85.11%	17 18 21 25
24	Xplore M28	79.60%	17 18 21
12	Nokia 7710	78.00%	18 21
20	Sagem my S-7	77.56%	17 21
7	Motorola E680	75.77%	17 21 25
1	Anextek SP230	74.57%	17 18
10	Nokia 6630	72.18%	21
15	O2 XDA II	70.10%	17
22	Sony Ericsson P910i	68.51%	18 21
19	Palmone Treo 600	67.58%	17 18 21
16	O2 XDA II Mini	64.57%	17 18 21
4	Eten P300	64.35%	17
14	Nokia 9300	64.02%	17 21
8	Motorola MPx	62.11%	17 21
5	Hewlett-Packard iPAQ h6365	61.71%	17 18
13	Nokia 9500	52.17%	17 18 21

As shown in Table 3, among the 25 smartphones being evaluated, four models are identified as efficient (efficiency score = 100%) while 21 models are identified as inefficient (efficiency score < 100%). Among the 21 models of the inefficient smartphones, four models have an efficiency score which can be considered as near efficient (McMullen and Tarasewich, 2000). The efficiency score of these four models are more than 90% [Nokia 6260 (94.36%), Axia A108 (93.59%), Motorola A768i (92.78%), Dallab DP-900 (92.45%)]. This shows that 28% (7 out of 25 models) of the smartphones in the local market could be considered as efficient and near efficient.

The niche and the broad player among the efficient smartphones can be distinguished by the frequency of its appearance in the benchmark set of other inefficient smartphones (Doyle and Green, 1991; 1994). Table 3 shows the frequency of the appearance for the four efficient smartphones as a benchmark against other inefficient smartphone models. Obviously, broad players O2 Xphone, Palmone Tungsten W and Siemens SX1 have become a benchmark for more than ten models of inefficient smartphone with 17, 15 and 12 appearances on other inefficient models respectively while niche player Zicron Wizard c33 becomes a benchmark for only four inefficient smartphones.

Nokia smartphones make up 24% of these compared smartphone which become the major contributor in our efficiency analysis. Analysis result shows that neither smartphone from US "Big M" (Motorola) nor Europe "Big N" (Nokia) that is the worldwide market leader is listed in the category of efficient smartphone. Average efficiency score for Motorola and Nokia is 76.89% and 75.06% respectively. One of the three smartphone models from Motorola are evaluated as near efficient whilst only one of the six smartphone models from Nokia has an efficiency score of more than 90%. It seems that the world market leader Nokia is now facing a lot of competition from different smartphone manufacturers which try to take over Nokia in this local market.

As shown in Table 4, all four efficient smartphones are priced less than RM1500 with Palmone Tungsten W offering the lowest selling price (RM1399). One third of inefficient smartphones are priced between RM1500 to RM2000. Two thirds of the inefficient smartphones are priced higher than RM2000 with two models priced over RM3000. Obviously, it shows that the market price[a] of more than RM1500 is not worth the features offered. Surprisingly, Nokia 9300 and Nokia 9500 which are rated as one of the most powerful smartphones are grouped in the inefficient smartphones. Both are listed at the bottom of the efficiency score list. This is due to the high selling price of these models [Nokia 9300 (RM3299) and Nokia 9500 (RM3499)]. From this observation, we can conclude that the price and efficiency score are highly correlated. The correlation between the price and efficiency score is -0.898. This indicates that a higher price will give a lower efficiency score for a smartphone.

Table 4: Comparison between original price and new suggested price for 25 DMUs

	DMU	Original Price (RM)	New Price (RM)	Total Price Reduction (RM)
17	O2 Xphone	1438	1438	0
18	Palmone Tungsten W	1399	1399	0
21	Siemens SX1	1499	1499	0
25	Zircon Wizard c33	1488	1488	0
9	Nokia 6260	1599	1508.75	90.25
2	Axia A108	1988	1860.65	127.35
6	Motorola A768i	1799	1669.09	129.91
3	Dallab DP-900	1999	1848.02	150.98
11	Nokia 6670	1899	1701.72	197.28
23	Xplore G88	1888	1606.83	281.17
24	Xplore M28	2188	1741.66	446.34
12	Nokia 7710	2699	2105.18	593.82
20	Sagem my S-7	1999	1550.35	448.65
7	Motorola E680	2199	1666.18	532.82
1	Anextek SP230	2299	1714.29	584.71
10	Nokia 6630	2499	1803.71	695.29
15	O2 XDA II	2918	2045.66	872.34
22	Sony Ericsson P910i	2999	2054.68	944.32
19	Palmone Treo 600	2088	1411.07	676.93
16	O2 XDA II Mini	2758	1780.71	977.29
4	Eten P300	2299	1479.51	819.49
14	Nokia 9300	3299	2112.01	1186.99
8	Motorola MPx	2799	1738.44	1060.56
5	Hewlett-Packard iPAQ h6365	2788	1720.53	1067.47
13	Nokia 9500	3499	1825.33	1673.67

Competition from other smartphone manufacturers soon will pressure the "Big N" to adjust their smartphone's high selling price to become lower whilst offering the same features compared to

[a] Market prices of 25 models of the smartphones available in the local market are based on the data taken from a local magazine *Mobile World May 2005 edition*. Price may vary from the current market price.

other brands. In the circumstance where the price adjustment is a better option to upgrade the inefficient smartphones to become efficient, we are seeking the percentage of price reduction through DEA's result.

In order to become efficient, current displayed price from *Mobile World Magazine May 2005 edition* for 21 inefficient smartphones will need to be revised as shown in Table 4. As can be seen from Table 3, Nokia 6260 is 94.36% efficient compared to Siemens SX1 and O2 Xphone while Nokia 9500 is 52.17% efficient compared to O2 Xphone, Palmone Tungsten W and Siemens SX1. Therefore, it is suggested that the price for Nokia 6260 should be reduced 5.64% without reducing any of its outputs while price reduction for Nokia 9500 should be 47.83%. The new suggested price for Nokia 6260 is RM1508.75, a price reduction of RM90.25. But the new price for Nokia 9500 (RM1825.33), a price reduction of RM1673.67, will impact the competitiveness of the smartphones. Suggestion on price reduction without reducing the numbers and the quality of the attributes will bring the smartphone manufacturers to produce more cost efficient products in order to continue to be competitive in the market.

Table 5: The Percentages of Weightages for Each Smartphone Attributes

	DMU	Price	Size	Performance	Total Memory	Connectivity	Features	Messaging	Screen
17	**O2 Xphone**	**100**	**0**	**68.79**	**13.93**	**5.65**	**11.63**	**0**	**0**
18	**Palmone Tungsten W**	**100**	**0**	**35.90**	**0**	**0**	**0**	**0**	**64.10**
21	**Siemens SX1**	**100**	**0**	**36.80**	**0**	**0**	**0**	**63.20**	**0**
25	**Zircon Wizard c33**	**100**	**35.96**	**0**	**0**	**0**	**0**	**0**	**64.04**
9	Nokia 6260	100	0	0	25.33	0	74.67	0	0
2	Axia A108	100	8.70	0	38.16	0	0	0	53.14
6	Motorola A768i	100	29.40	23.39	33.85	0	0	0	13.36
3	Dallab DP-900	100	0	0	47.37	0	0	0	52.63
11	Nokia 6670	100	0	0	0	0	100	0	0
23	Xplore G88	100	5.71	0	10.20	0	35.13	0	48.96
24	Xplore M28	100	0	0	10	0	42.15	0	47.85
12	Nokia 7710	100	0	0	0	0	43.27	0	56.73
20	Sagem my S-7	100	0	0	25.28	0	74.72	0	0
7	Motorola E680	100	0	0	22.33	0	0	31.34	46.34
1	Anextek SP230	100	0	29.37	70.63	0	0	0	0
10	Nokia 6630	100	0	0	0	0	100	0	0
15	O2 XDA II	100	0	0	100	0	0	0	0
22	Sony Ericsson P910i	100	0	71.15	0	0	0	28.85	0
19	Palmone Treo 600	100	0	31.85	46.30	0	0	21.85	0
16	O2 XDA II Mini	100	0	27.56	36.45	0	35.99	0	0
4	Eten P300	100	0	0	100	0	0	0	0
14	Nokia 9300	100	0	0	45.51	0	0	54.49	0
8	Motorola MPx	100	0	0	0	72.70	27.30	0	0
5	Hewlett-Packard iPAQ h6365	100	0	0	4.41	95.59	0	0	0
13	Nokia 9500	100	0	0	10.12	0	41.49	0	48.39

In DEA, the existences of zeros as the weights (multipliers) in the inputs or outputs indicate that the particular inputs or outputs are not utilized (Shang and Sueyoshi, 1995). Table 5 shows the weightage of each attribute in determining the efficiency score of each smartphone. Presence of zero as a weight means that the input/output was not considered important attribute of that smartphone. The non-zero weights are the strong attributes of the smartphone, thus could aid a customer's choice by considering which smartphone has his or her selected features. For example, a customer whose preference is size would choose Zircon Wizard c33 over the other three efficient smartphones.

6. Conclusion

When making product comparison, consumers will prefer simple and convenient tools to aid their decision making. In this paper we have shown that DEA is a simple and easy-to-use technique for smartphones comparison.

By using available smartphone data from a trade magazine or website, consumers avoid complex procedure and analysis. The computerised DEA software will present single efficiency scores for various smartphones which to ease purchase decision. Manufacturers can also use DEA analysis to benchmark the products and improve product performance.

References

Charnes, A. W., Cooper, W. W. and Rhodes, E. (1978). Measuring Efficiency of Decision Making Units, *European Journal of Operational Research.*, **2:** 429-444.

Doyle, J. R. and Green, R. H. (1991). Comparing products using Data Envelopment Analysis, *Omega*, **19:** 631-638.

Doyle, J. R. and Green, R. H. (1994). Strategic choice and data envelopment analysis: comparing computers across many attributes, *Journal of Information Technology.*, **9:** 61-69.

Gattoufi, S., Oral, M. and Reisman, A. (2004a). Epistemology of data envelopment analysis and comparison with other field of OR/MS for relevance to applications, *Socio-Economic Planning Sciences.*, **38:** 123-140.

Gattoufi, S., Oral, M. and Reisman, A. (2004b). A taxonomy for data envelopment analysis, *Socio-Economic Planning Sciences.*, **38:** 141-158.

McMullen, P. and Strong, R. (1998). Selection of Mutual Funds Using Data Envelopment Analysis, *Journal of Business and Economic Studies.*, **4:** 1-12.

McMullen, P. and Powers, J. (2000). Using Data Envelopment Analysis to Select Efficient Large Market Cap Securities, *Journal of Business and Management.*, **7:** 31-42.

McMullen, P. and Tarasewich, P. (2000). Selection of Notebook Personal Computers Using Data Envelopment Analysis, *The Southern Business and Economic Journal.*, **23:** 200-214.

Papahristodoulou, C. (1997). A DEA model to evaluate car efficiency, *Applied Economics.*, **29:** 1493 -1508.

Seiford, L. M. (1997). A bibliography for data envelopment analysis (1978-1996), *Annals of Operations Research.*, **73:** 393-438.

Shang, J. and Sueyoshi, T. (1995). A unified framework for the selection of a flexible manufacturing system, *European Journal of Operational Research.*, **85:** 297-315.

Storto, C. L. (1997). Technological Benchmarking of Products using the Data Envelopment Analysis: An Application to Segments 'A' and 'B' of the Italian Car Market, *Proceeding of the Portland International Conference on Management and Technology*. (27-31 July 1997) pp. 783-788.

Talluri, S. and Yoon, K. P. (2000). A cone-ratio DEA approach for AMT justification, *International Journal of Production Economics.*, **66:** 119-129.