Combining Hybrid MADM with Fuzzy Integral for Exploring the Smart Phone Improvement in M-Generation

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Abstract

With the advancements of mobile technologies, internet connection can be conveniently accessed by the fast-growing number of smart phones. This is a relevant feature, making smart phone devices highly attractive to the M-era. In order to understand the end-users' needs and elevate competitive advantage of the enterprises, this study has set up an evaluation model for the smart phone improvement by using Fuzzy Hybrid MADM method, which integrated DANP in the Fuzzy integral. Analysis of DANP revealed that Mobile convenience (D_3) has the highest impact to improvement of Customer Equity (D_1), while Mobile multimedia services (C_{34}) showed as the most influential criteria of D_3. In the case of performance evaluation, it was found out that non-additive (fuzzy integral method, FI) could represent more the real behavior than additive (simple additive weighting method, SAW). This study was able to provide the enterprises a recommended direction which can enhance competitiveness of the smart phone according to network relation map (NRM) and performance evaluation.

Keywords: Smart phone, MADM (Multiple Attribute Decision Making), DEMATEL (decision-making trial and evaluation laboratory), DANP (DEMATEL-based analytic network process), Fuzzy integral.

1. Introduction

Smart phones are integrated with functionalities such as e-mail, Web browsing, audiovisual entertainment, word processing, mobile camera/video and Global Positioning System (GPS), etc. Moreover, the smart phones enable convenient mobile environments such as electronic payment, broadband internet access, high computing and communication performance, and multimedia platform etc. According to Gartner's investigation [1], the most wanted consumption device for American consumers in 2011 are the smart phones - more than mobile phone, e-book reader, media tablet and gaming devices. The smart phones caught the fancy of M-era by possessing the above-mentioned multiple features, which cannot be catered by traditional mobile phone.

In the academic circle, the research for smart phone is still very scarce. These are necessary in order to recommend development strategies to smart phone companies. To understand how to evaluate and significantly improve the various smart phones, this study consults the related researches, and builds an evaluation or improvement model for the smart phone having Multi-features by using Fuzzy Hybrid Multiple Attribute Decision Making (Fuzzy Hybrid MADM) [2]. In this study it is considered that the attributes of smart phone technology have interrelationship with each other, thus the influential relation is created according to interrelation. Furthermore, the influential weights are obtained by combining the influential relation with super matrix. This helped realize that the fuzzy integral method conforms to the behavior of reality more than the simple additive weighting method. In other words, mobile convenience (D_3) can have priority to improve customer equity (D_1), and Mobile multimedia services (C_{34}) was the most influential among the criteria of D_3, and non-additive method (fuzzy integral) is closer to the aspired level than additive method (simple additive weighting method).

The remainder of this paper is organized as follows: Section 2 discusses literature review, Research method is illustrated in section 3, an empirical case analysis for smart phone is illustrated in section 4, and Conclusion is presented in section 5.

2. Literature Review

Nowadays, young people play games, listen to music, and watch streamed videos by using smart phone, as part of the modern trend. These activities were once only performable by using a computer [3]. The smart phones are integrated with the traditional mobile phone and personal digital assistant (PDA), which includes the ability convenient services such as mobile commerce, electronic wallet, wide band internet access and multimedia [4].

In a time of saturating and diversifying developments

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of media, this multitasking generation is termed by Times USA as the M-era. This is a generation of users who simultaneously use various instant network communication tools via computer, such as MSN, Yahoo Messenger, Facebook, Myspace, iTunes, network games, etc. The computer is another brain of M-era, the keyboard is extension of their four limbs, and the network is their nerve system. Similarly, mobile phones have been functioning somewhat as body organs like eyes, nose and mouth. Combining some functions of computer and mobile phone, the smart phone has become an indispensable tool of the M-era. Thus, it is important to establish evaluation and improvement models for smart phone, considering customer equity, product function and mobile convenience. These will positively affect the consumer's interest in buying smart phones.

Customer equity, published by Rust, Zeithaml and Lemon in 2000 [5], consists of value equity, brand equity and retention equity. It employs specific customer lifetime value [6], in which it is analyzed according to the total data [7]. This study makes use of the dimensions formed from value equity, brand equity and retention equity to probe the relation of customer equity and the smart phone. Value equity is the objective evaluation of benefit sensed from products and cost based on the consumers. Brand equity is subjective and invisible evaluation of brand stemming from brand awareness, brand ethics and brand attitude of customer. Retention equity is the tendency of the customers to insist on the brand.

With regards to product function and its relationship to smart phone, this study considers four aspects: memory, processor, touch panel and operating system. A Processor is a programmable integrated circuit, and is also called the central processing unit (CPU). An Embedded microprocessor can obtain high performance operation at low power and is a common designed structure among hardware/ software [8]. Memory is used for storage of data, and is usually manufactured by using semiconductor technology. The most advanced mobile memory has already entered an era of high performance, high capacity and low electric consumption [9]. Touch panel, or more commonly called as touch screen, is reaction type of liquid crystal display. Touch panels of smart phones has a reduced weight, can conveniently cater the needs of the user, and can provide functions of other scientific and technological products [10]. Operating system manages the programs of both hardware and software resources of the computer, thus making it the core foundation of the computer system. It enables hardware development and satisfies the user needs in calculating field [11].

With regards to mobile convenience and its relationship to smart phone, this study also considers for aspects: Remote Control Services (RCS), Location Based Services (LBS), Mobile Wallet Services (MWS) and Mobile Multimedia Services (MMS). Remote Control allows domination of the computer at a distance, through an online method of networking. Remote control system of mobile phone is simpler and lower cost compared to traditional phones, thus providing convenient services for daily life [12]. LBS is a kind of information services for mobile users. In order to provide services, LBS obtain position information of mobile users via wireless communication network (such as GSM) and outer positioning mode (such as GPS) [13]. Mobile users can obtain private services via LBS, such as weather information, advertisements, games, etc. [14]. MWS is applications providing mobile payment system. MWS can be also used to store personal and secret information in online services, such as passport, credit card, PIN card, shopping bill and insurance policy, etc. In addition, MWS can use the applications stored in the memory of mobile phone via mobile network system in order to provide additional mobile services [15]. MMS is composed of spread media and dynamic information exchange above two kinds of media, and are a type of mobile service with comprehensive electronic information technology. They need high-performance servers to support high quality video-information and provide multimedia services for consumers, such as audio-visual amusement, web browsing, mobile video-information etc. Servers with high efficiency are necessary in order to provide various kinds of bandwidth needs for MMS of the smart phone [16].

Table 1. Dimensions and criteria of evaluation.

Dimensions	Criteria
Customer equity (D_1)	Value equity (C_{11})
	Brand equity (C_{12})
	Retention equity (C_{13})
Product function (D_2)	Memory (C_{21})
	Processor (C_{22})
	Touch panel (C_{23})
	Operating system (C_{24})
Mobile convenience (D_3)	Remote control services (C_{31})
	Location based services (C_{32})
	Mobile wallet services (C_{33})
	Mobile multimedia services (C_{34})

Based on literature review and responses on the questionnaires, the evaluation model of the smart phone is defined. First, the dimensions and criteria for the assessment of the smart phone are selected, using the results of the literature review. The importance of dimensions and criteria are then confirmed through the responses of the experts and users to the questionnaires. These are included with open questions that inquire other opinions for these dimensions/criteria. Finally, evaluation attributes which are focused around two point scoring (ordinary) are adopted; i.e., the evaluating scales are 0-4 points, adopt above 2 point (including the 2 point). The evaluation model, with aforementioned three categories, has a total of eleven criteria as shown in Table 1.

3. Research Method

Based on the facts and relationships existing in real world, evaluation model of the smart phone can be established by using DEMATEL technique to find the interrelationships among dimensions/criteria and obtain total influence matrix by these criteria. This was applied in this paper, along with the basic concept of ANP [17], which determines the transpose of normalized total influence matrix by dimensions (or called clusters/groups) and provides the unweighted super-matrix. The weighted super-matrix W^{α} can also be obtained as the product between the total influence matrix by dimensions and the unweighted super-matrix. Finally, the relative influential weights of DANP (DEMATEL-based ANP) can be obtained by $\lim_{g\to\infty}(W^{\alpha})^{g}$. Furthermore, the relative influence weights are combined to each performance of the relative attributes to evaluate the integrated value problems of the smart phone by fuzzy integral method, i.e., whether it is called non-additive or super-additive.

This section will establish the evaluation model for the smart phone by using Fuzzy Hybrid MADM models [2], which integrates the DANP (DEMATEL-based ANP) [18-19] with fuzzy integral [20], as illustrated in section 3.1 and 3.2. DANP can build successful key-factors for the smart phone via understanding the structure of evaluation model. Thus, this study is to confirm/improve the influential relations among dimensions and criteria with the use of DEMATEL method in DANP, and to measure the degree of dynamic influential weights between each factor by using ANP method in DANP. Consequently, the fuzzy integral can proceed with the evaluation to explore the aspired level.

3.1 Building a network relation map (NRM) and obtaining the influential weights by DANP

DANP is a combined method of DEMATEL and ANP. Published by Battelle research center in 1972, DEMATEL analyzes the complicated problems in the real world via building a network interrelation [21]. It is an effective method in solving the complicated problems between the communities by way of the hierarchical structure, and in understanding the complicated causalities. Furthermore, DEMATEL is often applied to studies and deal with the complicated objects [22]. On the other hand, Analytic Network Process (ANP) was published by Saaty [17], and is a method that relaxes the restriction of hierarchical structure [23] from Analytic Hierarchy Process (AHP) [24]. It is applied to solve interdependence/interaction problems among the complicated network relations. This paper used the basic concept of ANP combined with the total influential matrix $\boldsymbol{T}$ of DEMATEL to build super-matrix of ANP for finding the influential weights among criteria.

DANP consists of the following steps. Firstly, the direct relation matrix is created by using DEMATEL. The questionnaires can be changed into direct relation matrix through feedback provided by experts answering the questionnaires. The expert questionnaires develop the evaluating scales: 0, 1, 2, 3, 4, which indicate as no influence (0), low influence (1), medium influence (2), high influence (3), and extremely high influence (4), respectively. These become the measuring standard for pair-wise comparisons. The second step is calculating the initial matrix ($\boldsymbol{A}=[a_{ij}]_{n\times n}$). $\boldsymbol{A}$ can be obtained through the convergence of expert opinion via direct relation matrix, where a_{ij} represents the degree of influence on i factor effects j factor.

$$\boldsymbol{A}=\begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

The third step is to build the normalized direct effect Matrix $\boldsymbol{N}$. $\boldsymbol{N}$ can be obtained by the normalization of $\boldsymbol{A}$ from (2) and (3).

$$\boldsymbol{N}=\boldsymbol{A}/s \quad (2)$$

$$s=\max\left[\max_{1\le i\le n}\sum_{j=1}^{n}a_{ij},\max_{1\le j\le n}\sum_{i=1}^{n}a_{ij}\right] \quad (3)$$

The fourth step is to obtain the total influence matrix $\boldsymbol{T}$, which is by (4), where $\boldsymbol{I}$ is identity matrix.

$$\begin{aligned}\boldsymbol{T}&=\boldsymbol{N}+\boldsymbol{N}^2+\boldsymbol{N}^3+...+\boldsymbol{N}^h\\ &=\boldsymbol{N}(\boldsymbol{I}+\boldsymbol{N}+\boldsymbol{N}^2+...+\boldsymbol{N}^{h-1})(\boldsymbol{I}-\boldsymbol{N})(\boldsymbol{I}-\boldsymbol{N})^{-1}\\ &=\boldsymbol{N}(\boldsymbol{I}-\boldsymbol{N}^h)(\boldsymbol{I}-\boldsymbol{N})^{-1}\\ &=\boldsymbol{N}(\boldsymbol{I}-\boldsymbol{N})^{-1},\ \text{when}\ \lim_{h\to\infty}\boldsymbol{N}^h=[0]_{n\times n}\end{aligned} \quad (4)$$

The fifth step is to build a network relation map (NRM). Equations (5)-(7) show how the sum of each row and column for $\boldsymbol{T}$ can be obtained, where $\boldsymbol{r}$ denotes the sum of all vector rows ($\boldsymbol{r}=r_1,...,r_i,...,r_n$) and $\boldsymbol{c}$ denotes the sum of all vector columns ($\boldsymbol{c}=c_1,...,c_j,...,c_n$). When i is equal to j, $i,j\in\{1,2,...,n\}$, the horizontal axis vector (r_i+c_i) represents degree of relationship among criterion. In addition, the vertical axis vector (r_i-c_i) represents degree of causality among criterion. If $(r_i - c_i)$ is positive, then the criterion influences other criteria; but if $(r_i - c_i)$ is negative, then the criterion is influenced by the other criteria. Degree of relationship and causality can be deemed important reference information to proceed decision making.

$$\boldsymbol{T} = \left[t_{ij}\right]_{n\times n}, \quad i,j = 1,2,...,n. \tag{5}$$

$$\boldsymbol{r} = (r_i)_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} = r_1,...,r_i,...,r_n \tag{6}$$

$$\boldsymbol{c} = (c_j)'_{1\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n} = c_1,...,c_j,...,c_n \tag{7}$$

The sixth step is to obtain the unweighted super-matrix. Each level is normalized with the total degree of effect that is based on $\boldsymbol{T}$ using DEMATEL, as shown in (8). $\boldsymbol{T}_c$ is then normalized with total degree of effect to obtain $\boldsymbol{T}_c^{\alpha}$ by dimensions as shown in (9). Next, $\boldsymbol{T}_c^{\alpha 11}$ is normalized as in (10) and (11) to obtain $\boldsymbol{T}_c^{\alpha nn}$. The normalized influence matrix $\boldsymbol{T}_c^{\alpha}$ is then transposed to obtain the unweighted super-matrix $\boldsymbol{W}$ as shown in (12).

The seventh step is to obtain the weighted super-matrix, which is creating a dimensions total influential relationship matrix $\boldsymbol{T}_D$ as (13). Each dimension of matrix $\boldsymbol{T}_D$ is normalized by (14) to obtain $\boldsymbol{T}_D^{\alpha}$ as shown in (15). Then, the normalized $\boldsymbol{T}_D^{\alpha}$ is driven into the unweighted super-matrix $\boldsymbol{W}$ to obtain the weighted super-matrix $\boldsymbol{W}^{\alpha}$ as shown in (16).

$$\boldsymbol{T}_c = \begin{array}{c} \\ D_1 \begin{smallmatrix} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{smallmatrix} \\ \vdots \\ D_i \begin{smallmatrix} c_{i1} \\ c_{i2} \\ \vdots \\ c_{im_i} \end{smallmatrix} \\ \vdots \\ D_n \begin{smallmatrix} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{smallmatrix} \end{array} \overset{\begin{matrix} D_1 & & D_j & & D_n \\ c_{11}\cdots c_{1m_1} & \cdots & c_{j1}\cdots c_{jm_j} & \cdots & c_{n1}\cdots c_{nm_n} \end{matrix}}{\begin{bmatrix} \boldsymbol{T}_c^{11} & \cdots & \boldsymbol{T}_c^{1j} & \cdots & \boldsymbol{T}_c^{1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{i1} & \cdots & \boldsymbol{T}_c^{ij} & \cdots & \boldsymbol{T}_c^{in} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{n1} & \cdots & \boldsymbol{T}_c^{nj} & \cdots & \boldsymbol{T}_c^{nn} \end{bmatrix}} \tag{8}$$

$$\boldsymbol{T}_c^{\alpha} = \begin{array}{c} \\ D_1 \begin{smallmatrix} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{smallmatrix} \\ \vdots \\ D_i \begin{smallmatrix} c_{i1} \\ c_{i2} \\ \vdots \\ c_{im_i} \end{smallmatrix} \\ \vdots \\ D_n \begin{smallmatrix} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{smallmatrix} \end{array} \overset{\begin{matrix} D_1 & & D_j & & D_n \\ c_{11}\cdots c_{1m_1} & \cdots & c_{j1}\cdots c_{jm_j} & \cdots & c_{n1}\cdots c_{nm_n} \end{matrix}}{\begin{bmatrix} \boldsymbol{T}_c^{\alpha 11} & \cdots & \boldsymbol{T}_c^{\alpha 1j} & \cdots & \boldsymbol{T}_c^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{\alpha i1} & \cdots & \boldsymbol{T}_c^{\alpha ij} & \cdots & \boldsymbol{T}_c^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{\alpha n1} & \cdots & \boldsymbol{T}_c^{\alpha nj} & \cdots & \boldsymbol{T}_c^{\alpha nn} \end{bmatrix}} \tag{9}$$

$$d_i^{11} = \sum_{j=1}^{m_1} t_{c\,ij}^{\,11}, \; i = 1,2,...,m_1 \tag{10}$$

$$\boldsymbol{T}_C^{\alpha 11} = \begin{bmatrix} t_{c\,11}^{\,11}/d_1^{11} & \cdots & t_{c\,1j}^{\,11}/d_1^{11} & \cdots & t_{c\,1m_1}^{\,11}/d_1^{11} \\ \vdots & & \vdots & & \vdots \\ t_{c\,i1}^{\,11}/d_i^{11} & \cdots & t_{c\,ij}^{\,11}/d_i^{11} & \cdots & t_{c\,im_1}^{\,11}/d_i^{11} \\ \vdots & & \vdots & & \vdots \\ t_{c\,m_1 1}^{\,11}/d_{m_1}^{11} & \cdots & t_{c\,m_1 j}^{\,11}/d_{m_1}^{11} & \cdots & t_{c\,m_1 m_1}^{\,11}/d_{m_1}^{11} \end{bmatrix} = \begin{bmatrix} t_{c\,11}^{\alpha 11} & \cdots & t_{c\,1j}^{\alpha 11} & \cdots & t_{c\,1m_1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{c\,i1}^{\alpha 11} & \cdots & t_{c\,ij}^{\alpha 11} & \cdots & t_{c\,im_1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{c\,m_1 1}^{\alpha 11} & \cdots & t_{c\,m_1 1}^{\alpha 11} & \cdots & t_{c\,m_1 m_1}^{\alpha 11} \end{bmatrix} \tag{11}$$

$$\boldsymbol{W} = (\boldsymbol{T}_c^{\alpha})' = \begin{array}{c} \\ D_1 \begin{smallmatrix} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{smallmatrix} \\ \vdots \\ D_j \begin{smallmatrix} c_{j1} \\ c_{j2} \\ \vdots \\ c_{jm_j} \end{smallmatrix} \\ \vdots \\ D_n \begin{smallmatrix} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{smallmatrix} \end{array} \overset{\begin{matrix} D_1 & & D_i & & D_n \\ c_{11}\cdots c_{1m_1} & \cdots & c_{i1}\cdots c_{im_i} & \cdots & c_{n1}\cdots c_{nm_n} \end{matrix}}{\begin{bmatrix} \boldsymbol{W}^{11} & \cdots & \boldsymbol{W}^{i1} & \cdots & \boldsymbol{W}^{n1} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{W}^{1j} & \cdots & \boldsymbol{W}^{ij} & \cdots & \boldsymbol{W}^{nj} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{W}^{1n} & \cdots & \boldsymbol{W}^{in} & \cdots & \boldsymbol{W}^{nn} \end{bmatrix}} \tag{12}$$

$$\boldsymbol{T}_D = \begin{bmatrix} t_D^{11} & \cdots & t_D^{1j} & \cdots & t_D^{1n} \\ \vdots & & \vdots & & \vdots \\ t_D^{i1} & \cdots & t_D^{ij} & \cdots & t_D^{in} \\ \vdots & & \vdots & & \vdots \\ t_D^{n1} & \cdots & t_D^{nj} & \cdots & t_D^{nn} \end{bmatrix} \tag{13}$$

$$d_i = \sum_{j=1}^{n} t_D^{ij}, \; i = 1,2,...,n \tag{14}$$

$$\boldsymbol{T}_D^{\alpha} = \begin{bmatrix} t_D^{11}/d_1 & \cdots & t_D^{1j}/d_1 & \cdots & t_D^{1n}/d_1 \\ \vdots & & \vdots & & \vdots \\ t_D^{i1}/d_i & \cdots & t_D^{ij}/d_i & \cdots & t_D^{in}/d_i \\ \vdots & & \vdots & & \vdots \\ t_D^{n1}/d_n & \cdots & t_D^{nj}/d_n & \cdots & t_D^{nn}/d_n \end{bmatrix} = \begin{bmatrix} t_D^{\alpha 11} & \cdots & t_D^{\alpha 1j} & \cdots & t_D^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha i1} & \cdots & t_D^{\alpha ij} & \cdots & t_D^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha n1} & \cdots & t_D^{\alpha nj} & \cdots & t_D^{\alpha nn} \end{bmatrix} \tag{15}$$

$$\boldsymbol{W}^{\alpha} = \boldsymbol{T}_D^{\alpha}\boldsymbol{W} = \begin{bmatrix} t_D^{\alpha 11}\times\boldsymbol{W}^{11} & \cdots & t_D^{\alpha i1}\times\boldsymbol{W}^{i1} & \cdots & t_D^{\alpha n1}\times\boldsymbol{W}^{n1} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha 1j}\times\boldsymbol{W}^{1j} & \cdots & t_D^{\alpha ij}\times\boldsymbol{W}^{ij} & \cdots & t_D^{\alpha nj}\times\boldsymbol{W}^{nj} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha 1n}\times\boldsymbol{W}^{1n} & \cdots & t_D^{\alpha in}\times\boldsymbol{W}^{in} & \cdots & t_D^{\alpha nn}\times\boldsymbol{W}^{nn} \end{bmatrix} \tag{16}$$

Finally, the eighth step is to obtain the limit super-matrix. The weighted super-matrix is multiplied by itself multiple times to obtain the limit super-matrix (a concept based on Markov Chain). Then, the influential weights of each criterion can be obtained by

$\lim_{g\to\infty}(\boldsymbol{W}^{\alpha})^{g}$. In other word, the influential weights of DANP, during the DANP process, can be obtained, where α is a natural number.

3.2 Basic concepts for fuzzy measure and fuzzy integral

Sugeno et al. [25-27] developed theory of fuzzy measure and fuzzy integral as a method of expressing fuzzy systems. Tzeng et al. [28-29] improved the assumption of independence among evaluation criteria for traditional Multiple Criteria Decision Making (by additive), and developed multiple criteria evaluation technique of non-additive/super-additive by fuzzy integral concept for suitable real world. The non-additive method can be used to solve real-world problems more than traditional additive method.

3.2.1 Fuzzy measure

Fuzzy measure g is defined on a power set $P(X)$, and satisfies the following characteristics:

$$\forall A,B\in P(X),\ A\cap B=\varnothing$$
$$g_{\lambda}(A\cup B)=g_{\lambda}(A)+g_{\lambda}(B)+\lambda g_{\lambda}(A)g_{\lambda}(B),\ for\ -1\le\lambda\le\infty \tag{17}$$

where set $X=\{x_1,x_2,...,x_n\}$, and the density of fuzzy measure $g_i=g_{\lambda}(\{x_i\})$ can be defined as follows [20, 25-31]:

$$g_{\lambda}(\{x_1,x_2,...,x_n\})=\sum_{i=1}^{n}g_i+\lambda\sum_{i_1=1}^{n-1}\sum_{i_2=i_1+1}^{n}g_{i_1}g_{i_2}+\cdots+\lambda^{n-1}g_1g_2\cdots g_n=\frac{1}{\lambda}\left|\prod_{i=1}^{n}(1+\lambda g_i)-1\right|,for\ -1\le\lambda\le\infty \tag{18}$$

where $g_{\lambda}(\{x_1,x_2,...,x_n\})=1$.

Fuzzy measure is based on the parameter λ, which describes the degree of additive fuzzy measure holds (interactive effects). We have three important types of λ-fuzzy measures. If $\lambda>0$, $g_{\lambda}(A\cup B)>g_{\lambda}(A)+g_{\lambda}(B)$, this means that A and B have multiplicative effect (super-additive). If $\lambda=0$, $g_{\lambda}(A\cup B)=g_{\lambda}(A)+g_{\lambda}(B)$, this means that A and B have additive effect (additive). If $\lambda<0$, $g_{\lambda}(A\cup B)<g_{\lambda}(A)+g_{\lambda}(B)$, this means that A and B have substitutive effect (sub-additive). The λ-fuzzy measure can be calculated by (18) from questionnaires. Fuzzy measure weights can be calculated by (18) and (19). In order to clarify the calculation of fuzzy measure, we give a numerical example in Appendix. Fuzzy measure is measured by judgment of knowledge of experts. Fuzzy measure is often used with fuzzy integral for the purpose of aggregating/fusing information evaluation for suitable real world.

$$g_{\lambda}(\{x_1,x_2,...,x_n\})=\sum_{i=1}^{n}w_i+\lambda\sum_{i_1=1}^{n-1}\sum_{i_2=i_1+1}^{n}w_{i1}w_{i2}+\cdots+\lambda^{n-1}w_1w_2\cdots w_n=\frac{1}{\lambda}\left|\prod_{i=1}^{n}(1+\lambda w_i)-1\right| \tag{19}$$

where $g_{\lambda}(\{x_1,x_2,...,x_n\})=1$.

3.2.2 Fuzzy integral

Let g be a fuzzy measure defined on a finite set $X=\{x_1,x_2,...,x_n\}$ and $h(\cdot)$ be a measurable function from X to [0, 1]. Assuming that $h(x_1)\ge h(x_2)\ge...\ge h(x_n)$, then the Choquet integral is defined as follows [25-31]:

$$(C)\int hdg=h(x_n)g(H_n)+[h(x_{n-1})-h(x_n)]g(H_{n-1})+\cdots+[h(x_1)-h(x_2)]g(H_1) \tag{20}$$

where $H_1=\{x_1\}$, $H_2=\{x_1,x_2\}$, …, $H_n=\{x_1,x_2,...,x_n\}$.

4. Empirical Analysis for Improving the Smart Phone

In the real world, everything that exists has an interrelationship with each other. For example, in the process of choosing of the smart phone, people will use their own evaluation index model to proceed the related evaluation for the smart phone. In addition, each attribute for the smart phone has interrelation. In this regard, this study is intended to build a network relation map (NRM) and the influential weights by using DANP based on DEMATEL technique. Finally, this study proceeds the evaluation by satisfaction (i.e., performance of the related property) for the smart phone by using fuzzy integral.

4.1 Analysis of evaluation model for smart phone

Table 2 and Table 3 summarize the interacting relationships at three dimensions and each criterion, where r_i is the influenced factor, c_i is the affected factor, ($r_i + c_i$) is the relation degree and (r_i - c_i) is the caused degree. In the case of dimensions, the attributes of evaluation model for the smart phone considered are customer equity (D_1), product function (D_2) and mobile convenience (D_3), as shown Table 2. Table 2 showed that ($r_i + c_i$) of product function (D_2) is the most obvious in evaluation model, with a value of 3.124. In addition, the influenced degrees of product function (D_2) and mobile convenience (D_3) are slightly obvious because of the positive value of (r_i - c_i), as well as the affected degree of customer equity (D_1), (r_i - c_i) being negative. On the other hand, the influenced and affected degree of (r_i - c_i) are not obvious in dimensions because their values are close to 0.

Table 2. The related and caused degree of network structure in dimensions.

Dimensions	r_i	c_i	$r_i + c_i$	r_i - c_i
D_1	1.434	1.506	2.941	-0.072
D_2	1.563	1.561	3.124	0.002
D_3	1.338	1.268	2.607	0.070

Table 3. The related and caused degree of network structure in criteria.

Criteria	r_i	c_i	$r_i + c_i$	$r_i - c_i$
C_{11}	5.601	5.939	11.540	-0.337
C_{12}	5.142	5.492	10.634	-0.351
C_{13}	5.010	5.191	10.201	-0.181
C_{21}	5.302	5.368	10.670	-0.066
C_{22}	5.721	6.049	11.770	-0.328
C_{23}	5.556	5.437	10.992	0.119
C_{24}	6.232	6.008	12.240	0.225
C_{31}	4.834	4.597	9.431	0.237
C_{32}	4.726	4.807	9.534	-0.081
C_{33}	4.489	3.920	8.410	0.569
C_{34}	5.492	5.298	10.791	0.194

In the case of criteria, customer equity (D_1) divides into three categories: value equity (C_{11}), brand equity (C_{12}) and retention equity (C_{13}), as shown Table 3. ($r_i + c_i$), with value equity (C_{11}) being the most obvious with a value is 11.540. In other words value equity (C_{11}) easily influences other criteria. The ($r_i - c_i$) of value equity (C_{11}), brand equity (C_{12}) and retention equity (C_{13}) are negative, thus the affected degree is obvious. In the other hand, brand equity (C_{12}), having the least value, is easily influenced by other criteria. Product function (D_2) divides into four categories: memory (C_{21}), processor (C_{22}), touch panel (C_{23}) and operating system (C_{24}). ($r_i + c_i$) of operating system (C_{24}) is the most obvious, with a value of 12.240. ($r_i - c_i$) of operating system (C_{24}) is positive and the largest, having the most obvious influenced degree. On the other hand, ($r_i - c_i$) of processor (C_{22}) is negative, thus obviously the least affected degree. Mobile convenience (D_3) divides into four categories: RCS (C_{31}), LBS (C_{32}), MWS (C_{33}) and MMS (C_{34}). ($r_i + c_i$) of MMS (C_{34}) is the most obvious, with a value of 10.791. ($r_i - c_i$) of MWS (C_{33}) is positive and the largest, thus having the most obvious influenced degree. On the other hand, ($r_i - c_i$) of LBS (C_{32}) is -0.081, i.e., and indicates being easily influenced by other criteria.

Fig. 1 is a Network Relation Map which explains the interacting structure in the evaluation model. Customer equity (D_1) is influenced by product function (D_2) and mobile convenience (D_3), this means that customer equity will be influenced by product function and mobile service offered from suppliers of the smart phone and the telecommunication service. Therefore, inter-firm cooperation is necessary for increasing the consumers' purchase intention. In the case of mobile convenience (D_3), the major advantage of smart phone over the universal phone is that it can provide several services to make life more convenient. Thus, MWS (C_{33}), RCS (C_{31}) and MMS (C_{34}), which are offered by the suppliers of the telecommunication services influences LBS (C_{32}). Furthermore, they also influence the perception of convenience for mobile convenience (D_3). In the case of product function (D_2), the criteria operating system (C_{24}) and touch panel (C_{23}) designed by the suppliers of the smart phone influence memory (C_{21}) and processor (C_{22}), and consequently influence the greatest efficiency of product function (D_2). Finally, in the case of customer equity (D_1), the consumers are influenced by mobile convenience (D_3) and product function (D_2), and the consumers can more understand retention equity (C_{13}) to influence value equity (C_{11}) and brand equity (C_{12}).

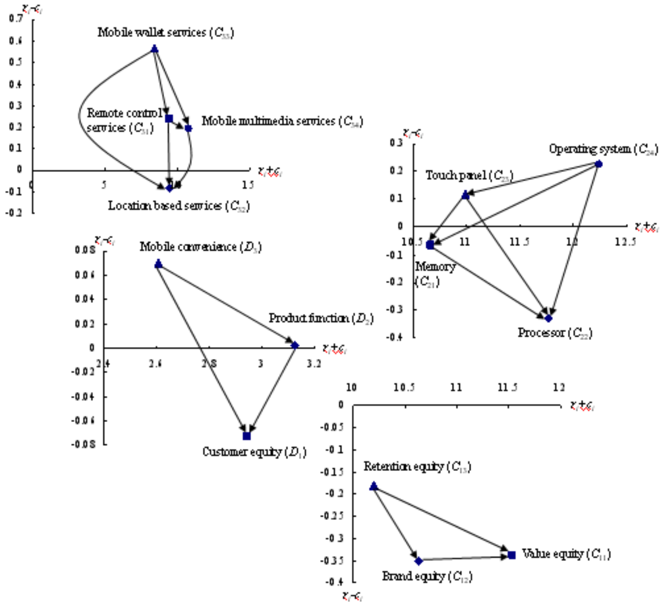

Fig. 1. Network relation map.

When people choose the smart phone, each evaluation index has different important degree, as shown Table 4. Table 4 shows that the important degree of product function (D_2) is the highest, followed by customer equity (D_1), and mobile convenience (D_3) having the least value. This means that the customer can choose different suppliers of the smart phone with the same supplier of the telecommunication service, thus it is importance of product function (D_2) is more apparent. In the case of criteria for customer equity (D_1), retention equity (C_{13}) show the least importance, which means that consumers will consider own equity in accordance with experience of value equity (C_{11}) and brand equity (C_{12}) in the past. In the case of criteria for product function (D_2), processor (C_{22}) is considered to be both good and bad for product function. In the case of criteria for mobile convenience (D_3), MMS (C_{34}) is most favored by the consumers.

Table 4 provides an analysis of the influential weights obtained from DANP and is used to obtain performances for SAW by weights and scores. It reveals that the weights of customer equity is higher than product function and mobile convenience, thus showing that a perfect customer equity can make consumers willing to purchase smart phone. Furthermore, it is realized that the performances for SAW are ordered as $C \succ B \succ D \succ E \succ A$, which means that the firm C is the most favorable firm. Performance for fuzzy integral can be calculated by following steps, with alternative C regarded as the calculated example. First, calculate λ-fuzzy measure is calculated by (18) and questionnaire. Second, initial weights of one group of dimension and three groups of criterion are obtained by using local weights of DANP, as shown Table 4. Then, let fuzzy measure weights $g_\lambda(\{x_1,x_2,...,x_n\}) = c$ (the adjusted actual weights)× $w_1,\cdots w_j,\cdots w_n$ (initial weights), according to (19), which consequently calculates value of c. λ and c for one group of dimension and three groups of criteria are presented in Table 5. Furthermore, according to Table 5, (18) and (19), the fuzzy measures are obtained, as shown in Table 6.

Table 4. The influential weights and performances of SAW.

D/C	Local weight	Global weight	Performance				
			Firm A	Firm B	Firm C	Firm D	Firm E
D_1	**0.347 (2)**		**2.384**	**2.322**	**3.191**	**3.156**	**2.339**
C_{11}	0.355 (1)	0.123 (1)	2.429	2.000	3.000	3.000	2.500
C_{12}	0.333 (2)	0.115 (2)	2.429	2.500	3.200	3.000	2.250
C_{13}	0.312 (3)	0.108 (3)	2.286	2.500	3.400	3.500	2.250
D_2	**0.360 (1)**		**2.317**	**2.391**	**2.791**	**2.303**	**2.439**
C_{21}	0.235 (4)	0.085 (7)	2.143	1.250	2.800	2.500	2.750
C_{22}	0.263 (1)	0.095 (4)	2.000	2.000	2.600	2.000	2.500
C_{23}	0.240 (3)	0.086 (6)	2.714	3.000	3.200	2.500	2.000
C_{24}	0.262 (2)	0.094 (5)	2.429	3.250	2.600	2.250	2.500
D_3	**0.293 (3)**		**2.133**	**2.872**	**2.536**	**1.957**	**2.411**
C_{31}	0.243 (3)	0.071(10)	2.143	2.500	2.000	1.000	2.500
C_{32}	0.256 (2)	0.075 (9)	2.143	3.250	3.200	2.500	2.500
C_{33}	0.214 (4)	0.064(11)	1.714	2.000	2.000	1.000	1.750
C_{34}	0.287 (1)	0.084 (8)	2.429	3.500	2.800	3.000	2.750
Total performance			**2.286**	**2.508**	**2.855**	**2.498**	**2.396**

Finally, we can calculate the Choquet integral for alternative C by Table 4, Table 6 and (19), as follows.

$$(C)\int hdg = (3.4-3.2)\times 0.334 + (3.2-3.0)\times 0.667 + (3)\times 1 = 3.2$$

$$(C)\int hdg = (3.2-2.8)\times 0.242 + (2.8-2.6)\times 0.479 + (2.6-2.6)\times 0.741 + (2.6)\times 1 = 2.793$$

$$(C)\int hdg = (3.2-2.8)\times 0.265 + (2.8-2.0)\times 0.555 + (2.0-2.0)\times 0.795 + (2.0)\times 1 = 2.55$$

Total performance is

$$(C)\int hdg = (3.2-2.793)\times 0.369 + (2.793-2.55)\times 0.727 + (2.5)\times 1 = 2.877$$

Similarly, total performance of alternative A, B, D and E can also be calculated, their performance are 2.314, 2.53, 2.535 and 2.404 respectively.

Table 5. λ and c for one group of dimension and three groups of criterion.

Dimensions/criteria	D	C_1	C_2	C_3
λ	-0.168	-0.184	-0.037	-0.094
c	1.062	1.069	1.014	1.037

Table 6. Fuzzy measure weights for one group of dimension and three groups of criterion.

D			
$g_\lambda(\{x_1\}) = 0.369$	$g_\lambda(\{x_1,x_2\}) = 0.727$	$g_\lambda(\{x_1,x_2,x_3\}) = 1$	
$g_\lambda(\{x_2\}) = 0.382$	$g_\lambda(\{x_1,x_3\}) = 0.660$		
$g_\lambda(\{x_3\}) = 0.311$	$g_\lambda(\{x_2,x_3\}) = 0.673$		
C_1			
$g_\lambda(\{x_{11}\}) = 0.379$	$g_\lambda(\{x_{11},x_{12}\}) = 0.709$	$g_\lambda(\{x_{11},x_{12},x_{13}\}) = 1$	
$g_\lambda(\{x_{12}\}) = 0.355$	$g_\lambda(\{x_{11},x_{13}\}) = 0.690$		
$g_\lambda(\{x_{13}\}) = 0.334$	$g_\lambda(\{x_{12},x_{13}\}) = 0.667$		
C_2			
$g_\lambda(\{x_{21}\}) = 0.239$	$g_\lambda(\{x_{21},x_{22}\}) = 0.503$	$g_\lambda(\{x_{21},x_{22},x_{23}\}) = 0.741$	$g_\lambda(\{x_{21},x_{22},x_{23},x_{24}\}) = 1$
$g_\lambda(\{x_{22}\}) = 0.267$	$g_\lambda(\{x_{21},x_{23}\}) = 0.479$	$g_\lambda(\{x_{21},x_{22},x_{24}\}) = 0.764$	
$g_\lambda(\{x_{23}\}) = 0.242$	$g_\lambda(\{x_{21},x_{24}\}) = 0.503$	$g_\lambda(\{x_{21},x_{23},x_{24}\}) = 0.741$	
$g_\lambda(\{x_{24}\}) = 0.266$	$g_\lambda(\{x_{22},x_{23}\}) = 0.507$	$g_\lambda(\{x_{22},x_{23},x_{24}\}) = 0.768$	
	$g_\lambda(\{x_{22},x_{24}\}) = 0.530$		
	$g_\lambda(\{x_{23},x_{24}\}) = 0.506$		
C_3			
$g_\lambda(\{x_{31}\}) = 0.253$	$g_\lambda(\{x_{31},x_{32}\}) = 0.512$	$g_\lambda(\{x_{31},x_{32},x_{33}\}) = 0.723$	$g_\lambda(\{x_{31},x_{32},x_{33},x_{34}\}) = 1$
$g_\lambda(\{x_{32}\}) = 0.265$	$g_\lambda(\{x_{31},x_{33}\}) = 0.469$	$g_\lambda(\{x_{31},x_{32},x_{34}\}) = 0.795$	
$g_\lambda(\{x_{33}\}) = 0.222$	$g_\lambda(\{x_{31},x_{34}\}) = 0.543$	$g_\lambda(\{x_{31},x_{33},x_{34}\}) = 0.753$	
$g_\lambda(\{x_{34}\}) = 0.297$	$g_\lambda(\{x_{32},x_{33}\}) = 0.482$	$g_\lambda(\{x_{32},x_{33},x_{34}\}) = 0.765$	
	$g_\lambda(\{x_{32},x_{34}\}) = 0.555$		
	$g_\lambda(\{x_{33},x_{34}\}) = 0.513$		

4.2 Performance comparison of satisfaction degree

Table 7 is total performance comparison of satisfaction degree for five smart phone brands. This study carries on a performance evaluation by simple additive weighting (SAW) and fuzzy integral (FI). SAW is an additive evaluation method which excludes the relationships among performances. On the other hand, FI is a non-additive evaluation method which considers the relationships. Table 7 shows that the satisfaction degrees in FI are all higher than SAW in five alternatives. This means that the non-additive method is closer to the aspired level. In addition, it reveals that the performances for FI are ordered as $C \succ B \succ D \succ E \succ A$. In performance comparison between SAW and FI shows that the difference between ranking for alternative B and D resulted from the influence of the interrelated performance, thus alternative D can obtain more performance than alternative B.

Table 7. Total performance comparison for SAW and FI.

Alternative	Performance (SAW)	Ranking (SAW)	Performance (FI)	Ranking (FI)
A	2.286	5	2.314	5
B	2.508	2	2.530	3
C	2.855	1	2.877	1
D	2.498	3	2.535	2
E	2.396	4	2.404	4

4.3 Result and discussion

According to empirical case of five manufacturers for smart phone using MADM model combining DANP with fuzzy integral, some results are obtained, such as: obtaining of the influential relationship matrix, map of dimensions/criteria in interdependent and feedback problems, and how to increase the performances of dimensions/criteria to achieve the aspired levels. Literature reviews help establish the assessment attributes (dimensions/criteria) of the smart phone. The importance of attributes can be confirmed via pre-test questionnaires answered by experts and users. The design of DEMATEL questionnaire is to fill in interacting influential degree among dimensions/criteria based on knowledge-view of pair-wise. Evaluation model can be established by DEMATEL technique, which does not increase the complexity of the creation of evaluation model due to constrained size of model. The large amount of assessment attributes will only result to complexity in preparing the questionnaires adopted from knowledge-view of pair-wise (n^2-n). The DEMATEL technique is used to construct the influential relationships among dimensions/criteria and to establish their influential NRM (network relation map) within dimensions/criteria by using pair-wise comparison (see Fig. 1). Therefore, from Fig. 1, it can easily be understood that the three dimensions are influencing each other. For example, product function (D_2) and mobile convenience (D_3) were the main influencing dimensions, and customer equity (D_1) is the affected dimension. In addition, product function (D_2) influences customer equity (D_1). These influential relationships help the managers in their decision-making. For example, they can look into how to effectively increase the market share of smart phone – by requesting firms to improve mobile convenience; or by referring to mobile convenience (D_3) in Fig. 1, advise their firms to improve MWS (C_{33}). The DEMATEL technique is used to construct interrelationships among dimensions/criteria, while ANP is used to overcome the problems of interdependence and feedback. Therefore, based on DANP (using basic concept of ANP in influence matrix of DEMATEL) the problems in real world of interdependence and feedback can be solved. As shown in Table 4, DANP method is used to obtain the influential weights of dimensions/criteria for applying the empirical real case. Based on DANP technique, the global influential weights and local influential weights of the dimensions/criteria can be obtained. By combining DANP with fuzzy integral method the performance of firm *A*, firm *B*, firm *C*, firm *D* and firm *E* are 2.314, 2.530, 2.877, 2.535 and 2.404, respectively. Performances obtained form FI method are all higher than SAW, which means that non-additive (fuzzy integral method, FI) is more corresponding to real behavior than additive (simple additive weighting method, SAW). In addition, the design of fuzzy integral questionnaire is set as 1, which corresponds to all attribute assumed good. The performance value of attribute A is good, while the other attributes are not. Fuzzy measure is measured by judgment of knowledge in experts. Computer simulation for three kinds of λ-fuzzy measure is shown in Table 8. The integrated performance in $\lambda>0$ is smaller than $\lambda<0$. This means that the integrated performance substantially reduce if performance among attributes has a large difference. Finally, provides an analysis of the performance of dimensions/criteria, to reveal which ones should be prioritized for improvement. In application, the managers can increase the performances to pull them closer to the aspired level in each firm. This is an important topic for future research.

Table 8. Computer simulation of other λ-fuzzy measures.

	A	B	C	D	E
$\lambda<0$	2.314 (5)	2.530 (3)	2.877 (1)	2.535 (2)	2.404 (4)
$\lambda=0$	2.286 (5)	2.508 (2)	2.855 (1)	2.498 (3)	2.396 (4)
$\lambda>0$ ($\lambda=0.5$)	2.280 (5)	2.450 (2)	2.786 (1)	2.388 (3)	2.384 (4)
$\lambda>0$ ($\lambda=1.0$)	2.223 (5)	2.350 (2)	2.717 (1)	2.272 (4)	2.335 (3)
$\lambda>0$ ($\lambda=1.5$)	2.179 (5)	2.286 (3)	2.664 (1)	2.181 (4)	2.306 (2)
$\lambda>0$ ($\lambda=2.0$)	2.145 (4)	2.242 (3)	2.621 (1)	2.107 (5)	2.287 (2)
$\lambda>0$ ($\lambda=3.0$)	2.094 (4)	2.185 (3)	2.555 (1)	1.992 (5)	2.264 (2)
$\lambda>0$ ($\lambda=4.0$)	2.057 (4)	2.150 (3)	2.506 (1)	1.907 (5)	2.251 (2)
$\lambda>0$ ($\lambda=5.0$)	2.029 (4)	2.126 (3)	2.467 (1)	1.839 (5)	2.243 (2)

5. Conclusions

In the real world, people's subconscious possesses the related properties to carry out evaluation/selection. Thus, evaluation models need to consider the interacting features among attributes. Therefore, this study aims to create the related NRM and the influenced weights with DANP to explain causality among factors. According to NRM, customer equity (D_1) can be improved by considering mobile convenience (D_3), as well as by improving product function (D_2). Also, mobile convenience (D_3), product function (D_2) and customer equity (D_1) can be influenced by MMS (C_{34}), processor (C_{22}) and value equity (C_{11}), being the most influential weights in each dimension. Furthermore, in the case of performance evaluation, this study compares difference of analyses between SAW and FI to explore the different properties between additive and non-additive method. It was found that without considering the interacting feature among performance of factors, the performance of SAW is lower than FI. Finally, according to NRM and performance evaluation, the enterprises can find an improved direction to promote competitive advantage of the smart phone.

Appendix

We give numerical example of fuzzy measure as follows:

In this study, there are four λ-fuzzy measures. The λ-fuzzy measure can be obtained by (18) from questionnaires. The calculated λ-fuzzy measure is the following.

	D	C_1	C_2	C_3
λ	-0.168	-0.184	-0.037	-0.094

The initial weights can be obtained by local weights of DANP. The case in this study, the initial weights $w_1, \cdots w_j, \cdots w_n$ have four parts as follows.

(0.347, 0.360, 0.293), (0.355, 0.332, 0.313), (0.235, 0.263, 0.239, 0.263), (0.244, 0.256, 0.213, 0.287).

In case of the initial weights (0.347, 0.360, 0.293) of dimension (D), let fuzzy measure weights be:

$$(g_\lambda(\{x_1\}), g_\lambda(\{x_2\}), g_\lambda(\{x_3\})) = c(w_1, w_2, w_3) = (0.347c, 0.360c, 0.293c)$$

In addition, the adjusted actual weights c can be obtained by λ and (19), as shown in the following Table.

	D	C_1	C_2	C_3
c	1.062	1.069	1.014	1.037

In the case of dimension, λ is -0.168, so value of c could be obtained as 1.602. Therefore, the fuzzy measure weights in Table 6 could be obtained by using (18). Similarly, other fuzzy measure weights can also be obtained as shown in Table 6.

$$g_\lambda(\{x_1\}) = 0.347c = 0.347 \times 1.602 = 0.369$$

$$g_\lambda(\{x_2\}) = 0.360c = 0.360 \times 1.602 = 0.382$$

$$g_\lambda(\{x_3\}) = 0.293c = 0.293 \times 1.602 = 0.311$$

$$g_\lambda(\{x_1, x_2\}) = g_\lambda(\{x_1\}) + g_\lambda(\{x_2\}) + \lambda g_\lambda(\{x_1\}) g_\lambda(\{x_2\})$$
$$= 0.369 + 0.382 + (-0.168 \times 0.369 \times 0.382) = 0.727$$

$$g_\lambda(\{x_1, x_3\}) = g_\lambda(\{x_1\}) + g_\lambda(\{x_3\}) + \lambda g_\lambda(\{x_1\}) g_\lambda(\{x_3\})$$
$$= 0.369 + 0.311 + (-0.168 \times 0.369 \times 0.311) = 0.660$$

$$g_\lambda(\{x_2, x_3\}) = g_\lambda(\{x_2\}) + g_\lambda(\{x_3\}) + \lambda g_\lambda(\{x_2\}) g_\lambda(\{x_3\})$$
$$= 0.382 + 0.311 + (-0.168 \times 0.382 \times 0.311) = 0.673$$

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