A MULTICRITERIA ANALYSIS ON THE STRATEGIES TO OPEN TAIWAN'S MOBILE VIRTUAL NETWORK OPERATORS SERVICES

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This study investigates the trends followed by MVNOs (Mobile Virtual Network Operators) in the last three years and analyzes the strategies that can contribute to the success of Taiwan's telecommunications industry and marketing. We apply the method and concept of PATTERN (Planning Assistance Through Technical Evaluation of Relevance Number) to establish relevant systems for searching out the key successful factors of strategies to attract MVNOs. We also use the fuzzy Multi-Criteria Decision Making (MCDM) method for analyzing the different preference of a decision group in the criteria weights and for ranking the alternatives in a fuzzy environment in order to provide a strategy scheme. These results provide a reference to assist telecommunications operators, 3G license owners, potential MVNOs, and equipment manufacturers when working out business plans.

Keywords: Mobile virtual network operators (MVNOs), mobile network operator (MNO), multiple criteria decision making (MCDM), analytic hierarchy process (AHP), telecommunications.

1. Introduction

Mobile communications has developed at an astonishing pace. In developing countries, the popularity rate of mobile communications also continues to hit all forecasts. Such a development speed and market scale has made mobile communications the new growth for an economy and an important pillar industry in each country.

The business model of MVNOs is derived from a combination of marketing sales, line facilities, and equipment operators in order to provide telecommunications services. An MVNO is a mobile operator that does not own spectrum or radio access network infrastructures. MVNOs must, however, have full control over all customer-facing services, such as branding, marketing, and billing. This differentiates them from airtime resellers, and much of an MVNO's success depends on the level of cooperation it receives from the mobile network operator (MNO). This is because the MNO owns the radio access infrastructure and spectrum resources, putting the operator in a very strong negotiating position. On the other side, taking the MNO's point of view, an MVNO can be likened to a very big customer that brings in a considerable amount of additional revenue [1, 2]. They are often competitors in the market, but conversely the MNO needs to utilize its spectrum to maximize revenue potential. [2-7]

Taiwan's Ministry of Transportation and Communications (MOTC) (Source: http://www.dgt.gov.tw) opened up MVNO services in September 2003, making it the only mobile communications service with no deadline for application. Three providers applied to be an MVNO, but up through September 2005 they have all experienced poor operations. In accordance with the past experiences of opening up the telecommunications market, the timing of it and the types of services are key factors in influencing whether a business succeeds or not. In fact, a good regulatory mechanism should consider the social, economic, and consumer aspects when doing so [8-10]. This paper proposes an ideal formulation of strategies for the timing of opening up a market to MVNOs. We note that the work reported here was done during policy formulation, and the recommendations as such were not adopted into policy. The scenario and reasoning behind the strategy formulation can be valuable references for MVNOs and 3G operators.

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This paper uses the method and concept of PATTERN (Planning Assistance Through Technical Evaluation of Relevance Number) [11-13] to establish relevant systems for catching the key success factors of the strategies for opening up to MVNOs. We also use fuzzy multiple criteria decision making (MCDM) to find and analyze the criteria weights through fuzzy AHP (Analytic Hierarchy Process) in different decision groups. We then analyze and rank the strategies in a fuzzy environment by using Simple Additive Weighting (SAW).

The remainder of this paper is organized as follows. Sec. 2 presents the overview of Taiwan's MVNOs. Sec. 3 offers the research methodology. A real case study in Taiwan is conducted and discussed in Sec. 4. Finally, conclusions are presented in Sec. 5.

2. An Overview of the MVNOs in Taiwan

This Sec. introduces a business concept of MVNO from the development of Taiwan's mobile communications for the next Sec.'s analysis on the strategies to open up Taiwan to MVNOs services and for policy making references. We analyze the evolution of mobile communications in Taiwan in SubSec. 2.1, and then we present the definitions and types of MVNOs and service development of MVNOs in Taiwan in SubSec. 2.2.

2.1 Evolution of mobile communications

With the increase in privatization and competition year by year, most countries have deregulated and reformed their telecommunications sectors. Policymakers therefore must look to the mobile phone market as a way of achieving social policy goals[9]**.** Moreover, to open up to competition - regardless of the government, industries, or consumers - a nation needs to stipulate more regulatory mechanisms[10].

To establish an environment of market competition based on fairness and efficiency, a government must devise a deregulated policy to ensure public interest and consumerism. This was exactly the working summary statement of the white paper policy for telecommunications liberalization issued by the MOTC of Taiwan in 2003 [14].

The flourishing development of mobile phones in Taiwan can be traced back to the course of the country's telecommunications liberalization in 1996. The evolution and milestones of the market are shown in **Fig. 1**. To realize its WTO (World Trade Organization) commitments, i.e., to establish an effective competition mechanism in Taiwan's telecommunications market, resale and 3G services were opened up, completing the full liberalization of the telecommunications market [15].

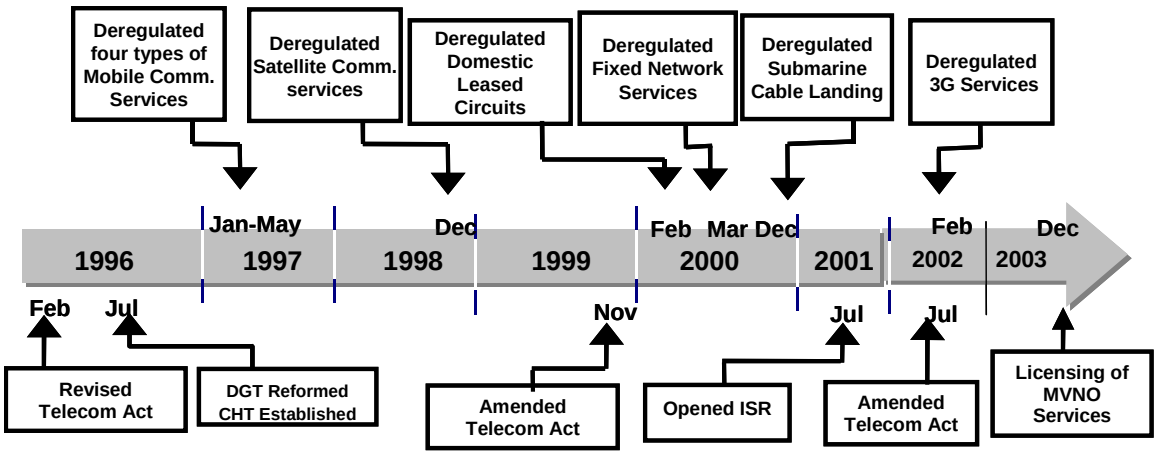

Fig. 1. Liberalization milestones in Taiwan. (*Source*: the MOTC, Taiwan.)

Data from Taiwan's Department of Statistics, Ministry of Transportation and Communications (MOTC) show that there are 112.5 mobile phone numbers per 100 persons at the end of August 2003. With this, Taiwan became number one in the world that year, with an average of more than one mobile phone number held by each Taiwanese. In reference to regulations covering 3G mobile phone services based on other countries, in September 2003 applications for MVNOs were opened after the respective laws had been amended [16].

Through electronic bidding for 3G (third generation) mobile services during a period covering 19 days and 180 rounds, the MOTC awarded 5 licenses from January 16 to February 6, 2002. These five 3G operators began deploying their 3G operations as early as end-2003 and as late as the winter of 2005.

The trend towards liberalization and the rapid development of the global telecommunications industry have contributed to the emergence of MVNOs. In December 2002 the DGT (Directorate General of Telecommunications) of MOTC announced its "Consultation Documents of the Deregulation of MVNOs" to collect public opinion. After collecting various ideas and carrying out the necessary administrative procedures, Taiwan officially deregulated its MVNO market in September 2003 [16].

2.2 MVNOs' development

MNOs traditionally need a lot of manpower and material resources to maintain and administer their operational systems. They have to also invest into a great deal of resources to increase their market share and meet consumers' demand. MNOs' comprehensive operations, however, show a lack of efficiency in terms of network management and business operations.

The core competence of Taiwan's MNOs is in the management of networks. As competition increases, MVNOs have emerged as a supplement to MNOs' ineffective marketing departments.

The definition of MVNO by the International Telecommunications Union (ITU) is stated as follows (*Source*: http://www.itu.int/osg/spu/ni/eg/resources/MVNO/index.html):

(1) MVNOs are operators that offer mobile communications services to end users without having their own radio spectrum. That is to say, MVNOs do not own licenses and must lease network capacity or equipment from licensed operators.

(2) An MVNO can be a provider of a mobile communications service or a value-added service and possess its own Mobile Network Code (MNC) and SIM (Subscriber Identity Module) cards.

One can look at an MVNO as having its own trademark and reselling the products and services of MNOs through their marketing strategies. While MVNOs combine communications technologies with marketing in order to satisfy customers' needs, the patterns of success or failure for developing MVNOs within each county are quite different [17, 18]. From the progress of telecommunications liberalization and the operations and differences in purpose of a supervision mechanism, Taiwan's MOTC (Source: http://www.dgt.gov.tw) categorized MVNOs into four levels. The four levels range from the conservative phase to the completely open phase and by the extent to which they rely on MNOs. The scope of business for each level is summarized in **Table 1**.

Level 1: MVNOs only become involved in the sale of their SIM cards. They get involved neither in building an infrastructure nor in installing switching equipment.

Level 2: MVNOs possess only a small amount of network elements to provide value-added services. They lease radio interfaces, registration systems, authentication systems, MNCs, MSCs (Mobile Switching Centers), and transmission systems from MNOs. They make the most use of MNOs' facilities in order to reduce their operational costs.

Level 3: Aside from using MNOs' radio interfaces, this type of MVNO installs some or all of the switching equipment and network elements by itself. It possesses at least its own registration and authentication systems, and in addition to MNC, it even establishes its own MSC. However, the provided telecommunications services are completely through the infrastructure of MNOs. Such a mode of operation allows this MVNO type to focus on the provision of its own special services. This MVNO is usually considered to be a more advanced service reseller, aiming at providing subscribers with special services.

Level 4: This type of MVNO is also called "Full MVNO" or "Pure MVNO", which means that its mobile communications services, to some extent, are similar to those of MNOs. This MVNO does not have an allocation of spectrum. This MVNO tries to replicate a majority of the host MNOs' infrastructure. It may establish its own MNC, HLR (Home Location Register), MSC, billing systems, and even some mobile ISP (Internet Service Provider) infrastructure such as a WAP (Wireless Application Protocol) gateway. Furthermore, it has full control over branding and pricing and has maximum independence from the host MNOs.

Table 1. Levels, scope of business, and facilities built by MVNOs.

Level	Scope of Business	Facilities Built by MVNOs
Level 1	Resell mobile communications services provided by MNOs	Business support system
Level 2	1. Resell mobile communications services provided by MNOs 2. Provide value-added services with their own network components	1. Business support system 2. Value-added services system 3.Registration and authentication systems (except telecommunications number resources, which belong to MNOs)
Level 3	Provide integrated mobile communications services	1. Business support system 2. Value-added services system 3. Registration and authentication systems 4. MSC
Level 4	Provide integrated mobile communications services	1. Business support system 2. Value-added services system 3. Registration and authentication systems 4. MSC 5. Transmission system

Source: The MOTC in Taiwan (http://www.dgt.gov.tw/).

With MVNOs' marketing expertise, MNOs can avoid losing customers and further boost their revenues and profits. Moreover, MVNOs can help MNOs attract new subscribers at lower costs. While it is often held that MVNOs are a good thing for competition, the opposing view is that the mobile environment is sufficiently competitive, and that the arrival of 3G operators (many for high-income countries adopting the "*n*+1" approach (Note: That when '*n*' is the number of existing licenses of 2G, then the '*n*+1 approach' will award one more (i.e. +1) license to 3G.)) will further increase competition. The stance taken by some is one of "wait and see", leaving time for the 3G market situation to become clearer.

To meet market demand, MVNOs must combine communications technologies with marketing endeavors for satisfying customers' needs. The patterns of success or failure for developing MVNOs in each county are also different. The regulator should carefully devise a mechanism when opening the market up to ensure consumerism and a healthy competitive market. It is still uncertain whether MVNOs will be a success in Taiwan.

Hicall Telecom is one of the three firms that has already obtained the first MVNO operational license and has started negotiating with local MNOs. MVNOs' subscriber phone numbers can be offered by MNOs after both parties finalize negotiations. The MOTC does not establish any related rules in advance to regulate this.

Although international attention has been directed to the development of MVNOs, it is still uncertain whether MVNOs will be a success in Taiwan. According to the spirit of the Telecommunications Law in Taiwan, the MOTC should establish an overall plan of telecommunications development to supervise telecommunications businesses and to promote the development of an information society as well as public welfare.

Based on concepts in Sec. 2, the opening up of telecommunications services must be a complete plan, not just talk without any design. The creation of competition and also market structure should be considered during the opening of the market. The opening timetable for telecommunications licenses should be well planned to influence society, economy, and customer levels.

3. MCDM Method for Evaluating the Strategies of Opening the Market up to MVNOs

We perform the two-stage multi-criteria for evaluating the strategies of opening the market up to MVNOs. In the initial stage we apply the PATTERN method and concepts[11, 12, 13] to establish a hierarchy system for searching out the criteria and evaluating the strategies in Taiwan. Secondly, we combine the fuzzy decision-making theory [19] with fuzzy AHP to determine the evaluation criteria weights. All alternatives are evaluated by experts who based on their personal subjective perception, and then analyzed and ranked by using SAW.

3.1 Establishing a hierarchy system for evaluating the strategies of opening the market up to MVNOs

The PATTERN method and concepts are used to establish a hierarchical strategic system for evaluating the strategies of opening Taiwan's market up to MVNOs.

The analytical procedures include three steps: (1) scenario writing - to write the scenarios from the public's point of view; (2) establishing a relevance tree - to build up the relevance tree from the contents of the scenarios; and (3) evaluation - to make the quantitative evaluation (preference and performance) on the relevance tree by subjective perception. In this SubSec. we focus on scenario writings and establish a relevance tree in decision-making process (Fig. 2). Those steps can be summarized as follows:

(1) Scenario writings. Scenario writings are based upon using the habitual domain [20, 21], i.e., the past understanding of problems, experience, knowledge, and information is derived from brainstorming techniques discussed in previous Sec.s to probe the strategies of opening the market to achieve the goals of MVNOs (goal level).

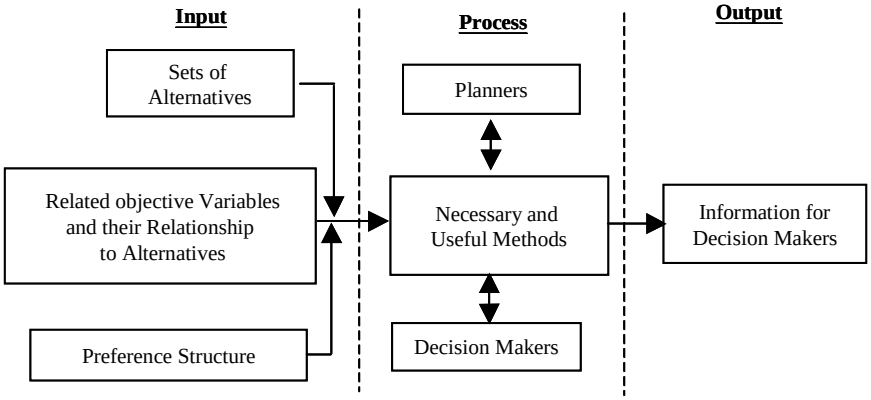

Fig. 2. Features of the decision-making process.[13]

Scenarios are generally composed of the following items:
(a) problem definition and its background;
(b) description of current conditions;
(c) possible future outcomes;
(d) social, economic, legal, and technological backgrounds, etc.

Basic on the scenario writings, we consider the problems from the following viewpoints in order to achieve the goal level: (a) social aspect; (b) customer aspect; (c) economic aspect. We build up the relevance tree from the content of the scenario writings.

(2) Relevance tree. The elements of relevance tree (In the mathematical decision tree, the elements are always called the 'nodes') are 'a relevance set' composed of statements derived from the "goal" level (the high level) through the objectives/aspects, criteria, policy or strategic planning, down to the implementation (the lower level). Elements of relevance trees are defined and identified in hierarchical strategies from brainstorming concepts. They are located at every level from the interaction feedback procedure from high to low levels (top down) and from the low level integrated up to the high level (bottom up). Such a structure constitutes a hierarchical system for the strategies to open up Taiwan's MVNO services.

According to the literature review and scenario writings, relevance tree is used to create a hierarchy strategy system for identifying the optimal trends in strategies of opening the market up to MVNOs using different scenario criteria and strategies. Elements (nodes) of relevance tree are defined and identified in hierarchy strategy systems through brainstorming concepts and a series of pre-tests with domain experts, including two professors (one in an MBA program, the other is in a Telecommunications Technique Center), two experienced mobile operators, and six government officers. These experts are asked to rate the accuracy, adequacy, and relevance of the criteria and dimensions and to verify their "content validity" in terms of the MVNO market-opening strategies. The results from the literature review and expert opinions lead to a decision for the modification and adoption of the hierarchy structure used in this study. The expert opinions are located at every level from the interaction feedback procedure of the high level all the way down to the low level (top down) and from the low level integrated up to the high level (bottom up). Such structures institute evaluation hierarchy strategies in order to establish the market opening strategies as shown in **Fig. 3**, which is an example of relevance tree of the strategies to open up Taiwan's MVNOs services.

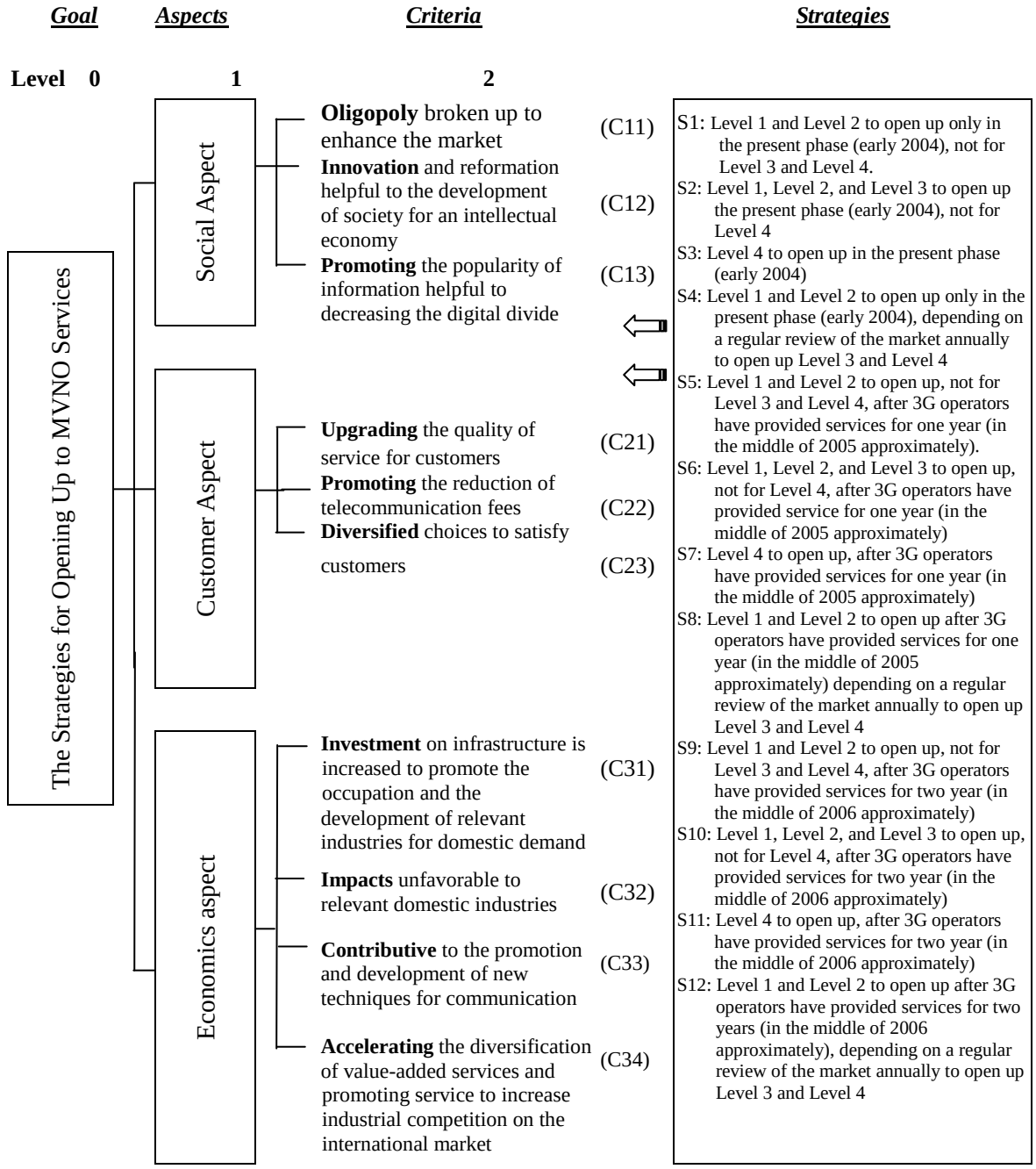

Fig. 3. Evaluation of the hierarchical structure for the strategies of opening up to MVNOs.

(3) Evaluation. This paper uses the fuzzy MCDM to find and analyze the criteria weights by fuzzy AHP in different decision groups. We then analyze and rank the strategies in a fuzzy environment by using SAW.

3.2 Determining the criteria weights

Because the evaluation of the criteria items entails diverse meanings, we cannot assume that each evaluation criterion is of equal importance. In this Sec. we use the fuzzy AHP and combine the fuzzy geometric mean method to determine the criteria weights. The best non-fuzzy/de-fuzzification and normalized weights are then used to locate the synthetic performance value.

(1) Getting the fuzzy weights for the hierarchy process

Because an evaluator always perceives the weight as his/her own subjective evaluation, an exact or precise weight for a specified criterion is not given. This leads to the use of the fuzzy weights of criteria. Buckley[22] initially investigated fuzzy weights and fuzzy utility for the AHP technique [23], extending it by the geometric mean method to derive the fuzzy weights. From Saaty (1980), if $\boldsymbol{A} = [a_{ij}]_{m\times m}$ is a positive reciprocal matrix,

then the geometric mean of each row r_i can be calculated as $r_i = \left(\prod_{j=1}^{m} a_{ij} \right)^{1/m}$. Here, Saaty defined $\lambda_{\max}$ as the largest eigenvalue of $\boldsymbol{A}$ ($C.I. = (\lambda_{\max} - m)/(m-1)$, see **Appendix** A) and the weights w_i are the components of the normalized eigenvector corresponding to $\lambda_{\max}$, where $w_i = r_i / (r_1 + \cdots + r_m)$.

For responding to the subjective perception in criteria weights, Buckley (1985) considered a fuzzy positive reciprocal matrix $\tilde{\boldsymbol{A}} = [\tilde{a}_{ij}]$, extending the geometric mean technique (see **Appendix B**) to define the fuzzy geometric mean of each row $\tilde{r}_i$ and fuzzy weight $\tilde{w}_i$ corresponding to each criterion as follows [22]:

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \cdots \otimes \tilde{a}_{im})^{1/m}; \quad \tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \cdots \oplus \tilde{r}_m)^{-1}. \tag{1}$$

(2) Evaluating performance

Bellman and Zadeh [19] were the first to investigate the decision-making problem in a fuzzy environment, initiating the fuzzy MCDM. We use this method to evaluate the strategies and alternatives of opening up to MVNOs and rank them accordingly. The method and procedures of fuzzy MCDM theory are as follows.

Measuring criteria: Using the measurement of linguistic variables to demonstrate the criteria performance (effect-values) by expressions such as "very very disagree", "very disagree", "disagree", "fair", "agree", "very agree", "very very agree", the evaluators are asked to make their subjective judgments [24]. Each linguistic variable can be indicated by a triangular fuzzy number (TFN) [25] within a range of 1-100 (as shown in **Fig. 4** and **Appendix C Fig. A2** and **Table A4)**. The evaluators can subjectively assign their personal perception to the performance value in alternative k of each criterion i ($i = 1, 2, ..., m$). In these linguistic variables, let $\tilde{v}_{ki}^{p}$ indicate the fuzzy performance value of evaluator p ($p = 1, 2, ..., n$) towards alternative k ($k = 1, 2, ..., K$) under criteria i, and let the criteria of the performance be indicated by the set S:

$$\tilde{v}_{ki}^{p} = (L_{ki}^{p}, M_{ki}^{p}, U_{ki}^{p}), \quad i \in S. \tag{2}$$

Since the perception of each evaluator varies according to the evaluator's experience and knowledge and the definitions of the linguistic variables vary as well, this study uses the notion of geometric mean/average value so as to integrate the fuzzy judgment values of n evaluators:

$$\tilde{v}_{ki} = (\tilde{v}_{ki}^{1} \otimes \tilde{v}_{ki}^{2} \otimes \cdots \otimes \tilde{v}_{ki}^{n})^{1/n}. \tag{3}$$

The sign $\otimes$ denotes fuzzy multiplication, and $\tilde{v}_{ki}$ is the geometric mean/average with the fuzzy number of subjective judgments of the group decision-makers. It can be indicated by a triangular fuzzy number as follows:

$$\tilde{v}_{ki} = (L_{ki}, M_{ki}, U_{ki}). \tag{4}$$

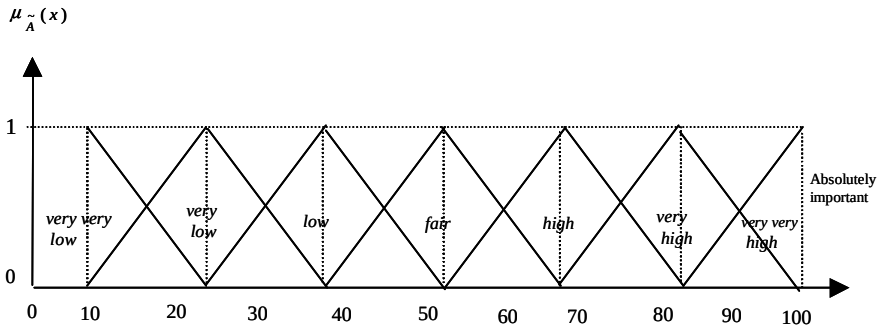

Fig. 4. Example of the membership functions of linguistic variables for measuring the performance value of alternatives.

(3) Driving the Synthetic Utility Values

The evaluators now choose a performance value for each criterion. In this investigation we use the geometric mean/average method to aggregate the anticipated performance values. The synthetic utility values can be driven as follows:

$$\tilde{R} = \tilde{\boldsymbol{V}} \otimes \tilde{\boldsymbol{w}}, \tag{5}$$

where $\tilde{\boldsymbol{V}} = \left[\tilde{v}_{ki}\right]_{K\times n}$ and $\tilde{v}_{ki} = (L_{ki}, M_{ki}, U_{ki})$; $\tilde{\boldsymbol{w}} = (\tilde{w}_1, ..., \tilde{w}_i, ..., \tilde{w}_m)$ and $\tilde{w}_i = (l_i, m_i, u_i)$.

$$\tilde{R}_k = \sum_{i=1}^{m} \tilde{w}_i \otimes \tilde{v}_{ki} = (\sum_{i=1}^{m} l_i L_{ki}, \sum_{i=1}^{m} m_i M_{ki}, \sum_{i=1}^{m} u_i U_{ki}), \quad k = 1, 2, ..., K\ . \tag{6}$$

where $\tilde{R}_k$ is the fuzzy synthetic value of the *k*th strategy. Therefore, the results of the fuzzy synthetic decision reached by each strategy $\tilde{R}_k$ are the fuzzy number.

We can analyze the similarity (closeness) among those strategies ($\tilde{R}_k$, $k = 1, 2, ..., K$ **)** which are classified by their types. The synthetic utility fuzzy values on these strategies not only can go under de-fuzzification, but also can be discussed and analyzed. It is also seen that the non-fuzzy ranking method for fuzzy numbers can be employed during the comparison of the strategies. In previous works the procedure of de-fuzzification has been to locate the best non-fuzzy performance (BNP) value. Methods of such de-fuzzified fuzzy ranking generally include the mean of maximal (MOM), the center of area (COA), and the α-cut - three kinds of methods [26, 27, 28]. Utilizing the COA method to determine the BNP is a simple and practical method [29], and there is no need to introduce the preferences of any evaluators. The BNP value of the triangular fuzzy number $\tilde{R}_k = (LR_k, MR_k, UR_k)$ can be found by the following equation:

$$BNP_k = [(UR_k - LR_k) + (MR_k - LR_k)]/3 + LR_k, \quad \forall_k. \tag{7}$$

The COA method is used in this paper to analyze and rank the order of importance of each criterion and strategy. According to the value of the derived BNP, we can now value each strategy to open up to MVNOs.

4. Empirical Study: Evaluating the Strategies of Opening up to MVNOs in Taiwan

According to the evaluating hierarchy and strategies, we estimate and proceed to the empirical study under three subSec.s: (1) finding and analyzing the weights of criteria, (2) analyzing the alternatives for evaluating the strategies of opening up to MVNOs in Taiwan, and (3) driving the synthetic utility values.

4.1 Finding and analyzing the weights of criteria.

We sent out a total of 28 questionnaires, 24 of which were completed. They include seven scholars, eight experienced mobile operators (five MNOs, including 2G and 3G service operators and three service providers), five equipment manufacturers (e.g. Motorola, Nokia, Ericson, etc.) and four government officers of MOTC. For the fuzzy AHP questionnaires example, see **Appendix C**. The results of the literature review and the experts are listed according to the formulated structure of the key factors, and as such the evaluation of the opening up to MVNOs and the weights of the objective hierarchy and attribute hierarchy can be analyzed. The weights from the decision groups are obtained by using Fuzzy AHP and BNP de-fuzzification (using Eq.(1) and Eq.(7), and results shown in **Tables 2 and 3**) and the consistency radio (*C.R.*) values are also checked, whereby the *C.R.* values are all smaller than 0.1 (**Appendix A**). If the *C.R.* values are larger than 0.1, then this questionnaire should be re-considered and re-written until this questionnaire can satisfy the smaller than 0.1.

Table 2. Weights (Triangular Fuzzy Number and Normalized BNP) of the Aspects and Ranking

Aspects	Social Aspect	Customer Aspect	Economics Aspect
	(*L*, *M*, *U* **)**	**(** *L*, *M*, *U* **)**	**(** *L*, *M*, *U* **)**
Scholars	(0.3101, 0.4511, 0.6336)	(0.1686, 0.2462, 0.3449)	(0.2139, 0.3026, 0.4654)
BNP	**0.4650**	**0.2532**	**0.3273**
2G & 3G Operators	(0.2061, 0.3927, 0.6081)	(0.1753, 0.3112, 0.5544)	(0.1857, 0.2961, 0.6008)
BNP	**0.4023**	**0.3470**	**0.3609**
Service Providers	(0.3471, 0.5723, 0.8227)	(0.1547, 0.1957, 0.2629)	(0.1667, 0.2320, 0.4102)
BNP	**0.5807**	**0.2044**	**0.2697**
Equipment	(0.3321, 0.4381, 0.5654)	(0.2180, 0.2821, 0.4189)	(0.1952, 0.2798, 0.3573)

Manufacturers			
BNP	**0.4452**	**0.3063**	**0.2774**
Government Officers	(0.2776, 0.3622, 0.4638)	(0.2547, 0.3189, 0.3999)	(0.2569, 0.3189, 0.4034)
BNP	**0.3679**	**0.3245**	**0.3264**
Total	(0.2891, 0.4362, 0.6079)	(0.1910, 0.2716, 0.3947)	(0.2063, 0.2922, 0.4542)
BNP	**0.444**	**0.2858**	**0.3176**
Total Ranking	**1**	**3**	**2**

Table 3. Local weights and global weights (GW; GW is Aspects' Weight × Local Weights) final normalized BNP of the criteria.

Criteria	Scholars		2G and 3G Operators		Service Providers	
	(L, M, U)	***GW***	(L, M, U)	***GW***	(L, M, U)	***GW***
C_{11}	(0.1609, 0.2168,0. 3192)		(0.2130, 0.4162, 0.6703)		(0.1580, 0.2303, 0.3679)	
BNP	**0.2323**	*0.0990*	**0.4331**	*0.1412*	**0.2521**	*0.1318*
C_{12}	(0.2392, 0.3499, 0.4928)		(0.2407, 0.4128, 0.7514)		(0.1456, 0.2077, 0.3180)	
BNP	**0.3606**	*0.0761*	**0.4683**	*0.1527*	**0.2238**	*0.1121*
C_{13}	(0.2967, 0.4332, 0.6232)		(0.1114, 0.1710, 0.3479)		(0.3426, 0.5620, 0.8616)	
BNP	**0.4510**	*0.0863*	**0.2101**	*0.0685*	**0.5887**	*0.3066*
C_{21}	(0.1984, 0.2918, 0.4493)		(0.2929, 0.4030, 0.5551)		(0.2389, 0.4180, 0.6118)	
BNP	**0.3132**	*0.0761*	**0.4170**	*0.1258*	**0.4229**	*0.0719*
C_{22}	(0.2276, 0.3553, 0.5182)		(0.2273, 0.3144, 0.4456)		(0.0794, 0.1077, 0.1647)	
BNP	**0.3671**	*0.0839*	**0.3291**	*0.0993*	**0.1172**	*0.0196*
C_{23}	(0.2301, 0.3529, 0.5567)		(0.2008, 0.2826, 0.3863)		(0.3200, 0.4744, 0.7902)	
BNP	**0.3799**	*0.0868*	**0.2899**	*0.0875*	**0.5282**	*0.1023*
C_{31}	(0.1464, 0.2421, 0.4708)		(0.1912, 0.2671, 0.3614)		(0.1861, 0.2615, 0.3642)	
BNP	**0.2864**	*0.0803*	**0.2732**	*0.9864*	**0.2706**	*0.0646*
C_{32}	(0.0700, 0.1113, 0.2000)		(0.3036, 0.3914, 0.5025)		(0.0829, 0.1346, 0.2242)	
BNP	**0.1271**	*0.0355*	**0.3992**	*0.1262*	**0.1472**	*0.0352*
C_{33}	(0.1453, 0.2585, 0.4707)		(0.1118, 0.1498, 0.2040)		(0.1480, 0.2544, 0.3732)	
BNP	**0.2915**	*0.0814*	**0.1552**	*0.0491*	**0.2586**	*0.0618*
C_{34}	(0.1893, 0.3882, 0.6735)		(0.1440, 0.1918, 0.2644)		(0.2173, 0.3494, 0.6149)	
BNP	**0.4170**	*0.1159*	**0.2001**	*0.0634*	**0.3939**	*0.0941*

Table 3. (Continued)

Criteria	Equipment Manufacturers		Government Officers		Total	
	(L, M, U)	***GW***	(L, M, U)	***GW***	(L, M, U)	***GW***
C_{11}	(0.3074, 0.3696, 0.4536)		(0.2658, 0.3418, 0.4282)		(0.2130, 0.3188, 0.4543)	
BNP	**0.3769**	*0.1613*	**0.3453**	*0.1227*	**0.3287**	*0.1332*
C_{12}	(0.3102, 0.3779, 0.4400)		(0.3922, 0.4824, 0.5964)		(0.2662, 0.3833, 0.5440)	
BNP	**0.3760**	*0.1609*	**0.4904**	*0.1742*	**0.3979**	*0.1612*
C_{13}	(0.2153, 0.2525, 0.3071)		(0.1426, 0.1758, 0.2244)		(0.2095, 0.2978, 0.4538)	
BNP	**0.2583**	*0.1105*	**0.1890**	*0.0643*	**0.3204**	*0.1298*
C_{21}	(0.4718, 0.5278, 0.6055)		(0.3139, 0.3801, 0.4556)		(0.2755, 0.3943, 0.5479)	
BNP	**0.5350**	*0.1586*	**0.3832**	*0.1250*	**0.4059**	*0.1066*
C_{22}	(0.1477, 0.1680, 0.1799)		(0.2744, 0.3419, 0.4248)		(0.1943, 0.2674, 0.3640)	
BNP	**0.1652**	*0.0490*	**0.3470**	*0.1091*	**0.2752**	*0.0723*
C_{23}	(0.2716, 0.3042, 0.3369)		(0.2352, 0.2780, 0.3339)		(0.2439, 0.3383, 0.4894)	
BNP	**0.3042**	*0.0902*	**0.2824**	*0.0888*	**0.3572**	*0.0938*
C_{31}	(0.2050, 0.2579, 0.3212)		(0.2461, 0.2733, 0.3112)		(0.1955, 0.2717, 0.3938)	
BNP	**0.2614**	*0.0683*	**0.2769**	*0.0883*	**0.2870**	*0.0831*
C_{32}	(0.0849, 0.1083, 0.1365)		(0.0685, 0.0793, 0.0926)		(0.1067, 0.1482, 0.2136)	
BNP	**0.1099**	*0.0287*	**0.0801**	*0.0256*	**0.1560**	*0.0452*
C_{33}	(0.1376, 0.2010, 0.2630)		(0.3086, 0.3514, 0.4021)		(0.1634, 0.2437, 0.3523)	
BNP	**0.2005**	*0.0524*	**0.3540**	*0.1129*	**0.2531**	*0.0732*
C_{34}	(0.3173, 0.4328, 0.6220)		(0.2619, 0.2960, 0.3239)		(0.2212, 0.3364, 0.4963)	
BNP	**0.4573**	*0.1202*	**0.2940**	*0.0936*	**0.3513**	*0.1016*

4.2 Analyzing the alternatives for evaluating the strategies of opening up to MVNOs in Taiwan

This subSec. analyzes and ranks the achievement level of each criterion in each strategy by using the methods of fuzzy theory for treating the fuzzy environmental problems.

(1) *Linguistic Variables*

According to Zadeh (1965) [30], it is very difficult for conventional quantification to express reasonably those situations that are overtly complex or hard to define. Thus, the notion of a linguistic variable is necessary under such a situation. A linguistic variable is a variable with values that are words or sentences in a natural or artificial language. For example, the evaluation of the alternative to the "the present stage (before January 2004) opens up Level 1 and Level 2, "rather than open up Level 3 and Level 4" being important as regards to the criteria "oligopoly broken to enhance the market " in this study. We take on values such as "very very dissatisfy", "very dissatisfy", "dissatisfy", "fair", "satisfy", "very satisfy", and "very very satisfy" [24], with respect to a fuzzy seven level scale. The membership functions of the expression values can be indicated by triangular fuzzy numbers (TFN) [25] within the scale range of 0-100 (see **Fig. 4**). The evaluators can also define their own individual range for the linguistic variables employed in this study according to their subjective judgments/perceptions within the scale of 0-100 (see **Fig. 4**).

(2) *Fuzzy Performance Score of Strategies with Respect to Criteria*

Since the perception of each evaluator varies according to the evaluator's experience and knowledge (subjective judgments/perceptions within the scale of 0-100), this empirical study uses the geometric mean/average value so as to integrate the fuzzy judgment values and BNP de-fuzzification of 24 evaluators (using Eq. (3) and Eq. (7), the results are shown in **Table 4**).

4.3 Driving the synthetic utility values

Traditional evaluation methods usually take the minimum cost or the maximum benefit as their only single index of measurement [26, 27]. However, in an increasingly complex and diversified decision-making environment, this approach may sacrifice too much valuable information in the process. Thus, this study proposes a multiple criteria decision making (MCDM) method to evaluate the hierarchy systems for the strategies of opening up to MVNOs.

Among the numerous approaches available for conflict management, the most prevalent includes MCDM. Practical problems are often characterized by several non-commensurable and competing (conflicting) criteria, with no solution satisfying all criteria simultaneously. Applying MCDM, the compromise solution for the problem with conflicting criteria can therefore be determined, which can help decision makers to reach a final decision.

SAW is introduced as one simple and applicable technique to implement within MCDM (Eqs. (5)-(6)). From the criteria weights obtained by the fuzzy AHP and the fuzzy performance values of each criterion and alternative (strategy), this final fuzzy synthetic utility value can finally be obtained (Eq. (6)). After the fuzzy integrated decision is made and subsequently the non-fuzzy ranking method is employed, the fuzzy numbers are changed into non-fuzzy values (BNP) (Eq. (7)). Though there are several methods to rank these fuzzy numbers, this study decides to use COA to find the BNP value that is used to rank each strategy. We use the symbol '$\succ$' to denote the preference with the convention that $S_i \succ S_j$ means S_i is a better choice than S_j. Here, $S_3 \succ S_7 \succ S_6 \succ S_2 \succ S_{11} \succ S_8 \succ S_5 \succ S_4 \succ S_{10} \succ S_1 \succ S_{12} \succ S_9$, which are presented in **Table 5**.

Table 4. Fuzzy performance score of strategies with respect to criteria.

Criteria / Strategies	C_{11} (L, M, U)	C_{12} (L, M, U)	C_{13} (L, M, U)	C_{21} (L, M, U)
S_1	(16.58, 28.21, 37.20)	(22.81, 33.93, 42.15)	(23.31, 34.19, 41.97)	(36.33, 45.07, 53.23)
S_2	(23.51, 35.02, 43.31)	(33.63, 44.47, 52.02)	(27.86, 39.51, 47.63)	(43.73, 52.36, 60.14)
S_3	(26.41, 38.51, 46.97)	(44.23, 53.81, 62.41)	(34.84, 47.81, 56.18)	(44.15, 54.93, 63.30)
S_4	(18.68, 30.21, 38.91)	(31.39, 39.94, 47.38)	(25.11, 36.75, 44.87)	(37.25, 46.47, 55.34)
S_5	(19.77, 31.92, 40.78)	(25.15, 37.04, 45.82)	(26.10, 37.46, 45.30)	(37.54, 46.22, 54.34)
S_6	(23.31, 36.12, 45.20)	(33.04, 45.17, 52.93)	(27.97, 39.69, 47.65)	(44.51, 53.47, 61.29)
S_7	(25.29, 39.05, 48.15)	(37.21, 48.18, 56.57)	(34.19, 46.24, 54.38)	(46.34, 55.55, 63.91)
S_8	(19.86, 31.90, 40.76)	(29.67, 39.64, 47.80)	(26.00, 38.10, 46.48)	(37.24, 46.47, 54.98)
S_9	(14.69, 26.41, 35.44)	(18.37, 29.79, 38.80)	(19.49, 30.51, 38.48)	(32.50, 41.03, 49.54)
S_{10}	(18.13, 30.64, 40.00)	(22.17, 33.92, 42.89)	(23.06, 33.28, 41.73)	(33.65, 42.86, 51.97)
S_{11}	(19.44, 33.54, 42.49)	(28.96, 41.16, 49.15)	(30.84, 40.76, 48.89)	(39.13, 49.03, 57.21)
S_{12}	(14.19, 26,20, 34.67)	(18.12, 29.19, 37.68)	(20.36, 30.74, 39.49)	(32.25, 40.91, 49.14)

Table. 4 (Continued)

Criteria / Strategies	C_{22} (L, M, U)	C_{23} (L, M, U)	C_{31} (L, M, U)	C_{32} (L, M, U)
S_1	(26.28, 36.06, 45.23)	(37.11, 47.85, 56.33)	(18.75, 31.96, 40.33)	(20.64, 31.76, 40.68)
S_2	(37.20, 46.38, 55.77)	(42.02, 52.90, 61.27)	(33.45, 44.73, 51.21)	(34.77, 45.62, 53.79)
S_3	(48.00, 57.63, 66.38)	(45.42, 56.43, 65.13)	(39.38, 52.01, 60.16)	(37.62, 50.09, 58.00)
S_4	(32.98, 42.53, 51.54)	(38.05, 48.89, 57.67)	(19.30, 32.21, 40.57)	(28.96, 39.30, 47.73)
S_5	(32.61, 43.45, 52.83)	(42.24, 53.05, 62.03)	(20.52, 34.07, 42.61)	(25.07, 36.29, 44.40)
S_6	(42.18, 50.92, 58.57)	(46.18, 56.87, 65.02)	(35.30, 45.93, 52.86)	(33.73, 43.36, 50.57)
S_7	(45.85, 55.03, 63.47)	(55.00, 63.37, 71.13)	(33.32, 46.78, 55.72)	(30.33, 41.62, 49.72)
S_8	(37.41, 45.63, 53.37)	(39.99, 50.99, 59.60)	(21.14, 34.61, 43.03)	(25.61, 36.84, 45.23)
S_9	(26.65, 36.74, 45.94)	(34.17, 44.35, 53.14)	(16.90, 29.89, 38.36)	(13.70, 26.17, 34.69)
S_{10}	(32.52, 41.46, 50.09)	(35.18, 45.50, 54.24)	(25.47, 37.00, 44.89)	(27.80, 38.11, 46.68)
S_{11}	(40.19, 47.90, 55.59)	(40.17, 50.21, 57.93)	(31.69, 43.96, 51.82)	(37.18, 46.29, 53.78)
S_{12}	(26.38, 36.24, 44.50)	(31.88, 41.70, 50.42)	(21.79, 32.78, 41.35)	(22.27, 33.13, 42.17)

Table. 4 (Continued)

Criteria / Strategies	C_{33} (L, M, U)	C_{34} (L, M, U)	Synthetic *Fuzzy Performance Score* (L, M, U)
S_1	(24.78, 35.56, 44.42)	(36.23, 46.31, 54.52)	(26.15, 36.96, 45.41)
S_2	(31.81, 43.13, 52.25)	(43.00, 52.27, 61.31)	(34.51, 45.21, 53.27)
S_3	(41.63, 53.04, 62.25)	(47.73, 57.48, 65.27)	(40.48, 51.63, 60.07)
S_4	(26.11, 37.24, 46.17)	(37.37, 47.61, 55.86)	(29.35, 39.86, 48.26)
S_5	(32.15, 43.32, 52.40)	(35.83, 45.75, 53.87)	(29.23, 40.42, 48.99)
S_6	(38.92, 49.18, 57.71)	(41.79, 52.03, 60.05)	(35.74, 46.62, 54.61)
S_7	(42.98, 53.78, 62.60)	(47.15, 55.36, 63.59)	(39.29, 50.14, 58.59)
S_8	(33.42, 44.52, 53.63)	(35.45, 45.29, 53.79)	(30.19, 41.02, 49.49)
S_9	(27.65, 38.95, 48.36)	(28.79, 39.51, 47.98)	(23.01, 34.00, 42.73)
S_{10}	(31.09, 42.36, 51.92)	(35.57, 45.33, 53.34)	(27.48, 38.21, 46.97)
S_{11}	(34.84, 46.81, 55.87)	(34.16, 44.60, 52.97)	(32.44, 43.49, 51.69)
S_{12}	(28.23, 39.15, 48.53)	(32.26, 42.04, 50.31)	(23.95, 34.44, 43.01)

Table 5. Synthetic fuzzy performance score with respect to criteria.

Criteria / Strategies	Synthetic *Fuzzy Performance Score* (L, M, U)	BNP	Ranking
S_1	**(26.15, 36.96, 45.41)**	**36.17**	**10**
S_2	**(34.51, 45.21, 53.27)**	**44.33**	**4**
S_3	**(40.48, 51.63, 60.07)**	**50.73**	**1**
S_4	**(29.35, 39.86, 48.26)**	**39.16**	**8**
S_5	**(29.23, 40.42, 48.99)**	**39.55**	**7**
S_6	**(35.74, 46.62, 54.61)**	**45.66**	**3**
S_7	**(39.29, 50.14, 58.59)**	**49.34**	**2**
S_8	**(30.19, 41.02, 49.49)**	**40.23**	**6**
S_9	**(23.01, 34.00, 42.73)**	**33.25**	**12**
S_{10}	**(27.48, 38.21, 46.97)**	**37.55**	**9**
S_{11}	**(32.44, 43.49, 51.69)**	**42.54**	**5**
S_{12}	**(23.95, 34.44, 43.01)**	**33.80**	**11**
Desired Performance Score*	**(85.82, 91.64, 100.00)**	**92.49**	**-**

* Desired/Aspired Performance Score (very very satisfy) is based on the result of expert questionnaires.

4.4 Discussions

Table 2 provides general perspectives on the three aspects in descending order of importance: social aspect, economic aspect, customer aspect. Social aspect is the most important factor, whereas the customer aspect is the least important factor in the strategies to open up to MVNOs. We now elaborate upon the reasons why. The opening up of MVNOs helps accelerate economic development. The government authority - the MOTC - not only legislates to protect customers' interests, but also opens up the market to competition. Therefore, each provider competes to promote quality services and to satisfy consumers. The monopoly on mobile communications can then be broken up to promote the market. Scholars and experts think this is a top

priority.

The weightings of the 10 criteria are shown in **Table 3** (from C_{11} to C_{34}). The results reveal that information literacy is helpful to decrease the digital divide. Promoting the reduction of telecommunication fees is considered a less important criterion.

Former U.S. President Bill Clinton announced a report in July 1999, titled "Falling Through the Net: Defining the Digital Divide", which was about the digital differences proposed by the National Telecommunications and Information Administration (NTIA). It was found that the digital differences among many groups - grouping based on some population structure or geographical locations - increase with time. This report showed that some minority groups and low-income groups are unable to easily obtain national information and resources. A nation should eliminate the digital differences by enthusiastically implementing an open market strategy. Opening up competition for MVNOs services can help the popularity of information usage and reduce the digital lag, which is verified in this study.

Ever since telecommunications liberalization was implemented in Taiwan in 1996, mobile phone fees have fallen from NT$0.2 per second to NT$ 0.05 per second, a decrease of 75%. Communication fees in Taiwan are less expensive than those in developed countries. As such, fees are no longer a roadblock in promoting the communications market. Therefore, this item is listed as a criterion with the least importance. **Table 5** shows that S_3 (Level 4 to open up in the present phase (early 2004)) is the best among all. The reasons are as follows.

The global 3G mobile phone market has not grown as expected, as evidenced by the first company to offer 3G services in Taiwan is in fact still using 2.5G technologies. MVNO seems to be a tool to open up 3G marketing, because its professional focus is on marketing strategies. The overall opening up to MVNOs for Level 4 services is believed to be helpful for market's development.

We now list why S_9 (Level 1 and Level 2 to open up, not for Level 3 and Level 4, after 3G operators have provided services for two year (in the middle of 2006 approximately)) is the worst case. It is the most conservative method. In fact, S_9 will open up Level 1 and Level 2 services after 3G providers have officially been running for two years (in the middle of 2006). That is, S_9 does not offer Level 3 and Level 4 services. By the year 2006, the 2G and 3G operators will be competing in a mature and competitive market. In that case, no related industries will benefit by the S_9 strategy. Hence, S_9 is too small in operation scale and too late in opening timing. Therefore, S_9 is the worst choice in selecting both the opening timing and operation type.

Note that the experts gave a score of 50.73 for S_3 (Level 4 to open up in the present phase (early 2004)), but the ideal or desired/aspired performance score of all experts for S_3 is 92.49. Why is there such a gap? Apparently, by considering only opening timing and operation types, the best score they can give is 50.73 to S_3. Therefore, there must be some other consideration or missing factors that can amount to 92.49 (desired/aspired performance score (very very satisfaction)). What and how can be the possible reason for achieving the desired/aspired performance score? In our other and future researches, we found that the collaboration between MVNOs and MNOs [31] is the key to its success. We briefly explain this as follows.

The negative attitude of MNOs in cooperating with MVNOs could due to the following reasons:

(1) Regardless of 2G or 3G MNOs, they both worry about losing the influence of their brands. Therefore, they hold a conservative attitude to not cooperate with MVNOs.

(2) Some MNOs believe they have great advantages in marketing as first-movers. Therefore, they do not want to cooperate with channel agents or MVNOs.

(3) Some successful channel agents such as 7-Eleven Taiwan think that the telecommunications field is too technical, and they do not want to participate in operating unfamiliar MVNOs.

If the MOTC wants to maintain a society of consumerism and an efficient or open competitive market, then it should devise a management mechanism which provides MNOs and MVNOs with a win-win situation.

5. Conclusions

Under the leadership of developed countries such as the U.S., the UK, and Japan, the trend of telecommunications liberalization has sprouted everywhere in the world. Many countries have followed suit

in carrying out the policy of liberalization, releasing unnecessary restrictions and reducing the government's administrative intervention. The mechanism of market competition is expected to be enacted, so that consumers can obtain the maximum welfare in order to help with the development of the overall economy. The results in this study confirm such a trend.

Issues in the field of policy decisions often face complex and multiple criteria. Through MCDM, this study makes use of Fuzzy AHP and SAW to sort out the priority of each project. For MVNOs to be successful, the following three factors, listed in order of importance, must be considered: social aspect, economic aspect, and customer aspect. Considering the social aspect, the most important thing is to promote information to reduce the digital divide. For the economic aspect, literacy is important in accelerating the diversification of value-added services and promoting global competitiveness of those services. As for the customer aspect, it is important that the strategy of opening up to MVNOs focuses on diversified choices to satisfy customers. The result from evaluating each strategy and ranking is: $S_3 \succ S_7 \succ S_6 \succ S_2 \succ S_{11} \succ S_8 \succ S_5 \succ S_4 \succ S_{10} \succ S_1 \succ S_{12} \succ S_9$.

This research notes that S_3 (Level 4 to open up in the present phase of 'early 2004') gives MVNOs the necessity to own telecommunications equipment so that they are pretty much similar to MNOs. Therefore, manufacturers can sell equipment. Moreover, S_3 triggers and activates the telecommunications industry so that the industry can create more job opportunities. According to the results of the "Analysis of the Effects of Telecommunications Liberalization in the Taiwan" study commissioned by the MOTC, a forward correlation exists between Taiwan's telecommunications liberalization and the development of its overall economy and related industries. The report points out that the input/output effect of telecommunications investment is that an "investment of NT$1 in telecommunications will have an overall multiple effect of increasing the total value of production to NT$ 2.89." Furthermore, S_3 helps bring an active market with competition among MNOs and MVNOs. Therefore, the consumers will benefit by seeing better services.

Strategies concerning this topic have been studied and established herein. We believe mobile communications can be rapidly and orderly developed so as to advance the opening up of this market in Taiwan.

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Appendix A. Consistency Ratio

The largest Consistency Ratio ($C.R.$) of pairwise comparison matrices from all respondents is under 0.09 and satisfies the practices that require $C.R. < 0.1$. We obtain values within 0.00 to 0.09. The following example illustrates the $C.R.$ test computation.

$C.I. = (\lambda_{\max} - m)/(m-1)$, where m is the dimension, and $\lambda_{\max}$ is the eigenvalue of the matrix.

Table A1. The random consistency index ($R.I.$) table.

Dimension m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$R.I.$	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

Source: Saaty, T. L., 1980. [23]

$C.R.(\text{Consistency Ratio}) = \dfrac{C.I.}{R.I.}$, where $R.I.$ is the Random Consistency Index.

$C.R.$ values for Aspects (Level 1): Social Aspect (C_1), Customer Aspect (C_2), and Economics Aspect (C_3) are in the range of [0.00, 0.09].

$C.R.$ values for Criteria (Level 2): C_{11}, C_{12}, and C_{13} are in the range of [0.00, 0.09].

C_{21}, C_{22}, and C_{23} are in the range of [0.01, 0.07].

C_{31}, C_{32}, $C_{33,}$ and C_{34} are in the range of [0.02, 0.09].

Appendix B. Why does one use the geometric mean/average for estimating the relative importance/ weights in each criterion by AHP?

(1) The concepts of using the geometric mean technique logic system procedure about the weight are obtained as follows.

$$\boldsymbol{W} = \begin{array}{c} \\ w_1 \\ \vdots \\ w_i \\ \vdots \\ w_m \end{array} \begin{array}{c} \begin{array}{ccccc} w_1 & & w_j & & w_m \end{array} \\ \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_j & \cdots & w_1/w_m \\ \vdots & & \vdots & & \vdots \\ w_i/w_1 & \cdots & w_i/w_j & \cdots & w_i/w_m \\ \vdots & & \vdots & & \vdots \\ w_m/w_1 & \cdots & w_m/w_j & \cdots & w_m/w_m \end{bmatrix} \end{array} \Rightarrow \underset{w_i,\ i=1,\ldots,m}{\begin{bmatrix} \prod_{j=1}^{m}(w_1/w_j) \\ \vdots \\ \prod_{j=1}^{m}(w_i/w_j) \\ \vdots \\ \prod_{j=1}^{m}(w_m/w_j) \end{bmatrix}} \Rightarrow \underset{w_i,\ i=1,\ldots,m}{\begin{bmatrix} (w_1^{\,m}/\prod_{j=1}^{m} w_j) \\ \vdots \\ (w_i^{\,m}/\prod_{j=1}^{m} w_j) \\ \vdots \\ (w_m^{\,m}/\prod_{j=1}^{m} w_j) \end{bmatrix}} \Rightarrow \underset{w_i,\ i=1,\ldots,m}{\begin{bmatrix} w_1/(\prod_{j=1}^{m} w_j)^{1/m} \\ \vdots \\ w_i/(\prod_{j=1}^{m} w_j)^{1/m} \\ \vdots \\ w_m/(\prod_{j=1}^{m} w_j)^{1/m} \end{bmatrix}} \Rightarrow$$

$$\sum_{i=1}^{m} w_i = 1$$

$$\begin{bmatrix} \dfrac{(w_1/(\prod_{j=1}^{m} w_j)^{1/m}}{\sum_{i=1}^{m}[w_i/(\prod_{j=1}^{m} w_j)^{1/m}]} \\ \vdots \\ \dfrac{(w_i/(\prod_{j=1}^{m} w_j)^{1/m}}{\sum_{i=1}^{m}[w_i/(\prod_{j=1}^{m} w_j)^{1/m}]} \\ \vdots \\ \dfrac{(w_n/(\prod_{j=1}^{m} w_j)^{1/m}}{\sum_{i=1}^{m}[w_i/(\prod_{j=1}^{m} w_j)^{1/m}]} \end{bmatrix} \Rightarrow \begin{bmatrix} \dfrac{(w_1/(\prod_{j=1}^{m} w_j)^{1/m}}{1/(\prod_{j=1}^{m} w_j)^{1/m}} \\ \vdots \\ \dfrac{(w_i/(\prod_{j=1}^{m} w_j)^{1/m}}{1/(\prod_{j=1}^{m} w_j)^{1/m}} \\ \vdots \\ \dfrac{(w_m/(\prod_{j=1}^{m} w_j)^{1/m}}{1/(\prod_{j=1}^{m} w_j)^{1/m}} \end{bmatrix} \Rightarrow \begin{bmatrix} w_1 \\ \vdots \\ w_i \\ \vdots \\ w_m \end{bmatrix}$$

$$\Downarrow$$

$$\sum_{i=1}^{m}[w_i/(\prod_{j=1}^{m} w_j)^{1/m}]$$
$$= \sum_{i=1}^{m} w_i/(\prod_{j=1}^{m} w_j)^{1/m}, \quad \sum_{i=1}^{m} w_i = 1$$
$$= 1/(\prod_{j=1}^{m} w_j)^{1/m}$$

(2) The empirical data of the procedure for using the geometric mean technique determine the relative importance (criteria weights). We can extend this procedure to determine the fuzzy weights as follows.

$$\boldsymbol{A} = \begin{array}{c} \\ w_1 \\ \vdots \\ w_i \\ \vdots \\ w_m \end{array} \begin{array}{c} \begin{array}{ccccc} w_1 & & w_j & & w_m \end{array} \\ \begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1m} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{im} \\ \vdots & & \vdots & & \vdots \\ a_{m1} & \cdots & a_{mj} & \cdots & a_{mm} \end{bmatrix} \end{array} \Rightarrow \begin{bmatrix} \prod_{j=1}^{m}(a_{1j}) \\ \vdots \\ \prod_{j=1}^{m}(a_{ij}) \\ \vdots \\ \prod_{j=1}^{m}(a_{mj}) \end{bmatrix} \Rightarrow \begin{bmatrix} r_1 \\ \vdots \\ r_i \\ \vdots \\ r_m \end{bmatrix} = \begin{bmatrix} [\prod_{j=1}^{m}(a_{1j})]^{1/m} \\ \vdots \\ [\prod_{j=1}^{m}(a_{ij})]^{1/m} \\ \vdots \\ [\prod_{j=1}^{m}(a_{mj})]^{1/m} \end{bmatrix} \Rightarrow$$

$$\begin{bmatrix} w_1 \\ \vdots \\ w_i \\ \vdots \\ w_m \end{bmatrix} \Rightarrow \begin{bmatrix} [\prod_{j=1}^{m}(a_{1j})]^{1/m} / \sum_{i}^{m}[\prod_{j=1}^{m}(a_{ij})]^{1/m} \\ \vdots \\ [\prod_{j=1}^{m}(a_{ij})]^{1/m} / \sum_{i}^{m}[\prod_{j=1}^{m}(a_{ij})]^{1/m} \\ \vdots \\ [\prod_{j=1}^{m}(a_{mj})]^{1/m} / \sum_{i}^{m}[\prod_{j=1}^{m}(a_{ij})]^{1/m} \end{bmatrix} \Rightarrow \begin{matrix} r_i = [\prod_{j}^{m} a_{ij}]^{1/m} \\ w_i = r_i / \sum_{i=1}^{m} r_i \end{matrix} \begin{bmatrix} w_1 \\ \vdots \\ w_i \\ \vdots \\ w_m \end{bmatrix} \Rightarrow \begin{bmatrix} r_1 / \sum_{i=1}^{m} r_i \\ \vdots \\ r_i / \sum_{i=1}^{m} r_i \\ \vdots \\ r_m / \sum_{i=1}^{m} r_i \end{bmatrix}$$

(3) Determining the fuzzy weights according to basic concepts (1) and (2) above.

$$\tilde{r}_i = [\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes ... \otimes \tilde{a}_{im}]^{1/m}, \quad i = 1, 2, ..., m$$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_m)^{-1}$$

The concept of the meanings in this paragraph is related to geometric average. We can then extend this concept to determine the fuzzy weights. Therefore, those processes of reasoning are only suitable to use the calculations of the geometric average and cannot use the calculation of the arithmetic average.

Appendix C. Explanation and samples of AHP questionnaire

Table A2. Example: A returned sample of AHP questionnaire (the level 1)

Level 1 Object ◄	Absolute important		Strong important		Equal important		Strong important		Absolute important		Level 1 Object ►
	▼		▼		▼		▼		▼		
Social	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9		Customer
Aspects	8:1	6:1	4:1	2:1	1:2	1:4	1:6	1:8			Aspects
Customer	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9		Economics
Aspects	8:1	6:1	4:1	2:1	1:2	1:4	1:6	1:8			Aspects
Economics	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9		Social
Aspects	8:1	6:1	4:1	2:1	1:2	1:4	1:6	1:8			Aspects

Note: 1. Each person received an identical questionnaire like this one. Twenty-four of the returned questionnaires are combined with their corresponding **Fig. A1** to produce Table 2 and Table 3.
2. In the consistency test, *C.R.* is utilized to determine the degree of consistency; when *C.R.*<0.1 it is considered to be acceptable.

We use the scale of absolute values shown in Table A3 to help the evaluator make the pairwise comparison.

Table A3. The fundamental scale of relative importance

Intensity of important	**Definition**	**Explanation**
1	Equal importance	**Two activities contribute equally to the objective**
2	Equally to moderately	
3	Moderate important	**Experience and judgment slightly favor one activity over another**
4	Moderate plus	
5	Strong important	**Experience and judgment strongly favor one activity over another**
6	Strong plus	
7	Very Strong or demonstrated important	**An activity is favored very strongly over another; its dominance demonstrated in practice**
8	Very, very strong	
9	Extreme important	**The evidence favoring one activity over another is of the highest possible order of affirmation**

Source: Saaty, T. L., 1980. [23]

The scale of "1-9" is the value of the different importance ranking by AHP, as shown in Table C2. The meanings in this part are based on our recognition to fill in the importance with the different values. Here, 1, 2, 3, 4, 5, 6, 7, 8, and 9 can be expressed as $\tilde{1}$, $\tilde{2}$, $\tilde{3}$, $\tilde{4}$, $\tilde{5}$, $\tilde{6}$, $\tilde{7}$, $\tilde{8}$, and $\tilde{9}$, respectively, which is filled in at the fuzzy triangle region. For example, $\tilde{7}$ = (6, 7, 8). An example of the size of "$\tilde{1} \sim \tilde{9}$" is the value of subjective recognition for the fuzzy region as shown in Fig. C1.

Example: The "1-9" scale value subjective recognition (fuzzy number) for personal fuzzy region *(L, M, U)*

Fuzzy number	$\tilde{1}$	$\tilde{2}$	$\tilde{3}$	$\tilde{4}$	$\tilde{5}$
(L, M, U)	(0.5, 1, 2)	(1, 2, 3)	(2, 3, 4)	(3, 4, 5)	(4, 5, 6)

Fuzzy number	$\tilde{6}$	$\tilde{7}$	$\tilde{8}$	$\tilde{9}$
(L, M, U)	(5, 6, 7)	(6, 7, 8)	(7, 8, 9)	(8, 9, 10)

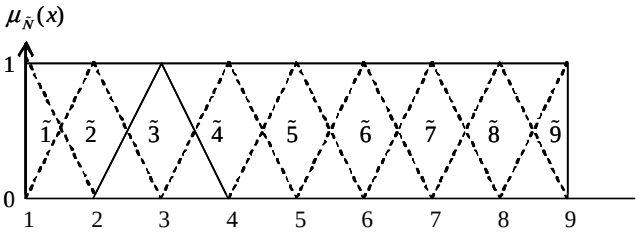

Fig. C1. The fuzzy scale of "$\tilde{1} \sim \tilde{9}$" of relative weights of criteria

We first asked each expert to specify their fuzzy scores **(** L, M, U **)** corresponding to each linguistic variable. By doing this, we allow each expert to specify their individual and unique range of corresponding fuzzy scores in the linguistic sense. In the survey we asked experts to answer with linguistic variable such as "agree", "very agree", "disagree"…instead of a crisp number with linguistic variables that are answered [24]. We then convert each of them into fuzzy scores which are offered separately described in Sec. 3.2(2). Likewise, through Fig. C2. and Table D1, we obtain Tables 4 and 5.

Example: The seven scales to measure the performance

Scale	1. very very dissatisfy	2. very dissatisfy	3. dissatisfy	4. fair
(L, M, U)	(10, 20, 30)	(35, 40, 45)	(50, 55, 60)	(60, 65, 70)

Scale	5. satisfy	6. very satisfy	7. very very satisfy
(L, M, U)	(70, 75, 80)	(80, 85, 90)	(90, 95, 100)

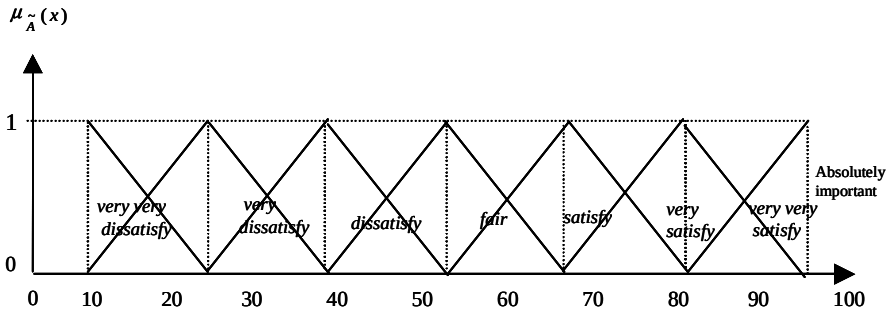

Fig. D1. The evaluator assigns his/her subjectively personal perception to the performance value

We explained in person about the questionnaire to the experts one by one. They all showed interest in participating in the survey.

Table A4. A returned sample of the questionnaire of fuzzy performance score of strategies with respect to criteria

Criteria / Alternate	Seven scale	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{33}	C_{34}
S_1	Very very agree										
	Very agree										
	Agree				v	v	v			v	v
	Fair	v	v	v				v			
	Disagree										
	Very disagree								v		
	Very very disagree										
S_2	Very very agree										
	Very agree										v
	Agree		v		v		v		v	v	
	Fair	v		v		v		v			
	Disagree										
	Very disagree										
	Very very disagree										
⋮	⋮					⋮					
S_{12}	Very very agree										
	Very agree										
	Agree										
	Fair	v	v	v	v		v				
	Disagree					v		v		v	v
	Very disagree										
	Very very disagree								v		

S_1 : Level 1 and level 2 to open up only in the present phase (early 2004), not for Level 3 and Level 4.
S_2 : Level 1, level 2, and level 3 to open up the present phase (early 2004), not for Level 4.
⋮
S_{12} : Level 1, level 2, and level 3 to open up after 3G operators have provided service for two years (in the middle of 2006 approximately), depending on a regular review of the market annually to open up Level 3 and Level 4.
C_{11}: Oligopoly broken up to enhance the market.
:
C_{34}: Accelerating the diversification of value-added services and promoting the matters of service to increase industrial competition on the international market (see **Fig. 3.** for details).

Appendix D. Fuzzy number operations

Fuzzy numbers are a fuzzy subset of real numbers, representing the expansion of the idea of the confidence interval. According to the definition by Laarhoven and Pedrycz [32], a triangular fuzzy number (TFN) should possess the following basic features.

A fuzzy number $\tilde{A}$ on R is a TFN if its membership function $\mu_{\tilde{A}}(x) : R \to [0,1]$ is equal to:

$$\mu_{\tilde{A}}(x)=\begin{cases}(x-L)/(M-L) & L \le x \le M \\ (U-x)/(U-M) & M \le x \le U \\ 0 & \text{otherwise}\end{cases} \quad \text{(A.1)}$$

where L and U stand for the lower and upper bounds of the fuzzy number $\tilde{A}$, respectively, and M stands for the modal value (see **Fig. A3.**). The TFN can be denoted by $\tilde{A}=(L, M, U)$ and the following is the operational laws of two TFNs $\tilde{A}_1=(L_1, M_1, U_1)$ and $\tilde{A}_2=(L_2, M_2, U_2)$, as shown in equations (2) to (6) [33]:

Addition of a fuzzy number $\oplus$

$$\tilde{A}_1 \oplus \tilde{A}_2 = (L_1, M_1, U_1) \oplus (L_2, M_2, U_2)=(L_1 + L_2, M_1 + M_2, U_1 + U_2) \quad \text{(A.2)}$$

Multiplication of a fuzzy number $\otimes$

$$\tilde{A}_1 \otimes \tilde{A}_2 = (L_1, M_1, U_1) \otimes (L_2, M_2, U_2) = (L_1L_2, M_1M_2, U_1U_2) \text{ for } L_i > 0, M_i > 0, U_i > 0 \quad \text{(A.3)}$$

Subtraction of a fuzzy number $\ominus$

$$\tilde{A}_1 \ominus \tilde{A}_2 = (L_1, M_1, U_1) \ominus (L_2, M_2, U_2) = (L_1 - U_2, M_1 - M_2, U_1 - L_2) \quad \text{(A.4)}$$

Division of a fuzzy number $\varnothing$

$$\tilde{A}_1 \varnothing \tilde{A}_2 = (L_1, M_1, U_1) \varnothing (L_2, M_2, U_2) = (L_1/U_2, M_1/M_2, U_1/L_2) \text{ for } L_i > 0, M_i > 0, U_i > 0 \quad \text{(A.5)}$$

Reciprocal of a fuzzy number

$$\tilde{A}_1^{-1} = (L_1, M_1, U_1)^{-1} = (1/U_1, 1/M_1, 1/L_1), \quad \text{for } L_i > 0, M_i > 0, U_i > 0 \quad \text{(A.6)}$$

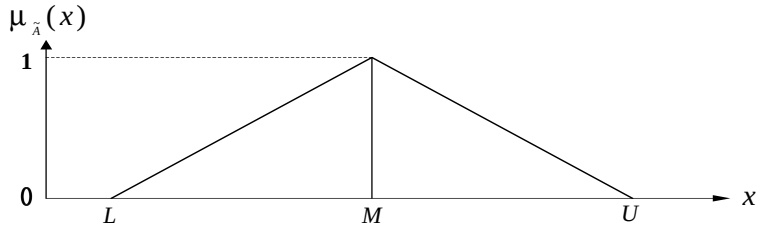

Fig. A3. The membership function of the triangular fuzzy number

References

1. Office of Telecommunications (OFTEL), *Mobile Virtual Network Operators: OFTEL Inquiry into What MVNOs Could Offer Consumers*. (OFTEL, June 1999).
2. Office of Telecommunications (OFTEL), *OFTEL Statement on Mobile Virtual Network Operators*, (OFTEL, October 1999).
3. M. Porter, *Competitive Advantage*. (Free Press, New York, 1985).
4. S. Ulset, Mobile virtual network operators: a strategic transaction cost analysis of preliminary experiences, *Telecommunications Policy* **26**(9/10) (2002) 537–549.
5. R. B. B. Evans, Conceptualising and operationalizing the business to business value chain, *Industrial Marketing Management* **30**(2) (2001) 135–148.
6. B. W. Wirtz, Reconfiguration of value chains in converging media and communication markets, *Long Range Planning* **34** (4) (2001) 489–506.
7. U. S. Bititci and A. S. Carrie, *Strategic Management of the Manufacturing Value Chain*. (Kluwer, Netherlands, 1998).
8. Taiwan MOTC, Telecommunications Act (2003), http://www.dgt.gov.tw/English/Regulations/TelecommunicationsAct.Shtml.
9. International Telecommunications Union (ITU), Reinventing Telecoms, Executive Summary, *World Telecommunication Development Report*, (2002) 4–11.
10. G. R. Faulhaber, Policy-induced competition: the telecommunications experiments, *Information Economics and Policy* **15**(1) (2003) 73–97.
11. NASA, *PATTERN relevance guide* (3 vols.), National Technical Information Service. U.S. Department of Commerce, Springfield, Virginia (1965).
12. NASA, *PATTERN procedure manual*, Honeywell Aero Report, National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia, (1966).
13. G. H. Tzeng and T. A. Shiau, Energy conservation strategies in urban transportation: Application of multiple criteria decision-making, *Energy Systems and Policy* **11**(1) (1987) 1–19.
14. DGT (2003), *Telecommunications Policy White Paper*, published by the DGT, MOTC in Taiwan.
15. DGT (2001), *Telecommunications Policy White Paper*, published by the DGT, MOTC in Taiwan.
16. DGT (2004), *Telecommunications Policy White Paper*, published by the DGT, MOTC in Taiwan.
17. S. Wallsten, An econometric analysis of telecom competition, privatization, and regulation in Africa and Latin America, *Journal of Industrial Economics* **49**(1) (2001) 1–20.
18. M. Secker, The Right MVNO Cocktail? – View from the Top, *Telecommunications International* (2002), http://www.findarticles.com/p/articles/mi_m0IUL/is_5_36/ai_86648880.
19. R. E. Bellman and L. A. Zadeh, Decision-making in a fuzzy environment, *Management Science* **17**(4) (1970) 141–164.
20. P. L. Yu, *Forming winning strategies: An integrated theory of habitual domains*. (Springer-Verlag, New York, 1990).

21. P. L. Yu, *Habitual Domains: Freeing Yourself from the Limits on Your Life*. (Highwater Editions, KS, 1995).
22. J. J. Buckley, Fuzzy Hierarchical Analysis, *Fuzzy Sets and Systems* **17**(3) (1985) 233–247.
23. T. L. Saaty, *The Analytic Hierarchy Process*. (McGraw-Hall, New York**,** 1980).
24. L. A. Zadeh, Fuzzy Logic = Computing with Words, *IEEE Transaction on Fuzzy Systems*, **4**(2) (1996) 103–111.
25. W. Pedrycz, Why triangular membership functions?, *Fuzzy Sets and Systems* **64**(1) (1994) 21–30.
26. R. Zhao and R. Govind, Algebraic Characteristics of Extended Fuzzy Numbers, *Information Science* **54**(1) (1991) 103–130.
27. S. H. Tsaur, G. H. Tzeng and G. C. Wang, The Application of AHP and Fuzzy MCDM on the Evaluation Study of Tourist Risk, *Annals of Tourism Research* **24**(4) (1997) 796–812.
28. G. H. Tzeng and S. H. Tsaur, Application of multiple criteria decision making for network improvement plan model, *Journal of Advanced Transportation* **31**(1) (1999) 49–74.
29. S. Opricovic and G. H. Tzeng, Defuzzification within a multicriteria decision model, *International Journal of Uncertainty, Fuzziness and Knowledge-based Systems* **11**(5) (2003) 635–652.
30. L. A. Zadeh, Fuzzy Sets, *Information and control* **8**(3) (1965) 338–353.
31. C. Yang, G. L. Fu and G. H. Tzeng, Creating a win-win in the telecommunications industry: the relationship between MVNOs and MNOs in Taiwan, *Canadian Journal of Administrative Sciences* **22**(4) (2005) 316–328.
32. P. J. M. Laarhoven and W. Pedrycz, A fuzzy extension of Saaty's priority theory, *Fuzzy Sets and Systems* **11**(3) (1983) 229–227.
33. S. J. Chen and C. L. Hwang, Fuzzy multiple attribute decision making: methods and applications, in *Lecture Notes in Economics and Mathematical Systems*, eds. S. J. Chen and C. L. Hwang and Frank P. Hwang (Springer-Verlag, New York, 1992).