



## COMPARING THE APPLE IPAD AND NON-APPLE CAMP TABLET PCS: A MULTICRITERIA DECISION ANALYSIS

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**Abstract.** This study mainly evaluates the performances of Tablet PCs such as the Apple iPad based on a benefits, opportunity, costs, and risks (BOCR) conceptual framework with qualitative and quantitative criteria. We apply four methods, namely, the multiple-criteria decision-making (MCDM) tools (grey relational analysis (GRA), the technique for order performance by similarity to ideal solution (TOPSIS), the VlseKriterijumska Optimizacija I Kompromisno (VIKOR) method, and fuzzy approach) to evaluate and select the tablet PCs' rankings and then construct a tablet PCs evaluation performance model under an analytic hierarchy process (AHP). The empirical results reveal that a firm's revenue growth, capacity for profitability, product design and product function are highly important evaluation indexes. This indicates that Tablet PC companies should channel more efforts into their product innovation for creating revenue growth and maintaining customer loyalty. Finally, fuzzy AHP also leads to the same findings.

**Keywords:** tablet PCs, multiple-criteria decision-making, analytic hierarchy process (AHP), product innovation, fuzzy AHP.

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**JEL Classification:** C44, C51, C52.

## **Introduction**

The CEO of Apple, Steve Jobs, first launched the tablet PC “iPad” on January 27, 2010, and generated sales of about 14 million of the tablets in the same year. He not only introduced an innovative product, but also opened up a new market of pan PC/NB-related products. Apple iPad adopted an acceleration sensor, a capacitive multi-touch, iPhone operating system coupled with a QWERTY software keyboard. iPad provides support for games and software applications downloaded from the Apple store and it also provides e-books for on-line store iBooks that can read colour-display e-books, newspapers and magazines.

The killer application of the iPad is the App Store plus iTunes. In the stores, various programs are available for users to download which attracts many users outside the PC users. The platform represents the successful experiences accumulated by Apple from the iPod to the iPhone in which software can make more money than hardware. Obviously, two key barriers preventing other competitors from entering the tablet PC market are operating systems and application platforms. Most of them have to rely on Microsoft Windows RT or Google Android, HP WebOS and RIM QNX for their operating systems. However, if they only focus on the development of hardware, they may face the same situation as those selling e-book readers in that the sales performance is not as good as expected due to the sparse content (application programs). Therefore, Google, the leader of the non-Apple camp, has had to engage in the Android operating system and Android Market application programs to help its partners to adopt integration across hardware and software.

Undoubtedly, the upsurge of tablet PCs has swept all over the world and brought tsunami-like demand in recent years. According to data compiled by Garther (2012), the global output of tablet PCs jumped to 60 million in 2011. As for the prospects for the future, with more and more operators entering the battlefield of tablet computers, the output is predicted to reach 208.3 million in 2014. Due to the popularity of the iPad, global key PC/NB and consumer electronics manufacturers are channelling resources to produce tablet PCs in the hope that they can have a share of the market. The leading NB firms such as HP, Dell, Acer, Lenovo and Asus, as well as smart phone leaders such as Samsung, Nokia, RIM, HTC and Motorola have introduced iPad-like products to compete for a share of the tablet PC market<sup>1</sup>.

There is so far no complete set of evaluation models of the tablet PC market for the reference of the tablet PC firms in their operations even though the tablet PC has rapidly been popularized. In this study, we consider a couple of criteria to assess the tablet PC, namely, quantitative indicators (i.e. prices, revenue growth and profitability) and qualitative indicators (i.e. brand attractiveness). As a decision method, the analytic hierarchy process (AHP) or fuzzy AHP decomposes a complex multi-criteria decision-making (MCDM) problem into a hierarchy (Secem *et al.* 2009; Büyüközkan *et al.* 2011; Wu *et al.* 2009b, 2010, 2011a; Bentes *et al.* 2012; Choudhary, Shankar 2012; Cox 2012). Therefore, this study addresses the concept

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<sup>1</sup> Because there is no specific name for the tablet PC products similar to the Apple iPad, we refer to them as “iPad-like” products that include the Samsung Galaxy Tab, Motorola Xoom, HP TouchPad, BlackBerry PlayBook, Asus Eee Pad Transformer and Acer Iconia Tab W500. From the viewpoint of their characteristics, the iPad and iPad-like products should be closer to consumer electronics products related to the PC or NB.

of benefits, opportunity, costs, and risks (BOCR)<sup>2</sup> to construct an alternative to the performance measurement for tablet PCs as well as selection models for tablet-PC firms under AHP and fuzzy AHP hierarchical forms, respectively (Saaty, Ozdemir 2003; Wijnmalen 2007).

In the literature, there are few MCDM theories aimed at evaluating the performances of consumer electronics products multi-dimensionally (Tsai 2012). This study provides the following four MCDM methods, namely, AHP-grey relational analysis (AHP-GRA), the AHP-technique for order performance by similarity to ideal solution (AHP-TOPSIS), AHP-VlseKriterijumska Optimizacija I Kompromisno (AHP-VIKOR) and Fuzzy AHP for constructing the Tablet PC's performance evaluation model. Based on the four perspectives of the BOCR research framework, AHP is first used to obtain the weights of the indexes. Then, the three MCDM analytical tools, GRA, TOPSIS, and VIKOR, are respectively used to evaluate and select the tablet PC rankings based on the weight of each index. On the other hand, we also utilize fuzzy AHP to evaluate the ranking of tablet PCs.

The empirical results reveal that the Apple iPad has the highest value and that the Samsung Galaxy Tab follows among the seven main tablet PCs in all four MCDM models. The results are consistent with the current realities in the tablet PC market in which the Apple iPad is the dominant tablet PC with a 54.7% market share and Samsung has a share of over 5% in 2011 Q4 (International Data Corporation (IDC) 2012). Furthermore, the results of the AHP and FAHP analysis reveal that the benefits and opportunities are the two most important criteria for tablet PCs companies to improve the performance of their tablet PC products. As for revenue growth, the capacity for profitability, product design, and product function are highly important evaluation indexes, which indicates that Tablet PC companies should expend more efforts on their product innovation for creating revenue growth and maintaining customer loyalty. In other words, they should provide more product functions and fun features on their tablet PC products.

The remainder of this study is organized as follows. Section 1 provides an evaluation analysis (including the concept of the BOCR Model, and MCDM methods). Section 2 presents the study's empirical results and related discussions. Finally, the conclusions and managerial implications are then given in the last section.

## 1. Evaluation analysis

### 1.1. The BOCR model

The concept of BOCR (benefits, opportunity, costs, and risks) was developed by Saaty (1996), Saaty and Ozdemir (2003). The BOCR model has been widely applied to various fields, such as the high-tech industry (Eroğmuş *et al.* 2005; Lee *et al.* 2009), strategic selection (Chen *et al.* 2010a; Fouladgar *et al.* 2012), and project evaluation (Jung, Seo 2010).

In evaluating each solution, these four evaluation criteria may be sub-divided into more detailed sub-criteria that will help policy-makers to derive more perfect results from the

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<sup>2</sup> The concept of BOCR was developed by Saaty and Ozdemir (2003). In evaluating each solution, these four evaluation criteria could often cover every aspect that needs to be considered. If necessary, the four criteria may be sub-divided into more detailed sub-criteria that will help policy-makers to work out more perfect results of evaluation.

evaluation. The four principles of evaluation are qualitative principles in this study. Therefore, we have adopted pairwise comparisons with AHP to obtain the weights of individual principles. Besides, in order to ensure the rationality of filling in questionnaires, we have performed consistency tests before calculating the values of weights and compiling the degree of the effects of each principle of evaluation for each solution. Subsequently, we have used the “proposal combination” method to consider the degree of the effects of maximum benefits brought to affect and control “benefits, opportunity, cost and risks” and the synthetic effects that it may cause in implementing two or more plans. In practice, the model should include not only all positive aspects of the evaluation, but it should also consider two aspects: the risks that in fact possibly occur and the costs that such risks possibly entail. However, like AHP, such a model also uses pairwise comparisons to confirm its relative weight. Any principle in BOCR has significant effects on the strategy choice and the chosen strategy has the highest weight. It explains why BOCR can find the best solution in combining the value of each strategy and can help us analyse the decision-making issues (Saaty, Ozdemir 2003; Wijnmalen 2007; Heo *et al.* 2012).

## 1.2. Multiple criteria decision making

This section introduces four multiple criteria decision making (MCDM) techniques, namely, fuzzy AHP (FAHP), GRA, TOPSIS and VIKOR. The three MCDM analytical tools of GRA, TOPSIS, and VIKOR are for ranking and improving the tablet PCs’ performance (Secme *et al.* 2009; Wu *et al.* 2009a, 2010; Zavadskas, Turskis 2011; Baležentis *et al.* 2012; Chen 2012), while we use AHP to determine the relative weights of the main and sub-criteria. Another method, the FAHP, is structured to evaluate the proposed Tablet PC framework (Büyüközkan *et al.* 2011; Baležentis *et al.* 2012; Lee *et al.* 2011a). The details of the four methods are explained as follows.

### A. Grey relational analysis (GRA)

GRA is a quantitative tool used to explore the similarities and dissimilarities among factors in developing dynamic processes (Deng 1982) and has been widely applied to various fields including performance evaluation (Wu *et al.* 2010), stock investments (Zhang *et al.* 2011), and service quality (Kuo, Liang 2011). One of the features of GRA is that both qualitative and quantitative relationships can be identified among complex factors with insufficient information (relative to conventional statistical methods). Under such conditions, the results generated by conventional statistical techniques may not be acceptable without sufficient data to achieve the desired confidence levels. By contrast, grey system theory can be used to identify major correlations among factors of a system with a relatively small amount of data. The procedure for performing GRA is as follows:

Step 1: Calculate the Grey Relation Grade

Let  $X_0$  be the referential series with  $k$  entities (or criteria) of  $X_1, X_2, \dots, X_k, \dots, X_N$  (or  $N$  measurement criteria). Then:

$$X_i = \{x_i(1), x_i(2), \dots, x_i(j), \dots, x_i(k)\}, i = 1, \dots, N.$$

The grey relational coefficient between the compared series  $X_i$  and the referential series of  $X_0$  at the  $j$ th entity is defined as:  $\gamma_{0i}(j) = \frac{\Delta \min + \Delta \max}{\Delta_{0i}(j) + \Delta \max}$ , where  $\Delta_{0i}(j)$  is the absolute value of the difference between  $X_0$  and  $X_i$  at the  $j$ th entity, that is  $\Delta_{0i}(j) = |x_0(j) - x_i(j)|$ , and  $\Delta \max = \max_i \max_j \Delta_{0i}(j)$ ,  $\Delta \min = \min_i \min_j \Delta_{0i}(j)$ . The grey relational grade (GRG) for a series of  $X_i$  is given as:  $\tilde{A}_{0i} = \sum_{j=1}^K w_j \tilde{a}_{0i}(j)$ , where  $w_j$  is the weight of  $j$ th entity. If it is not necessary to apply the weight, take  $\omega_j = \frac{1}{K}$  as an average.

Step 2: Data Normalization (or Data Dimensionless)

Before calculating the grey relation coefficients, the data series can be treated, based on the following three kinds of situation and the linearity of data normalization, to avoid distorting the normalized data. These are:

a) Upper-bound effectiveness measuring (i.e. the larger the better):

$$x_i^*(j) = \frac{x_i(j) - \min_j x_i(j)}{\max_j x_i(j) - \min_j x_i(j)} \tag{1}$$

b) Lower-bound effectiveness measuring (i.e. the smaller the better):

$$x_i^*(j) = \frac{\max_j x_i(j) - x_i(j)}{\max_j x_i(j) - \min_j x_i(j)} \tag{2}$$

c) Moderate effectiveness measuring (i.e. nominal the best):

If  $\min_j x_i(j) \leq x_{ob}(j) \leq \max_j x_i(j)$ , then  $x_i^*(j) = \frac{|x_i(j) - x_{ob}(j)|}{\max_j x_i(j) - \min_j x_i(j)}$ .

If  $\max_j x_i(j) \leq x_{ob}(j)$ , then  $x_i^*(j) = \frac{x_i(j) - \min_j x_i(j)}{x_{ob}(j) - \min_j x_i(j)}$ .

If  $x_{ob}(j) \leq \min_j x_i(j)$ , then  $x_i^*(j) = \frac{\max_j x_i(j) - x_i(j)}{\max_j x_i(j) - x_{ob}(j)}$ , where  $x_{ob}(j)$  is the objective value of entity  $j$ .

**B. The TOPSIS method**

The TOPSIS method (Hwang, Yoon 1981) simultaneously considers the distances between a positive ideal solution (PIS) and a negative ideal solution (NIS).

In this study, the final ranking of tablet PCs using the TOPSIS method is based on ‘the relative similarity to the ideal solution’, which avoids similarities between ideal and negative ideal solutions. The TOPSIS steps are as follows:

a) Establish a decision (D) matrix for alternative performance:

$$D = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} X_{11} & X_{12} & \cdots & \cdots & X_{1j} & X_{1n} \\ X_{21} & X_{22} & \cdots & \cdots & X_{2j} & X_{2n} \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots \\ X_{i1} & X_{i2} & \vdots & \vdots & X_{ij} & X_{in} \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots \\ X_{m1} & X_{m2} & \cdots & \cdots & X_{mj} & X_{mn} \end{bmatrix}, \tag{3}$$

where:  $A_i$  denotes the possible alternatives,  $i = 1, \dots, m$ ;  $X_j$  represents attributes or criteria relating to alternative performance,  $j = 1, \dots, n$ ; and  $X_{ij}$  is a crisp value denoting the performance rating of each alternative  $A_i$  with respect to each criterion  $X_j$ .

b) Normalize the  $D$  matrix.

Calculate the normalized decision matrix  $R$  ( $R = r_{ij}$ ). The normalized value  $r_{ij}$  is calculated as follows:

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{j=1}^n X_{ij}^2}}, \quad j = 1, \dots, n; \quad i = 1, \dots, m.$$

c) Create the weighted normalized performance matrix.

A set of weights  $w = (w_1, w_2, \dots, w_n)$ ,  $\sum_{j=1}^n w_j = 1$ , from the AHP is the accommodated weight.

This matrix can be calculated by multiplying each column of  $R$  by its associated weight  $w_j$ . Therefore, the weighted normalized decision matrix is denoted by  $V$ :

$$V = \begin{bmatrix} V_{11} & V_{12} & \cdots & V_{1j} & \cdots & V_{1n} \\ \vdots & \vdots & & \vdots & & \vdots \\ V_{i1} & V_{i2} & \cdots & V_{ij} & \cdots & V_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ V_{m1} & V_{m2} & \cdots & V_{mj} & \cdots & V_{mn} \end{bmatrix} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_j r_{1j} & \cdots & w_n r_{1n} \\ \vdots & \vdots & & \vdots & & \vdots \\ w_1 r_{i1} & w_2 r_{i2} & \cdots & w_j r_{ij} & \cdots & w_n r_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_j r_{mj} & \cdots & w_n r_{mn} \end{bmatrix}.$$

d) Determine the ideal solution and negative ideal solution.

The ideal solution is computed using the following equations:

$$A^* = \{(\max V_{ij} \mid j \in J), (\min V_{ij} \mid j \in J'), i = 1, 2, \dots, m\},$$

$$A^- = \{(\min V_{ij} \mid j \in J), (\max V_{ij} \mid j \in J'), i = 1, 2, \dots, m\},$$

where  $j = \{j = 1, 2, \dots, n \mid j \text{ belongs to benefit criteria}\}$ ,  $j' = \{j = 1, 2, \dots, n \mid j \text{ belongs to cost criteria}\}$ .

e) Calculate the distance between the ideal solution and the negative ideal solution for each alternative as follows:

$$S_i^* = \sqrt{\sum_{j=1}^n (V_{ij} - V_j^*)^2} \quad i = 1, 2, \dots, m; \tag{4}$$

$$S_i^- = \sqrt{\sum_{j=1}^n (V_{ij} - V_j^-)^2} \quad i = 1, 2, \dots, m. \tag{5}$$

f) Calculate the relative closeness to the ideal solution for each alternative:

$$C_i^* = \frac{S_i^-}{S_i^* + S_i^-} \quad i = 1, 2, \dots, m, \tag{6}$$

where:  $0 \leq C_i^* \leq 1$ ; that is, an alternative  $i$  is closer to  $A^*$  as  $C_i^*$  approaches 1.

g) A set of alternatives can be preference-ranked according to the descending order of  $C_i^*$ .

**C. The VIKOR method**

The VIKOR method was proposed by Opricovic and Tzeng (2004). The basic concept of the VIKOR method is based on the compromise programming utilized in MCDM by comparing the measure of “closeness” to the “ideal” alternative (Opricovic, Tzeng 2004; Baležentis *et al.* 2012). The various alternatives are denoted by  $a_1, a_2, \dots, a_m$ . For an alternative  $a_i$ , the merit of the  $j$ th aspect is denoted by  $f_{ij}$ , that is,  $f_{ij}$  is the value of the  $j$ th criterion function for the alternative  $a_i$ .

The compromise ranking algorithm is summarized as follows (Opricovic, Tzeng 2004; Wu *et al.* 2009a; Kuo, Liang 2011):

Step 1: Determine the best  $f_j^*$  and the worst  $f_j^-$  values of all criterion functions. Assume that the  $j$ th criterion function represents a benefit:

$$f_j^* = \max_i f_{ij}, \quad i = 1, 2, 3, \dots, m, \quad f_j^- = \min_i f_{ij}, \quad i = 1, 2, 3, \dots, m, \tag{7}$$

Step 2: Compute the values  $S_i$  and  $R_i, i = 1, 2, 3, \dots, m$ , by the relations:

$$S_i = \sum_{j=1}^n w_j (f_j^* - f_{ij}) / (f_j^* - f_j^-); \tag{8}$$

$$R_i = \max_j [w_j (f_j^* - f_{ij}) / (f_j^* - f_j^-)], \tag{9}$$

where:  $w_j$  is the weight of the  $j$ th criteria, expressing the DM’s preference in terms of the relative importance of the criteria.

Step 3: Compute the values  $Q_i$  for  $i = 1, 2, 3, \dots, m$ , which are defined as:

$$Q_i = \nu \left[ \frac{S_i - S^*}{S^- - S^*} \right] + (1 - \nu) \left[ \frac{R_i - R^*}{R^- - R^*} \right], \tag{10}$$

where:  $S^* = \min_i S_i, S^- = \max_i S_i, R^* = \min_i R_i, R^- = \max_i R_i$ , and  $\nu$  is a weighting reference,  $\nu$  is introduced as the weight of the strategy of the maximum group utility, whereas

$(1-\nu)$  is the weight of the individual regret. Thus, when the  $\nu$  reference is larger ( $> 0.5$ ), the index of  $Q_i$  will tend toward majority rule.

Step 4: Compute a compromise solution in which the alternative ( $a'$ ) is ranked the best by the measure  $Q$  (minimum) if it satisfies the following two conditions:

1.  $Q(a'') - Q(a') \geq DQ$ , which is called an “acceptable advantage”.

In this equation,  $a''$  is the alternative with the second position in the ranking list according to  $DQ = 1/(J-1)$ .  $J$  is the number of alternatives;

2. The decision-making process demonstrates acceptable stability. Alternative  $d$  must also be ranked the best by  $S$  and/or  $R$ . This solution is stable in a decision-making process, which could consist of “voting by majority rule” (when  $\nu > 0.5$  is needed), “by consensus”  $\nu \approx 0.5$ , or “with veto” ( $\nu < 0.5$ ). Here,  $\nu$  is the weight of the decision-making strategy with the max group utility.

If conditions are not fully satisfied, then a set of compromise solutions is proposed, as shown by the following two alternatives:

1. Alternatives  $a'$  and  $a''$  are used only if condition 2 is not satisfied;
2. Alternatives  $a'$ ;  $a''$ , ...,  $a^{(M)}$  are used if condition 1 is not satisfied.  $a^{(M)}$  is determined by the relation  $Q(a^{(M)}) - Q(a') < DQ$  for maximum  $M$ .

The best alternative, ranked by  $Q$ , is the one with the minimum value of  $Q$ ; the main ranking result is the compromise ranking list of alternatives and the compromise solution with the advantage rate (Tzeng *et al.* 2002; Opricovic, Tzeng 2004).

Ranking obtained by the VIKOR method requires the use of different values of the criteria weights and an analysis of the impact of the criteria weights on the proposed compromise solution. We determine the weight stability intervals by using the methodology presented in Opricovic (1998). The compromise solution gained with the initial weights ( $w_i, i = 1, \dots, n$ ) will be replaced if the value of a weight is missing from the stability interval. The analysis of the weight stability intervals for a single criterion is utilised for all criterion functions with the initial values of the weights. By doing so, the stability of the preferences in a gained compromise solution may be analysed utilising the VIKOR program (Opricovic, Tzeng 2004).

VIKOR is a tool that benefits MCDM in situations where the decision maker is unstable at the beginning of the system’s design. In addition, decision makers accept the compromise solution because it provides a maximum group utility, which is represented by  $\text{Min } Q$  and a minimum individual regret, which is represented by  $\text{Min } R$  (Tzeng *et al.* 2002).

#### D. Fuzzy AHP method

Fuzzy set theory was introduced by Zadeh in 1965. As an important concept applied in the scientific environment, it has been made available to other fields as well (Wu *et al.* 2009a; Arslan, Aydin 2009). Fuzzy set theory is an important method used to measure the ambiguity of concepts that are associated with human beings’ subjective judgments including linguistic terms<sup>3</sup>, degree of satisfaction and degree of importance that are often vague (Secme *et al.*

<sup>3</sup> A linguistic variable is a variable whose values are not numbers but phrases in a natural language. For example, lingual expressions, such as satisfied, fair, and dissatisfied, are usually regarded as natural representations of humans’ preferences or judgments (Zimmermann 1991; Herrera, Herrera-Viedma 2000; Secme *et al.* 2009).



2009). AHP is one of the well-known MCDM techniques (Saaty 1980). Although classical AHP includes the opinions of experts and involves a multiple criteria evaluation, it is not capable of reflecting the vague thoughts of humans. Therefore, FAHP should be more appropriate and effective than conventional AHP in actual practice where an uncertain pairwise comparison environment exists (Gumus 2009; Baležentis *et al.* 2012; Chen 2012).

There are many FAHP methods proposed by various authors (Buckley 1985; Chang 1996; Deng 1999; Mikhailov 2004). In this study, we prefer Chang’s (1996) extent analysis method (EAM) because the steps of this approach can be more easily applied than the other FAHP approaches (Büyükožkan *et al.* 2008; Celik *et al.* 2009; Choudhary, Shankar 2012; Sevkli *et al.* 2012). Let  $X = \{x_1, x_2, \dots, x_n\}$  be an object set, and  $U = \{u_1, u_2, \dots, u_m\}$  be a goal set. Each object is taken and extent analysis for each goal is performed, respectively. Therefore,  $m$  extent analysis values for each object can be obtained, with the following signs:  $M_{gi}^1, M_{gi}^2, \dots, M_{gi}^m$ ,  $i = 1, 2, \dots, n$ , where all the  $M_{gi}^j$  ( $j = 1, 2, \dots, m$ ) are triangular fuzzy numbers (TFNs).

The steps for Chang’s (1996) extent analysis can be given as follows (Gumus, 2009; Secme *et al.* 2009).

Step 1: The value of the fuzzy synthetic extent with respect to the  $i$ th object is defined as:

$$S_i = \sum_{j=1}^m M_{gi}^j \otimes \left[ \sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} . \quad (11)$$

To obtain  $\sum_{j=1}^m M_{gi}^j$  perform the fuzzy addition operation of  $m$  extent analysis values for a particular matrix such that:

$$\sum_{j=1}^m M_{gi}^j = \left( \sum_{j=1}^m l_j, \sum_{j=1}^m m_j, \sum_{j=1}^m u_j \right),$$

Step 2: As  $\tilde{M}_2$  and  $\tilde{M}_1$  are two TFNs, the degree of possibility of  $\tilde{M}_2 = (l_2, m_2, u_2) \geq \tilde{M}_1 (l_1, m_1, u_1)$  is defined as:

$$V(\tilde{M}_2 \geq \tilde{M}_1) = \sup_{y \geq x} \left[ \min(\mu_{M_1}(x), \mu_{M_2}(y)) \right],$$

and can be equivalently expressed as follows:

$$V(\tilde{M}_2 \geq \tilde{M}_1) = \text{hgt}(\tilde{M}_1 \cap \tilde{M}_2) = \mu(d) = \begin{cases} 1, & \text{if } m_2 \geq m_1, \\ 0, & \text{if } l_1 \geq u_2, \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{otherwise,} \end{cases} \quad (12)$$

where  $d$  is the ordinate of the highest intersection point  $D$  between  $\mu_{\tilde{M}_1}$  and  $\mu_{\tilde{M}_2}$  (Fig. 1).

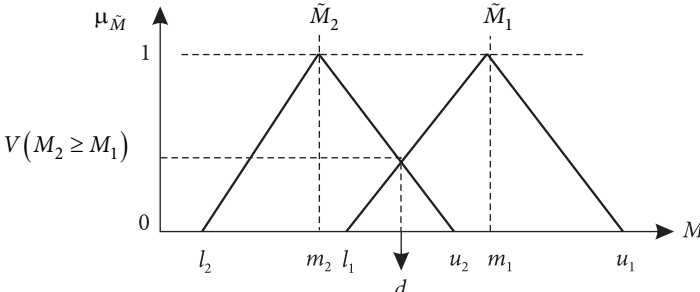


Fig. 1. The intersection between  $\mu_1$  and  $\mu_2$

To compare  $\tilde{M}_2$  and  $\tilde{M}_1$ , we need both values of  $V(\tilde{M}_1 \geq \tilde{M}_2)$  and  $V(\tilde{M}_2 \geq \tilde{M}_1)$ .

Step 3: The degree of possibility for a convex fuzzy number to be greater than  $k$  convex fuzzy numbers  $\tilde{M}_i (i=1,2,\dots,k)$  can be defined by:

$$V(\tilde{M} \geq \tilde{M}_1, \tilde{M}_2, \dots, \tilde{M}_k) = [V(\tilde{M} \geq \tilde{M}_1) \text{ and } (\tilde{M} \geq \tilde{M}_2)] \text{ and } \dots \text{ and } (\tilde{M} \geq \tilde{M}_k) = \min V(\tilde{M} \geq \tilde{M}_i), i=1,2,3,\dots,k.$$

Assume that  $d'(A_i) = \min V(S_i \geq S_k)$ . For  $k=1,2,\dots,n; k \neq i$ . Then the weight vector is given by  $W' = (d'(A_1), d'(A_2), \dots, d'(A_n))^T$ , where  $A_i (i=1,2,\dots,n)$  comprises  $n$  elements.

Step 4: Via normalization, the normalized weight vectors are  $W = (d(A_1), d(A_2), \dots, d(A_n))^T$ , where  $W$  is a non-fuzzy number.

**2. An empirical study**

The four perspectives of BOCR are taken as the framework for establishing tablet PCs evaluation indicators in this study. Based on this research framework, we first use AHP to calculate the weights of the indicators and then utilize AHP-GRA, AHP-TOPSIS, and AHP-VIKOR to evaluate the tablet PC ranking based on the weight of each indicator. The study further applies FAHP to evaluate the ranking of tablet PCs. The hierarchical framework of the BOCR evaluation criteria and the resulting discussions are illustrated as follows.

**2.1. Hierarchical framework of the BOCR evaluation criteria**

Based on the four principles of evaluation (BOCR), experts' questionnaires were introduced to screen the indices' fit for the tablet PCs' evaluation and selection. Twenty-three evaluation indicators were selected by a committee of experts, comprising 21 professional experts from tablet PC-related industries including those engaged in R&D, project management (PM), marketing, procurement, and as touch product managers. Appendix Table A1 provides each supporting reference for the performance evaluation criteria and sub-criteria. Apple

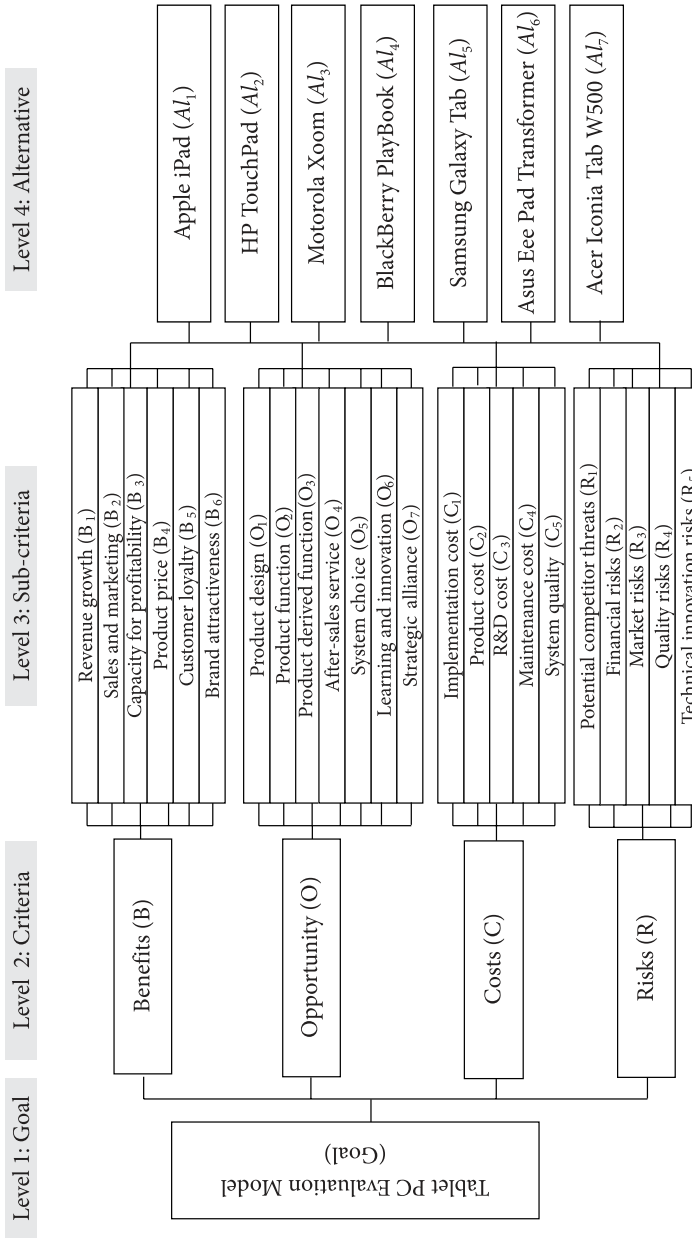


Fig. 2. Hierarchical framework of BOCR evaluation criteria for tablet PCs evaluation model

and Samsung are the top two leaders in the tablet PC industry, while HP, Asus and Acer are key leaders in the NB industry and Apple, Samsung, Motorola and BlackBerry are the main manufacturers in the smart phone industry. All of them produce tablet PCs. For this reason, we choose the following seven firms’ tablet PC products as alternatives in this research: Apple iPad, HP TouchPad, Motorola Xoom, BlackBerry PlayBook, Samsung Galaxy Tab, Asus Eee Pad Transformer, and Acer Iconia Tab W500.

The hierarchical framework of the BOCR evaluation criteria (i.e. four dimensions and 23 indicators) for tablet PCs is shown in Figure 2. The four dimensions are ‘B: Benefits (B<sub>1</sub>–B<sub>6</sub>)’, ‘O: Opportunity (O<sub>1</sub>–O<sub>7</sub>)’, ‘C: Costs (C<sub>1</sub>–C<sub>5</sub>)’, and ‘R: Risks (R<sub>1</sub>–R<sub>5</sub>)’. Table A2 (the Appendix) provides a brief description of these seven alternatives among tablet PCs.

**2.2. Application of AHP in determining the weights of criteria**

Based on the hierarchical framework of the BOCR evaluation criteria and sub-criteria, the AHP questionnaire using the geometric mean method (GMM) was distributed among the 21 experts for soliciting their professional opinions. Table 1 describes the aggregate pairwise comparison matrix for the criteria; the sub-criteria are listed in Appendix Table A3. The relative importance scores of each evaluation indicator analysed by the AHP are listed in Table 2.

Table 1. Aggregate pairwise comparison matrix for criteria of level 2

Criteria	B	O	C	R
B	1.000	2.097	1.698	1.561
O	0.477	1.000	1.820	1.662
C	0.589	0.550	1.000	1.689
R	0.641	0.602	0.592	1.000

Note:  $\lambda_{max} = 4.150$ ; CI = 0.050; RI = 0.900; CR = 0.056 ≤ 0.1.

Table 2. Weights of the BOCR evaluation index by AHP

Criteria	Weights for level 2	Sub-criteria	Weights for level 3	Weights of the overall
B	0.369	B <sub>1</sub>	0.213	0.079 (1)
		B <sub>2</sub>	0.168	0.062 (3)
		B <sub>3</sub>	0.193	0.071 (2)
		B <sub>4</sub>	0.159	0.059 (4)
		B <sub>5</sub>	0.125	0.046 (10)
		B <sub>6</sub>	0.142	0.052 (7)
O	0.262	O <sub>1</sub>	0.209	0.055 (5)
		O <sub>2</sub>	0.151	0.040 (12)
		O <sub>3</sub>	0.121	0.032 (16-17)
		O <sub>4</sub>	0.110	0.029 (20-21)

Continued Table 2

Criteria	Weights for level 2	Sub-criteria	Weights for level 3	Weights of the overall		
C	0.204	O <sub>5</sub>	0.147	0.039 (13)		
		O <sub>6</sub>	0.123	0.032 (16-17)		
		O <sub>7</sub>	0.138	0.036 (14)		
		C <sub>1</sub>	0.241	0.049 (8)		
		C <sub>2</sub>	0.231	0.047 (9)		
		C <sub>3</sub>	0.214	0.044 (11)		
		C <sub>4</sub>	0.162	0.033 (15)		
		C <sub>5</sub>	0.153	0.031 (18-19)		
		R	0.165	R <sub>1</sub>	0.325	0.054 (6)
				R <sub>2</sub>	0.191	0.031 (18-19)
R <sub>3</sub>	0.174			0.029 (20-21)		
R <sub>4</sub>	0.147			0.024 (23)		
R <sub>5</sub>	0.163			0.027 (22)		

Note: () denotes ranking order.

The results show that the critical order of the four BOCR dimensions for the evaluation of tablet PCs is “B: Benefits (0.369)”, “O: Opportunity (0.262)”, “C: Costs (0.204)”, and “R: Risks (0.165)”. Table 1 presents the respective weights of the six indicators for the “Benefits perspective, B<sub>1</sub> (0.213), B<sub>2</sub> (0.168), B<sub>3</sub> (0.193), B<sub>4</sub> (0.159), B<sub>5</sub> (0.125), and B<sub>6</sub> (0.142)”. The respective weights of the seven indicators for the “Opportunity perspective are O<sub>1</sub> (0.209), O<sub>2</sub> (0.151), O<sub>3</sub> (0.121), O<sub>4</sub> (0.110), O<sub>5</sub> (0.147), O<sub>6</sub> (0.123), and O<sub>7</sub> (0.138)”. The respective weights of the five indicators for the “Costs perspective are C<sub>1</sub> (0.241), C<sub>2</sub> (0.231), C<sub>3</sub> (0.214), C<sub>4</sub> (0.162), and C<sub>5</sub> (0.153)”. The respective weights of the five indicators for the “Risks perspective are R<sub>1</sub> (0.325), R<sub>2</sub> (0.191), R<sub>3</sub> (0.174), R<sub>4</sub> (0.147), and R<sub>5</sub> (0.163)”.

The following are the synthesis values (overall weights) of the seven tablet PCs under the twenty-three indicators: B<sub>1</sub> (0.079), B<sub>2</sub> (0.062), B<sub>3</sub> (0.071), B<sub>4</sub> (0.059), B<sub>5</sub> (0.046), B<sub>6</sub> (0.052), O<sub>1</sub> (0.055), O<sub>2</sub> (0.040), O<sub>3</sub> (0.032), O<sub>4</sub> (0.029), O<sub>5</sub> (0.039), O<sub>6</sub> (0.032), and O<sub>7</sub> (0.036), C<sub>1</sub> (0.049), C<sub>2</sub> (0.047), C<sub>3</sub> (0.044), C<sub>4</sub> (0.033), C<sub>5</sub> (0.031), R<sub>1</sub> (0.054), R<sub>2</sub> (0.031), R<sub>3</sub> (0.029), R<sub>4</sub> (0.024), and R<sub>5</sub> (0.027). As indicated in Table 1, the eight most important evaluation indicators are “B<sub>1</sub>: Revenue growth (0.079)”, “B<sub>3</sub>: Capacity for profitability (0.071)”, “B<sub>2</sub>: Sales and marketing (0.062)”, “B<sub>4</sub>: Product price (0.059)”, “O<sub>1</sub>: Product design (0.055)”, “R<sub>1</sub>: Potential competitor threats (0.054)”, “B<sub>6</sub>: Brand attractiveness (0.052)”, and “C<sub>1</sub>: Implementation cost (0.049)”.

### 2.3. Application of AHP-GRA, AHP-TOPSIS, and AHP-VIKOR in ranking alternatives

In this section, the GRA, TOPSIS, and VIKOR methods are introduced to rank the alternative performances. The priority weights of alternative performances with respect to the sub-criteria (decision matrix) calculated by AHP are shown in Table 3.

Table 3. Weights of tablet PCs evaluation with respect to sub-criteria (decision matrix)

Indicators	Apple	HP	Motorola	BB	Samsung	Asus	Acer
B <sub>1</sub>	0.433	0.098	0.092	0.079	0.104	0.110	0.084
B <sub>2</sub>	0.449	0.100	0.093	0.072	0.108	0.098	0.079
B <sub>3</sub>	0.468	0.102	0.087	0.073	0.102	0.088	0.081
B <sub>4</sub>	0.370	0.103	0.101	0.090	0.127	0.117	0.092
B <sub>5</sub>	0.483	0.091	0.094	0.088	0.094	0.082	0.069
B <sub>6</sub>	0.493	0.083	0.091	0.087	0.094	0.076	0.076
O <sub>1</sub>	0.477	0.092	0.096	0.082	0.091	0.090	0.071
O <sub>2</sub>	0.408	0.098	0.091	0.095	0.108	0.113	0.088
O <sub>3</sub>	0.409	0.106	0.099	0.100	0.095	0.104	0.088
O <sub>4</sub>	0.341	0.113	0.109	0.090	0.113	0.116	0.117
O <sub>5</sub>	0.382	0.106	0.103	0.105	0.105	0.099	0.100
O <sub>6</sub>	0.454	0.088	0.089	0.080	0.102	0.111	0.076
O <sub>7</sub>	0.339	0.120	0.115	0.101	0.112	0.114	0.098
C <sub>1</sub>	0.409	0.105	0.087	0.090	0.116	0.101	0.093
C <sub>2</sub>	0.423	0.111	0.083	0.078	0.107	0.103	0.094
C <sub>3</sub>	0.436	0.098	0.104	0.101	0.103	0.084	0.075
C <sub>4</sub>	0.437	0.099	0.079	0.091	0.100	0.100	0.095
C <sub>5</sub>	0.425	0.103	0.092	0.088	0.099	0.100	0.093
R <sub>1</sub>	0.321	0.106	0.121	0.109	0.118	0.121	0.104
R <sub>2</sub>	0.299	0.130	0.125	0.112	0.120	0.112	0.101
R <sub>3</sub>	0.237	0.133	0.128	0.134	0.129	0.122	0.116
R <sub>4</sub>	0.255	0.116	0.109	0.118	0.139	0.134	0.128
R <sub>5</sub>	0.292	0.117	0.118	0.116	0.130	0.121	0.106

I. Selection of the best tablet PCs by AHP-GRA

The weights are estimated by 21 experts with each of the respondents using Saaty’s relative importance scale and averaging their scales to assess candidates, before establishing a decision making matrix as shown in Table 3.

The thirteen sub-criteria (for the “B” and “O” perspective) are ‘the larger the better’ and the ten sub-criteria (for the “C” and “R” perspective) are ‘the smaller the better’. Accordingly, the referential series can be  $X_0 = (0.433, 0.449, 0.468, 0.370, 0.483, 0.493, 0.477, 0.408, 0.409, 0.341, 0.382, 0.454, 0.339, 0.087, 0.078, 0.075, 0.079, 0.088, 0.104, 0.101, 0.116, 0.109, \text{ and } 0.106)$ . The tablet PCs are  $X_1, X_2, X_3, X_4, X_5, X_6,$  and  $X_7$ . Data are normalized for twenty-three sub-criteria by using Eqs. (1) and (2). Following the normalization of the data and the relational coefficients of the compared series, Table 4 reveals the result that the Apple iPad is the top one and is followed by the Samsung Galaxy Tab and the Asus Eee Pad Transformer.

Table 4. The final evaluation and ranking of tablet PCs (Summary of the GRA  $\Gamma_{0i}$ )

Tablet PCs selection	$\Gamma_{0i}$	Ranking
Apple (A <sub>1</sub> )	1.000	1
HP (A <sub>2</sub> )	0.348	4
Motorola (A <sub>3</sub> )	0.344	5
BB (A <sub>4</sub> )	0.340	6
Samsung (A <sub>5</sub> )	0.352	2
Asus (A <sub>6</sub> )	0.348	3
Acer (A <sub>7</sub> )	0.338	7

## II. Selection of the best tablet PCs by AHP-TOPSIS

Based on the AHP-TOPSIS method, by using the decision, normalized, and weighted normalized decision matrices, Eqs. (4) and (5) determine the ideal solution and negative ideal solution (Table 5). Following the TOPSIS weights and the relative closeness to the ideal solution of each alternative,  $C_i^*$  from Eq. (6), we have the performance ranking order of the seven tablet PCs as follows: Apple (A<sub>1</sub>) (1.000) > Samsung (A<sub>5</sub>) (0.074) > HP (A<sub>2</sub>) (0.063) > Asus (A<sub>6</sub>) (0.061) > Motorola (A<sub>3</sub>) (0.050) > BB (A<sub>4</sub>) (0.031) > Acer (A<sub>7</sub>) (0.024) (Table 5).

Table 5. Final evaluation of the alternatives in TOPSIS

Tablet PCs Selection	$S_i^+$	$S_i^-$	$C_i^*$	Ranking
Apple (A <sub>1</sub> )	0.000	0.549	1.000	1
HP (A <sub>2</sub> )	0.518	0.035	0.063	3
Motorola (A <sub>3</sub> )	0.527	0.028	0.050	5
BB (A <sub>4</sub> )	0.538	0.017	0.031	6
Samsung (A <sub>5</sub> )	0.511	0.041	0.074	2
Asus (A <sub>6</sub> )	0.519	0.034	0.061	4
Acer (A <sub>7</sub> )	0.542	0.014	0.024	7

## III. Selection of the best tablet PCs by AHP-VIKOR

The AHP-VIKOR approach ranks the performance of the seven tablet PCs based on the weights of the BOCR performance evaluation indicators by AHP as shown in Table 3. Table A4 (Appendix) shows the performance matrix given by Eq. (7) with the best value  $f_j^*$  and the worst value  $f_j^-$ . The values of  $S_i$  and  $R_i$  by Eqs. (8) and (9) are shown in Table A5 (Appendix), while the computed value  $Q_i$  (with  $\nu=0, 0.5, 1$ ) using Eq. (10) and the preference order tablet PCs ranking are given in Table 6.

Table 6. The preference order ranking by VIKOR for sensitivity analysis

Tablet PCs Selection	$Q_i [v = 0]$	$Q_i [v = 0.5]$	$Q_i [v = 1]$
Apple (AI <sub>1</sub> )	0.000 (1)	0.000 (1)	0.000 (1)
HP (AI <sub>2</sub> )	0.987 (6)	0.971 (5)	0.955 (3-4)
Motorola (AI <sub>3</sub> )	0.918 (2)	0.944 (4)	0.970 (5)
BB (AI <sub>4</sub> )	0.975 (5)	0.982 (6)	0.988 (6)
Samsung (AI <sub>5</sub> )	0.933 (4)	0.936 (2)	0.938 (2)
Asus (AI <sub>6</sub> )	0.919 (3)	0.937 (3)	0.955 (3-4)
Acer (AI <sub>7</sub> )	1.000 (7)	1.000 (7)	1.000 (7)

Note: () denotes ranking order.

The final ranking result is judged and produced according to two cardinal conditions (C1 and C2) stated in Section 1.2 (Wu *et al.* 2011b). The judging methods are as follows:

**C1. “Acceptable advantage”:**

In this study (which postulates that  $v = 0.5$ ), the  $DQ$  threshold value is 0.167 ( $DQ = 1/(7-1) = 0.167$ ). According to the  $Q_i$  value in Table 6, the gap between the ranked first Apple (0.000) and ranked second Samsung (0.936) is 0.936. Since 0.936 surpasses the acceptable profit threshold value 0.167, it meets the acceptable profit threshold of condition one (C1). Besides, the gap of the  $Q_i$  value between the ranked second Samsung (0.936) and ranked third Asus (0.937) is 0.001 less than 0.167 therefore it does not meet the condition one (C1). Then, the gap of the  $Q_i$  value between the ranked third Asus (0.937) and the ranked fourth Motorola (0.944) is 0.007, which does not fit in with the condition one (C1). The acceptable profit threshold of condition one (C1) does not be satisfied, while the gap of the  $Q_i$  value between the ranked fourth Motorola (0.944) and the ranked fifth HP (0.971) is 0.027 (< 0.167). The gap of the  $Q_i$  value between the ranked fifth HP (0.971) and the ranked sixth BB (0.982) is 0.011 (< 0.167) which does not fit in with the acceptable profit threshold of condition one (C1). Finally, the gap of the  $Q_i$  value between the ranked sixth BB (0.982) and the ranked seventh Acer (1.000) is 0.018 (< 0.167). That is, the gap does not be satisfy condition one (C1).

**C2. “Acceptable stability in decision making”:**

As Table A5 (Appendix) shows, the  $S_i$  value and the  $R_i$  value of the ranked first Apple in the  $Q_i$  value are superior to those of the ranked other tablet PCs which confirms to the reliability of the analysis of the acceptable policy of condition two (C2).

Based on the analysis results of the above two conditions, we have that Apple > Samsung ≈ Asus ≈ Motorola ≈ HP ≈ BB ≈ Acer . Consequently, Apple is superior to the other six tablet PCs. Apple should be the preferred choice because it has the “best relative weights”.



**2.4. Application of fuzzy AHP on tablet PCs evaluation and selection problem**

In FAHP, firstly, the main criteria, sub-criteria, and the importance weights of alternatives must be compared. For this reason, there must be linguistic terms and their equivalent fuzzy numbers denoting comparison measures. The linguistic comparison terms and their equivalent fuzzy numbers considered in this study are shown in Table 7.

Table 7. Membership function of linguistic scale

Fuzzy Number	Linguistic Scale	Triangular Fuzzy Scale	Inverse of Triangular Fuzzy Scale
$\tilde{1}$	Equal	(1, 1, 1)	(1, 1, 1)
$\tilde{2}$	Weak advantage	(1, 2, 3)	(1/3, 1/2, 1)
$\tilde{3}$	Not bad	(2, 3, 4)	(1/4, 1/3, 1/2)
$\tilde{4}$	Preferable	(3, 4, 5)	(1/5, 1/4, 1/3)
$\tilde{5}$	Good	(4, 5, 6)	(1/6, 1/5, 1/4)
$\tilde{6}$	Fairly good	(5, 6, 7)	(1/7, 1/6, 1/5)
$\tilde{7}$	Very good	(6, 7, 8)	(1/8, 1/7, 1/6)
$\tilde{8}$	Absolute	(7, 8, 9)	(1/9, 1/8, 1/7)
$\tilde{9}$	Perfect	(8, 9, 10)	(1/10, 1/9, 1/8)

The weights of the criteria and sub-criteria are determined by FAHP. The pairwise comparison scores were carried out by 21 experts working in R&D, project management (PM), marketing, procurement, and as touch product managers in the tablet PC industry. The fuzzy pairwise comparisons matrix for the goal is presented in Table A6 (Appendix).

The values of fuzzy synthetic extents with respect to the goal were computed using Eq. (11) as follows:

$$S_B = (5.220, 6.356, 7.583) \otimes (1/26.619, 1/17.977, 1/14.863) = (0.241, 0.354, 0.510);$$

$$S_O = (3.996, 4.959, 6.007) \otimes (1/26.619, 1/17.977, 1/14.863) = (0.185, 0.276, 0.404);$$

$$S_C = (3.187, 3.828, 4.647) \otimes (1/26.619, 1/17.977, 1/14.863) = (0.147, 0.213, 0.313);$$

$$S_R = (2.459, 2.834, 3.382) \otimes (1/26.619, 1/17.977, 1/14.863) = (0.114, 0.158, 0.228).$$

The synthetic values obtained were compared by using Eq. (12) and the following results were obtained:

Comparison of  $S_B$  with the others:  $V(S_B \geq S_O) = 1, V(S_B \geq S_C) = 1, V(S_B \geq S_R) = 1.$

Comparison of  $S_O$  with the others:  $V(S_O \geq S_B) = 0.667, V(S_O \geq S_C) = 1, V(S_O \geq S_R) = 1.$

Comparison of  $S_C$  with the others:  $V(S_C \geq S_B) = 0.336, V(S_C \geq S_O) = 0.670, V(S_C \geq S_R) = 1.$  Comparison of  $S_R$  with the others:  $V(S_R \geq S_B) = 0.076, V(S_R \geq S_O) = 0.265, V(S_R \geq S_C) = 0.592.$

The priority weights were subsequently calculated as follows:

$$d'(S_B) = \min V(S_B \geq S_O, S_C, S_R) = 1; \quad d'(S_O) = \min V(S_O \geq S_B, S_C, S_R) = 0.677;$$

$$d'(S_C) = \min V(S_C \geq S_B, S_O, S_R) = 0.336; \quad d'(S_R) = \min V(S_R \geq S_B, S_O, S_C) = 0.076.$$

The weights vector is  $W'_{goal} = (1, 0.677, 0.336, 0.076)^T$ . After the normalization, the normalized weight vector with respect to the goal is  $W_{goal} = (0.479, 0.324, 0.161, 0.036)^T$ . In a similar way, following the fuzzy pairwise comparisons matrix for the sub-criteria, the weights of importance of sub-criteria with BOCR should be calculated respectively as shown in Table A7 (Appendix).

Finally, the performance ranking order of the seven tablet PCs using FAHP is Apple ( $AI_1$ ) (0.210) > Samsung ( $AI_5$ ) (0.142) > HP ( $AI_2$ ) (0.140) > Motorola ( $AI_6$ ) (0.133) > Asus ( $AI_3$ ) (0.128) > BB ( $AI_4$ ) (0.126) > Acer ( $AI_7$ ) (0.122) as shown in Table 8. The final values and preference order ranking for these four MCDM models, namely, AHP-GRA, AHP-TOPSIS, AHP-VIKOR, and FAHP, are summarized in Table 9.

Table 8. Summary of priority weights of the tablet PCs with respect to each criterion by FAHP

	B	O	C	R	Alternative priority weight	Ranking
w	0.479	0.324	0.161	0.036		
Apple ( $AI_1$ )	0.207	0.199	0.197	0.397	0.210	1
HP ( $AI_2$ )	0.144	0.139	0.137	0.099	0.140	3
Motorola ( $AI_3$ )	0.130	0.140	0.140	0.069	0.133	4
BB ( $AI_4$ )	0.119	0.134	0.132	0.120	0.126	6
Samsung ( $AI_5$ )	0.151	0.139	0.134	0.086	0.142	2
Asus ( $AI_6$ )	0.125	0.133	0.135	0.087	0.128	5
Acer ( $AI_7$ )	0.124	0.116	0.125	0.142	0.122	7

Table 9. Summary of preference order ranking by four MCDM methods

Tablet PCs selection	AHP-GRA	AHP-TOPSIS	AHP-VIKOR	FAHP
Apple ( $AI_1$ )	1.000 (1)	1.000 (1)	0.000 (1)	0.210 (1)
HP ( $AI_2$ )	0.348 (4)	0.063 (3)	0.971 (5)	0.140 (3)
Motorola ( $AI_3$ )	0.344 (5)	0.050 (5)	0.944 (4)	0.133 (4)
BB ( $AI_4$ )	0.340 (6)	0.031 (6)	0.982 (6)	0.126 (6)
Samsung ( $AI_5$ )	0.352 (2)	0.074 (2)	0.936 (2)	0.142 (2)
Asus ( $AI_6$ )	0.348 (3)	0.061 (4)	0.937 (3)	0.128 (5)
Acer ( $AI_7$ )	0.338 (7)	0.024 (7)	1.000 (7)	0.122 (7)

Note: () denotes ranking order.

### 2.5. Discussions

This study conducted a performance analysis for the top seven tablet PCs using a MCDM approach based on the BOCR perspectives. The four MCDM models (i.e. AHP-GRA, AHP-TOPSIS, AHP-VIKOR, and FAHP) were employed in the performance analysis to

compute the weights of the criteria, ranking the tablet PCs' performance and attempting to explain the differences among the seven tablet PCs, respectively.

Based on the empirical results, we find that the Apple iPad has the highest value among the seven tablet PCs for the four MCDM models (i.e. AHP-GRA (1.000), AHP-TOPSIS (1.000), AHP-VIKOR (0.000), and FAHP (0.210)); the Samsung Galaxy Tab has the second highest value (i.e. AHP-GRA (0.352), AHP-TOPSIS (0.074), AHP-VIKOR (0.936), and FAHP (0.142)); and the Acer Iconia Tab W500 is the last with the lowest weight (i.e. AHP-GRA (0.338), AHP-TOPSIS (0.024), AHP-VIKOR (1.000), and FAHP (0.122)). As shown in Table 1 and Table A5, the results of the AHP and FAHP analysis reveal that the "benefits" perspective ( $W_{\text{AHP}}$  (0.369);  $W_{\text{FAHP}}$  (0.479)) and "opportunity" perspective ( $W_{\text{AHP}}$  (0.262);  $W_{\text{FAHP}}$  (0.324)) have higher weightings. Revenue growth, the capacity for profitability, product design, and product function are most important evaluation indicators in terms of benefits and opportunity, respectively. This is because tablet PCs are part of the consumer electronics (CE) industry, and the performance of tablet PCs is strongly connected to revenue growth, the capacity for profitability, product design, and product function. Sales and marketing, product price, systems choice, and strategic alliances are the other most important indicators for sustaining a high tablet PC market performance.

In Consumer Reports (2012), the 2012 best tablet PCs evaluation indicated that the Apple iPad was the best tablet PC among all tablet PCs. There are two key factors to make the Apple iPad a success. First, the iPad follows other successful devices in the market by offering a complete solution that includes the device, the wireless service, and the content. The second reason is that the iPad finds the right combination of new technology, content, applications, and services that provide a unique usage experience and then combine it with the appropriate business model. Obviously, how to find a right business model for monetizing a device, connectivity and content has become the first priority in successfully launching new platforms in the tablet PC industry. For instance, the Apple iPad has created a new market with promising growth opportunities and logically new players must appear. However, Apple has a unique strategy of addressing the mass-market at a premium price and with a design based in its brand strength, setting the new rules and standards for this new market. In addition, the Apple iPad's biggest competitive advantage is the "content controllability" based on the iTunes and Apps Store, which no other competitor will have in the short-term.

## Conclusions and implications

This study adopts the MCDM point of view to construct the Tablet PCs performance evaluation model based on the BOCR conceptual framework. The chief advantage of this research is that it can be used for both qualitative and quantitative criteria (Wu *et al.* 2010). Systematic approaches using AHP-GRA, AHP-TOPSIS, AHP-VIKOR, and Fuzzy AHP have been applied in Tablet PC performance evaluation.

The empirical findings of this research can be summarized as follows. First, by integrating all the relevant literature reviews and experts' opinions, 23 indicators are selected as being suitable for the Tablet PCs' performance in terms of four perspectives, namely, the benefits, opportunity, costs, and risks. Secondly, the weights of the AHP criteria reveal that the ranking of the Tablet PCs' performance of the seven main Tablet PCs by employing the GRA,

TOPSIS, VIKOR and FAHP methods is as shown in Table 8. In particular, the Apple iPad and Samsung Galaxy Tab are the top two based on the four MCDM methods while the Acer Iconia W500 (AHP-GRA) comes last.

We hope the four MCDM models in this study could be helpful to Tablet PC company managers and other decision makers for creating a more effective performance evaluation system. For example, the results of the AHP and FAHP analysis reveal that the “benefits” perspective and “opportunity” perspective are the two most important criteria. Revenue growth, the capacity for profitability, product design, and product function are highly important evaluation indicators. This indicates that Tablet PC companies should expend more effort on their product innovation for creating revenue growth and maintaining customer loyalty. They should also provide more product functions and fun features on their Tablet PC products. After observing the iPad’s success, some PC manufacturers such as HP, Asus, Dell, and Microsoft have announced the launch of their new Tablet PCs by the end of 2012. In addition, Google-Android and Windows RT or 8 are becoming a big threat due to their large numbers of applications being created and their high performance OS. Most of the key competitors (such as Samsung and Microsoft) in the Tablet PCs market must launch their products with additional features in order to increase their own competitive advantage in the future.

Of course, this study provides two important criteria and sub-criteria for the Tablet PCs performance evaluation based on this concept of MCDM. In a future study, we could utilize the fuzzy analytic network process (Fuzzy ANP) with decision making trials and an evaluation laboratory to discuss the interactive and feedback relationships among indexes of the BOCR to enrich the research on the Tablet PC industry.

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APPENDIX

Table A1. Supporting literature of the BOCR performance evaluation criteria and sub-criteria

Criteria	Supporting literature	Sub-criteria	Supporting literature
Benefits (B)	Saaty (1996); Saaty and Ozdemir (2003); Wijnmalen (2007)	Revenue growth (B <sub>1</sub> )	Cebeci (2009); Liu <i>et al.</i> (2010)
		Sales and marketing (B <sub>2</sub> )	Cook and Hababou (2001); Amiri <i>et al.</i> (2009)
		Capacity for profitability (B <sub>3</sub> )	Cebeci (2009); Wu <i>et al.</i> (2010); Lee <i>et al.</i> (2010)
		Product price (B <sub>4</sub> )	Chan and Kumar (2007); Moon <i>et al.</i> (2008); Lin <i>et al.</i> (2010)
		Customer loyalty (B <sub>5</sub> )	Flint <i>et al.</i> (2011); Ramanathan (2010); Deng <i>et al.</i> (2010)
Opportunity (O)	Saaty (1996); Saaty and Ozdemir (2003); Wijnmalen (2007)	Product design (O <sub>1</sub> )	Chan <i>et al.</i> (2010); Lin <i>et al.</i> (2010)
		Product function (O <sub>2</sub> )	Lin <i>et al.</i> (2010)
		Product derived function (O <sub>3</sub> )	Lin <i>et al.</i> (2010)
		After-sales service (O <sub>4</sub> )	Birgelen <i>et al.</i> (2002); Gaiardelli <i>et al.</i> (2007)
		System choice (O <sub>5</sub> )	Lin <i>et al.</i> (2007); Jadhav and Sonar (2011)
		Learning and innovation (O <sub>6</sub> )	Lee and Kim (2000); Chen <i>et al.</i> (2010b).
		Strategic alliance (O <sub>7</sub> )	Korhonen and Voutilainen (2006); Chen <i>et al.</i> (2010b); Liou <i>et al.</i> (2011)
Costs (C)	Saaty (1996); Saaty and Ozdemir (2003); Wijnmalen (2007)	Implementation cost (C <sub>1</sub> )	Liang and Li (2008); Lee <i>et al.</i> (2010)
		Product cost (C <sub>2</sub> )	Chan and Kumar (2007); Lee <i>et al.</i> (2011b)
		R&D cost (C <sub>3</sub> )	Markarian <i>et al.</i> (2008); Wang <i>et al.</i> (2010)
		Maintenance cost (C <sub>4</sub> )	Lee and Kim (2000); Liang and Li (2008); Jadhav and Sonar (2009)
		System quality (C <sub>5</sub> )	Lee and Kozar (2006)
Risks (R)	Saaty (1996); Saaty and Ozdemir (2003); Wijnmalen (2007)	Potential competitor threats (R <sub>1</sub> )	Porter (1980)
		Financial risks (R <sub>2</sub> )	Yurdakul and Tansel İÇ (2004)
		Market risks (R <sub>3</sub> )	Li and Liao (2007)
		Quality risks (RC <sub>4</sub> )	Li and Liao (2007); Gray <i>et al.</i> (2011)
		Technical innovation risks (C <sub>5</sub> )	Li and Liao (2007)

Table A2. Brief description of seven alternatives among tablet PCs

Tablet PCs	Description
Apple iPad	The iPad is the first tablet computer from Apple (2010). The iPad is designed for consumers who want a mobile device that is bigger than a smartphone but smaller than a laptop for entertainment multimedia.
HP TouchPad	The HP TouchPad is a tablet computer developed and designed by Hewlett-Packard (HP). The HP TouchPad was launched on July 1, 2011 in the U.S. The HP TouchPad is one of many new multi-touch, capacitive touchscreen tablets, such as the Apple iPad and Android tablets, but the TouchPad runs HP webOS, which has several notable features, sharing the same card multitasking found in the Palm Pre 2, HP Veer, and HP Pre 3 including the highly regarded “stack” feature.
Motorola Xoom	The Motorola Xoom was introduced at CES 2011 on January 5, 2011. It is the first tablet to touchdown with Android 3.0, Honeycomb, and the Google operating system designed for tablet devices.
BlackBerry PlayBook	The BlackBerry PlayBook is a tablet computer by Research in Motion (RIM). The BlackBerry PlayBook (launched April 2011) has multi-touch capacitive 7-inch display, 1GHz dual-core CPU, 1GB of RAM, an e-reader app, and the ability to tether to a BlackBerry phone.
Samsung Galaxy Tab	The Samsung Galaxy Tab is an Android-based tablet computer produced by Samsung that debuted on September at the 2010 IFA in Berlin. The Galaxy Tab features a 7-inch (180 mm) TFT-LCD touchscreen, Wi-Fi capability, a 1.0 GHz ARM Cortex-A8 processor, the Swype input system, a 3.2 MP rear-facing camera and a 1.3 MP front-facing camera for video calls running the Android 2.2 operating system.
Asus Eee Pad Transformer	The Asus Eee Pad Transformer is an Android 3.2 Honeycomb tablet computer announced at CES 2011 and launched on March 30, 2011. The Transformer design includes an optional docking keyboard.
Acer Iconia Tab W500	Acer’s new Iconia Tab W500 lightweight tablet computer features a 10.1-inch screen, 1080p video support, and a full-size docking chiclet keyboard.

Table A3. Criteria for aggregate pairwise comparison matrix for sub-criteria of level 3

Benefits (B)	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>	B <sub>4</sub>	B <sub>5</sub>	B <sub>6</sub>	
B <sub>1</sub>	1.000	1.946	1.280	1.477	1.161	1.054	
B <sub>2</sub>	0.514	1.000	1.285	1.395	1.186	0.984	
B <sub>3</sub>	0.781	0.778	1.000	1.514	1.835	1.614	
B <sub>4</sub>	0.677	0.717	0.660	1.000	1.713	1.544	
B <sub>5</sub>	0.862	0.843	0.545	0.584	1.000	0.891	
B <sub>6</sub>	0.948	1.016	0.619	0.647	1.122	1.000	
Opportunity (O)	O <sub>1</sub>	O <sub>2</sub>	O <sub>3</sub>	O <sub>4</sub>	O <sub>5</sub>	O <sub>6</sub>	O <sub>7</sub>
O <sub>1</sub>	1.000	2.144	1.876	1.400	1.384	1.629	1.471
O <sub>2</sub>	0.466	1.000	1.110	1.687	1.313	1.230	1.131
O <sub>3</sub>	0.533	0.901	1.000	1.219	0.708	1.062	0.848
O <sub>4</sub>	0.714	0.593	0.821	1.000	0.772	0.797	0.859

Continued Table A3

Benefits (B)	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>	B <sub>4</sub>	B <sub>5</sub>	B <sub>6</sub>	
O <sub>5</sub>	0.723	0.762	1.412	1.295	1.000	1.209	1.213
O <sub>6</sub>	0.614	0.813	0.942	1.255	0.827	1.000	0.910
O <sub>7</sub>	0.850	0.884	1.180	1.165	0.824	1.098	1.000
Costs (C)	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>	C <sub>5</sub>		
C <sub>1</sub>	1.000	1.252	1.243	1.361	1.293		
C <sub>2</sub>	0.799	1.000	1.129	1.505	1.677		
C <sub>3</sub>	0.804	0.885	1.000	1.643	1.310		
C <sub>4</sub>	0.735	0.665	0.609	1.000	1.255		
C <sub>5</sub>	0.773	0.596	0.763	0.797	1.000		
Risks (R)	R <sub>1</sub>	R <sub>2</sub>	R <sub>3</sub>	R <sub>4</sub>	R <sub>5</sub>		
R <sub>1</sub>	1.000	1.812	2.389	1.746	1.811		
R <sub>2</sub>	0.552	1.000	1.049	1.455	1.214		
R <sub>3</sub>	0.419	0.953	1.000	1.468	1.030		
R <sub>4</sub>	0.573	0.687	0.681	1.000	0.955		
R <sub>5</sub>	0.552	0.824	0.971	1.047	1.000		

Note: Benefits (B):  $\lambda_{\max} = 6.150$ ; CI = 0.030; RI = 1.240; CR =  $0.024 \leq 0.1$ ; Opportunity (O):  $\lambda_{\max} = 7.060$ ; CI = 0.010; RI = 1.300; CR =  $0.008 \leq 0.1$ ; Costs (C):  $\lambda_{\max} = 5.040$ ; CI = 0.010; RI = 1.100; CR =  $0.009 \leq 0.1$ ; Risks (R):  $\lambda_{\max} = 5.040$ ; CI = 0.010; RI = 1.100; CR =  $0.009 \leq 0.1$ .

Table A4. Performance matrix with the best value and the worst value by VIKOR

Indexes	Apple	HP	Mo-torola	BB	Sam-sung	Asus	Acer	$f_j^*$	$f_j^-$
B <sub>1</sub> <sup>a</sup>	0.433	0.098	0.092	0.079	0.104	0.110	0.084	0.433	0.079
B <sub>2</sub> <sup>a</sup>	0.449	0.100	0.093	0.072	0.108	0.098	0.079	0.449	0.072
B <sub>3</sub> <sup>a</sup>	0.468	0.102	0.087	0.073	0.102	0.088	0.081	0.468	0.073
B <sub>4</sub> <sup>a</sup>	0.370	0.103	0.101	0.090	0.127	0.117	0.092	0.370	0.090
B <sub>5</sub> <sup>a</sup>	0.483	0.091	0.094	0.088	0.094	0.082	0.069	0.483	0.069
B <sub>6</sub> <sup>a</sup>	0.493	0.083	0.091	0.087	0.094	0.076	0.076	0.493	0.076
O <sub>1</sub> <sup>a</sup>	0.477	0.092	0.096	0.082	0.091	0.090	0.071	0.477	0.071
O <sub>2</sub> <sup>a</sup>	0.408	0.098	0.091	0.095	0.108	0.113	0.088	0.408	0.088
O <sub>3</sub> <sup>a</sup>	0.409	0.106	0.099	0.100	0.095	0.104	0.088	0.409	0.088
O <sub>4</sub> <sup>a</sup>	0.341	0.113	0.109	0.090	0.113	0.116	0.117	0.341	0.090
O <sub>5</sub> <sup>a</sup>	0.382	0.106	0.103	0.105	0.105	0.099	0.100	0.382	0.099
O <sub>6</sub> <sup>a</sup>	0.454	0.088	0.089	0.080	0.102	0.111	0.076	0.454	0.076
O <sub>7</sub> <sup>a</sup>	0.339	0.120	0.115	0.101	0.112	0.114	0.098	0.339	0.098

Continued Table A4

Indexes	Apple	HP	Mo- torola	BB	Sam- sung	Asus	Acer	$f_j^*$	$f_j^-$
$C_1^b$	0.409	0.105	0.087	0.090	0.116	0.101	0.093	0.087	0.409
$C_2^b$	0.423	0.111	0.083	0.078	0.107	0.103	0.094	0.078	0.423
$C_3^b$	0.436	0.098	0.104	0.101	0.103	0.084	0.075	0.075	0.436
$C_4^b$	0.437	0.099	0.079	0.091	0.100	0.100	0.095	0.079	0.437
$C_5^b$	0.425	0.103	0.092	0.088	0.099	0.100	0.093	0.088	0.425
$R_1^b$	0.321	0.106	0.121	0.109	0.118	0.121	0.104	0.104	0.321
$R_2^b$	0.299	0.130	0.125	0.112	0.120	0.112	0.101	0.101	0.299
$R_3^b$	0.237	0.133	0.128	0.134	0.129	0.122	0.116	0.116	0.237
$R_4^b$	0.255	0.116	0.109	0.118	0.139	0.134	0.128	0.109	0.255
$R_5^b$	0.292	0.117	0.118	0.116	0.130	0.121	0.106	0.106	0.292

Note: a: Indicates that the evaluation indicator is associated with benefits and opportunity criteria and the maximum is the ideal solution; b: Indicates that the evaluation indicator is associated with cost and risk criteria and the minimum is the ideal solution.

Table A5. The values  $S_i$  and  $R_i$  by VIKOR

Tablet PCs selection	$S_i$	$R_i$
Apple ( $Al_1$ )	0.000 (1)	0.000 (1)
HP ( $Al_2$ )	3.754 (4)	0.321 (6)
Motorola ( $Al_3$ )	3.815 (5)	0.298 (2)
BB ( $Al_4$ )	3.887 (6)	0.317 (5)
Samsung ( $Al_5$ )	3.689 (2)	0.303 (4)
Asus ( $Al_6$ )	3.753 (3)	0.299 (3)
Acer ( $Al_7$ )	3.932 (7)	0.325 (7)

Note: () denotes ranking order.

Table A6. Fuzzy pairwise comparison matrix of four decision criteria with respect to the goal

Criteria	B	O	C	R	Weights
B	(1, 1, 1)	(1.676, 2.097, 2.557)	(1.316, 1.698, 2.069)	(1.228, 1.561, 1.957)	0.479
O	(0.391, 0.477, 0.597)	(1, 1, 1)	(1.328, 1.820, 2.324)	(1.278, 1.662, 2.086)	0.324
C	(0.483, 0.589, 0.760)	(0.430, 0.550, 0.753)	(1, 1, 1)	(1.273, 1.689, 2.134)	0.161
R	(0.511, 0.641, 0.814)	(0.479, 0.602, 0.783)	(0.469, 0.592, 0.785)	(1, 1, 1)	0.036

Note: B = Benefits, O = Opportunity, C = Costs, and R = Risks.

Table A7. The importance weights of sub-criteria with BOCR by FAHP

Benefits	Weights	Opportu- nity	Weights	Costs	Weights	Risks	Weights
B <sub>1</sub>	0.230	O <sub>1</sub>	0.248	C <sub>1</sub>	0.252	R <sub>1</sub>	0.466
B <sub>2</sub>	0.171	O <sub>2</sub>	0.171	C <sub>2</sub>	0.250	R <sub>2</sub>	0.218
B <sub>3</sub>	0.217	O <sub>3</sub>	0.098	C <sub>3</sub>	0.227	R <sub>3</sub>	0.160
B <sub>4</sub>	0.169	O <sub>4</sub>	0.070	C <sub>4</sub>	0.149	R <sub>4</sub>	0.058
B <sub>5</sub>	0.087	O <sub>5</sub>	0.159	C <sub>5</sub>	0.122	R <sub>5</sub>	0.098
B <sub>6</sub>	0.126	O <sub>6</sub>	0.114				
		O <sub>7</sub>	0.140				

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