Undergraduate Review

Volume 11 | Article 26

2015

Phone Selection Through Data Envelopment Analysis

Elissa R. Turpin
Bridgewater State University

Adam Sanchez

Phone Selection through Data Envelopment Analysis

ELISSA TURPIN & ADAM SANCHEZ

Introduction

The advances in smartphone technology are making phones the most popular "smart" devices among technology consumers today. A smartphone is a mobile device that allows users to make calls as well as perform actions such as sending email, managing information, and using calendar and planning functions of a PDA (personal digital assistant) or personal computer. In 2013, 14% of the global population used smartphones; in the United States, that number was 37%. With all of the new innovations in the smartphone market, that 37% is expected to rise to 59% in the United States by 2016 (CMO Council, 2012).

As the smartphone market grows and competition increases, it is imperative for smartphone manufacturers to maintain or improve the level of satisfaction among customers during the phone selection process. Smartphone competition in the United States is fierce as a result of easy access to technology, as well as events such as the legal feud between Apple and Samsung. Smartphone makers in the United States are constantly competing to create the next best phone in order to entice consumers and increase market shares. In order to take advantage of the intense competition and variety of features, it is important for potential buyers to conduct product comparisons before deciding upon which phone to purchase.
The purpose of this paper is to use Data Envelopment Analysis to determine, out of eight popular smartphones, which is the most efficient: (1) Apple iPhone 5, (2) HTC Windows Phone 8s, (3) HTC Desire, (4) Samsung Galaxy S4, (5) Samsung Galaxy S4 Mini, (6) Samsung Gusto 3, (7) LG Cosmos 3, and (8) Nokia Lumia 928. These eight phones have been the top choices by consumers in the past few years (Brian, 2012). Not only were they among the top grossing smartphones, but these eight were also selected based on the number of market shares in the United States. Although Apple and Samsung were the only two companies with market shares in the double digits, the other companies still hold a great deal of promise for benefiting the growing smartphone market.

Literature Review

Bayraktar, Tatoglu, Turkyilmaz, Delen, and Zaim (2014) found that customer satisfaction is an important aspect in the phone selection process because product enjoyment and satisfaction have a positive impact on phone selection. Their research reflected only one particular perspective of customer satisfaction, but satisfying a customer is complicated because it involves multiple dimensions of comparisons. For example, Khawand (2007) tested each smartphone on his own and then published a book based on his daily blog about his experience with each product. Khawand listed all of the pros and cons of each phone to help in order to share his knowledge of the products with consumers, but he did not conclude with which were the best. During the selection process, consumers can benefit from Khawand's hands-on experiment, using his feedback as a means of choosing a phone that will meet their specific needs. However, more comprehensive quantitative analyses, which compare the multi-dimensional data of the different smartphone features, are desirable.

Taking multi-dimensional data into consideration, the Analytic Hierarchy Process (AHP) has good potential to solve phone selection problems. The AHP provides a comprehensive and rational framework for structuring a decision problem for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. All the dimensions for the alternatives need to be evaluated by customers objectively and integrated in order to obtain the "best" in the end. Tan and Mustafa (2006) compared 19 attributes (mobile phone options): dimensions, standby time, weight, talk time, memory, ROM, expansion slot, Wi-Fi, Infrared, Bluetooth Java application, MP3, messaging types, GPRS, WAP, camera resolution, color display, screen resolution, and price. They then used the AHP method to minimize the pool of attributes. To reflect the new features of cell phones, Falaki et al. (2010) employed the same method using only four attributes for comparison: user interactions, the use of the applications, network trafficking, and the amount of energy used.

Consumers are limited by the nature of the AHP method because it is very difficult, first, to weight each attribute of a product; then they would need to evaluate each attribute in relation to the same attribute in all of the alternative products. Another major method to handle multi-dimensional data, Data Envelopment Analysis (DEA), directly uses the quantitative data of various products and applies mathematical programming to calculate weights for each attribute. By calculating weights for each attribute, DEA clearly reflects the trade-offs among different attributes. DEA is a powerful quantitative, analytical tool for measuring and evaluating performance using a variety of criteria.
The DEA model offers wide applications in real-world

problems, such as determining the eco-efficiency of electric and electronic appliances (Barba-Gutiérrez, Adenso-Díaz, & Lozano, 2009). Our research applies the DEA approach in order to compare the purchasing efficiency of eight popular smartphones and determine the best among them. The purchasing efficiency refers to the ratio of all of the important attributes customers obtain from the smartphone (the outputs) in relation to the phone's cost to the consumer (the input).

Methodology

The methodology used to conduct this study is known as Data Envelopment Analysis (DEA). DEA is a non-parametric approach suggested by Charnes, Cooper, and Rhodes (1978). It is used to evaluate the performance of decision-making units (DMUs) where there are multiple inputs and outputs.

All of the DMUs that are being evaluated are assumed to operate homogeneously, with an outcome known as an efficiency ratio. The measure of efficiency of a DMU is defined as the ratio of a weighted sum of outputs to a weighted sum of inputs. In this particular study the focus is on maximizing efficiency; therefore, the formula used is as follows:

Objective Function:

$$E_e = \frac{\sum_{i-1}^{M} u_i o_{ie}}{\sum_{j=1}^{N} v_j I_{je}} = \frac{u_1 O_{1e} + u_2 O_{2e} + .. + u_M O_{Me}}{v_1 I_{1e} + v_2 I_{2e} + .. + v_N I_{Ne}}$$

Subject To:

$$\frac{\sum_{m=1}^{M} u_m o_{mk}}{\sum_{n=1}^{N} v_n I_{nk}} = \frac{u_1 O_{1k} + u_2 O_{2k} + .. + u_M O_M}{v_1 I_{1k} + v_2 I_{2k} + .. + v_N I_{Nk}}$$

Symbol	Representing
Ee	Efficiency of the eth DMU
Oie	The ith output dimension for the eth DMU
ui	The weight for the ith output dimension
Ije	The jth input dimension for the eth DMU
Vj	The weight for the jth input dimension
Oik	The ith output dimension for the kth DMU
Ijk	The jth imput dimension for the kth DMU
i	The index for output dimension
j	The index for input dimension
e	The target DMU, e =1
k	The kth DMU, =1...K

To solve the formula using standard linear programming software, the ratio above must be restated as a linear function. And in order to restate the objective function as a linear function, the inputs for the DMU under evaluation must be scaled to a sum of 1.

Objective Function:

$$\text{Max } Ee = u_1 O_{1e} + u_2 O_{2e} + ... + u_M O_{Me}$$

Subject to:

$$v_1 I_{1e} + v_2 I_{2e} + ... v_N I_{Ne} = 1$$

For each DMU, the constraints are similarly reformulated:

$$(u_1 O_{1k} + u_2 O_{2k} + \dots u_M O_{Mk}) - (v_1 I_{1k} + v_2 I_{2k} + \dots v_N I_{Nk}) <= 0$$
$$k = 1, 2, \dots, K$$

$$\text{Where: } u_j >= 0 \quad j = 1, 2, \dots, M$$
$$v_i >= 0 \quad i = 1, 2, \dots, N$$

Data Analysis

Eight types of smartphones were the decision-making units: (1) Apple iPhone5, (2) HTC Windows Phone 8s, (3) HTC Desire, (4) Samsung Galaxy S4, (5) Samsung Galaxy S4 Mini, (6) Samsung Gusto 3, (7) LG Cosmos 3, and (8) Nokia Lumia 928. There are many dimensions to look at when selecting a phone. For the DEA method, it is only possible to compare those variables that are quantitative. Therefore, the output variables chosen for this comparative study were weight (ounces), standby time (hours/unit), battery life (mAh), and camera resolution (megapixels). As for the inputs, the only variable chosen in this study was the retail price.

Weight, in ounces, is one of the quantitative measurements consumers find important when selecting a phone that meets their needs. Standby time, another output measure, is the officially quoted longest time (measured in hours) that a single battery charge will last when the phone is constantly connected to the GSM network but is not in active use. Standby time relates to the battery life of the phone, which consumers consider one of the most important characteristics when choosing a phone. The battery life of a phone is measured in a unit known as mAh, which measures electric power over time. mAh is commonly used to describe the total amount of energy a battery can store at one time. A battery rated for more mAh will power a phone for a longer period of time, given the usage pattern. Buyers also compare the quality of cameras when selecting a phone. Now that smartphones have the ability to take high quality pictures with more convenience, it is important to know how many megapixels the camera has; more megapixels create better image resolution.

Results

Information about weight, standby time, battery life, and camera resolution of the smartphones was gathered from network suppliers' websites which list phones' technical specifications, such as zerizon.com and phonearena.com. (See Table 1.)

Table 1. Output and Input Values

Decision Making Unit	Battery (mAh)	Weight (oz.)	Camera (MP)	Standby Time (hours)	Retail Price (US $)
iPhone 5	1800	3.95	8	225	359.99
HTC Windows 8s	1800	4.6	8	300	399.99
HTC Desire	1230	5.15	5	384	299.99
Samsung Galaxy S4	2600	4.59	13	370	499.99
Samsung Galaxy S4 Mini	1900	3.77	8	300	399.99
Samsung Gusto 3	1000	3.5	1.3	770.4	149.99
LG Cosmos	950	4.58	1.3	818	149.99
Nokia Lumia 928	2000	5.75	8.7	606	399.99

The efficiency scores were calculated by using the Data Envelopment Analysis method and Linear Programming through Excel Solver Software. Table 2 shows the scores, which indicate that four of the eight phones are considered efficient: Samsung Galaxy S4, Samsung Gusto 3, LG Cosmos 3, and Nokia Lumia 928. Phones were considered efficient or inefficient based on the results gathered from using the Excel Solver Software. Those that obtained an optimal solution of 1 were considered to be efficient, and anything lower than 1 was classified as inefficient.

Table 2. Efficiency Scores

Type of Phone	Efficiency Score
iPhone 5	0.93
HTC Windows 8s	0.88
HTC Desire	0.91
Samsung Galaxy S4	1
Samsung Galaxy S4 Mini	0.87
Samsung Gusto 3	1
LG Cosmos 3	1
Nokia Lumia 928	1

The following table (Table 3) represents the improvements that would need to be made to the four inefficient DMUs in order to become efficient. By altering the inputs and outputs these select devices will become efficient. The values to focus on based off of the efficiency test performed are the battery life and the standby time. From a manufacturer's point of view, battery life is an important improvement because it is at the top of the priority list for consumers. However, this would not be an easy fix and would require extensive research. A study is circulating the smartphone-world about using silicon in place of the graphite in batteries in order to prolong the life of these devices (Newman, 2013). This switch of material also comes with limitations because silicon makes the battery swell, which would have implications for the size of smartphones. Eventually there will be a solution to the battery-life complication that will drive the smartphone market in a positive direction.

Table 3. Recommended Improvements

Decision Making Unit	Battery (mAh)	Weight (oz.)	Camera (MP)	Standby Time (Hours)	Retail Price (US $)
iPhone 5	1800	3.95	8	448.85	336.30
HTC Windows 8s	1897	4.6	8	564.16	350.76
HTC Desire	1566	5.15	5	370	274.43
Samsung Galaxy S4	2600	4.59	13	525.02	499.99
Samsung Galaxy S4 Mini	1900	4.06	8	770.4	348.22
Samsung Gusto 3	1000	3.5	1.3	818	149.99
LG Cosmos	950	4.58	1.3	606	149.99
Nokia Lumia 928	2000	5.75	8.7		399.99

Conclusion and Limitations

Product comparison is never an easy task, especially when it involves deciding on which phone to purchase. In this paper, the DEA approach is demonstrated as a simple and easy technique for comparing phones. The DEA model is a good way to narrow down a search made difficult by the presence of multiple outputs and inputs.

As a final result, these efficiency scores will be helpful during the purchase decision process. The DEA approach will not only help the consumer, but it can also be beneficial to the manufacturer. Manufacturers can take information from a cellphone comparison via DEA to benchmark specific products and improve how well the product performs.

Including more features whenever those features can be quantified can further extend the DEA model. For instance, this study was limited to features that make up the phone (battery, camera resolution and size), but future studies could focus on the operating systems and applications. The applications available in the App Store contribute to making smartphones more appealing and functional. Therefore, future research could include the number of applications each phone can use as an output variable to determine the influence they have on purchasing efficiency and eventually the consumers' phone-selection results.

References

Bayraktar, E., Tatoglu, E., Turkyilmaz, A., Delen, D., & Zaim, S. (2014). Measuring the efficiency of customer satisfaction and loyalty for mobile phone brands with DEA. *Expert Systems with Applications*, 39. 99-106.

Barba-Gutérrez, Y., Adenso-Díaz, B., & Lozano, S. (2009). Eco-efficiency of electric and electronic appliances: A data envelopment analysis (DEA). *Environmental Modeling & Assessment,* 14(4). 439-447.

Brian, M. (2012b, December 23). The 6 best smartphones of 2012. Retrieved 13 February 2015, from http://thenextweb.com/mobile/2012/12/23/the-6-best-smartphones-of-2012/

CMO Council. (2012). Mobile marketing. Retrieved 13 February 2015, from http://www.cmocouncil.org/facts-stats-categories.php?category=mobile-marketing

Falaki, H., Mahajan, R., Kandula, S., Lymberopoulos, D., Govindan, R., & Estri, D. (2010). Diversity in smartphone usage. MobiSys '10 Proceedings of the 8th International Conference on Mobile Systems, Applications, and Services.

Khawand, P. (2007). The Smartphone Experiment. OnTheGo Technologies, LLC.

Mustafa, A. & Tan, L. P. (2006). Incorporating AHP in DEA Analysis for smartphone comparisons. Proceedings of the 2nd IMT-GT Regional Conference on Mathematics, Statistics and Applications.

Newman, J. (2013, April 1). Peak Battery: Why smartphone battery life still stinks, and will for years. Retrieved 14 February 2015, from http://techland.time.com/2013/04/01/peak-battery-why-smartphone-battery-life-still-stinks-and-will-for-years/

Tan, W., Yeh, Y., Chen, S., Lin, Y. & Kuo, C. (2012). How consumers assess product's features: A case study of product features of smartphones. Recent Researches in Applied Mathematics and Economics: Proceedings of the 6th International Conference on Applied Mathematics, Simulation, Modeling. 131-137.

About the Authors

Elissa Turpin is a senior studying Business Management with a concentration in operations, as well as Accounting and Finance with a concentration in finance. She and her research partner, Adam Sanchez, began this project in the fall of 2014 for Dr. Xiangrong Liu's (Management) Production Operations Management course and was later presented at the 2014 BSU Mid-Year Symposium.