



Using a fuzzy multi-criteria decision making approach to evaluate alternative licensing mechanisms

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Abstract

Selecting a licensing policy for third-generation (3G) mobile communications services in Taiwan will have a profound impact on the government's fiscal income, the advancement of domestic telecommunications technologies and services, and the potential return on investment for 3G licensees. Evaluation criteria should include satisfying multi-goals. The top-level goals are set to satisfy requirements of the government, consumers, and need for competence of the operators. Under each of these three first-tier goals, four second-tier evaluation criteria may be used to assess to what extent the first-tier goals are satisfied. Scholars and experts in the Taiwan telecommunications arena were surveyed to determine their preferences between pairs of evaluation criteria. Additionally, they were asked to estimate the utility scores of each criteria achieved by alternative licensing policies. Fuzzy multi-criteria decision making (MCDM) methodology was then used to evaluate four 3G licensing policies in Taiwan, including: auction, beauty contest, tender, and beauty contest with fixed license fee. The survey results revealed the views and preferences of experts with different backgrounds. The methodology and experience presented in this study could serve as a reference for telecom regulators in constructing their 3G licensing policies.

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1. Introduction

In the past, telecommunication services were mostly state owned and operated. This was necessary because of the huge investment required to construct a nationwide telecommunications network; also it is easier to ensure equipment compatibility and interoperability among telecommunications systems if they are operated by a single telecommunications operator. However, in the past two decades, interna-

tional standards bodies have established communications protocols and interface standards; these have opened up the telecommunications equipment market to competition. As interoperable telecommunications equipment is readily available, independently operated networks can make up a nationwide network. This has further opened up the telecom marketplace. As the networks start to be operated by private enterprises, they are subject to competition, which usually results in improvements in service quality and operational efficiency. The mobile communications market provides a good proof of this trend of liberalization.

The Directory General of Telecommunications (DGT) in Taiwan decided to award five 3G licenses

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in the end of 2001. The challenge of selecting a 3G licensing mechanism falls into satisfying multiple objectives. This study used a multi-criteria decision making model to evaluate alternative mechanisms. Experts in the Taiwan telecommunications arena were surveyed to provide input to this model.

Until recently, there was very little literature about the models/methodologies that could be used to select telecom licensing policies. Only expert opinions or government policies on this subject were available. The purpose of this study was to demonstrate the effectiveness of using an MCDM to evaluate 3G licensing mechanisms.

2. Alternative 3G licensing mechanisms

2.1. Descriptions of 3G licensing mechanisms

Alternative 3G licensing mechanisms used by different countries can be classified into four categories:

2.1.1. The auction mechanism

In this, 3G licenses are awarded to contenders with the highest bids. Under a multiple-round bidding system, every contender feels pressure from each other. Often this results in extraordinarily high bids. If a country adopts the auction mechanism, it usually does not levy annual 3G permit fees or frequency usage fees.

2.1.2. The beauty contest mechanism

For this, a selection committee evaluates each of the contender's potential contribution to society, benefits to service subscribers, fulfillment of government objectives, etc. The 3G licensees in Taiwan would pay 2% of their annual revenue as the 3G-permit fee in addition to the frequency usage fee. Since the 3G-permit fee is directly proportional to the revenue, income to the government would increase as the 3G businesses expand. The Taiwan frequency usage fee is related to the bandwidth used and the number of subscribers; it would also increase as the 3G business grows. The biggest criticism of this licensing mechanism is the concern that the selection committee might not be completely objective and impartial when making their decision.

2.1.3. The tender mechanism

With this, the selection committee first screens the qualifications of the contenders. Those that pass the first screening can then enter the bidding process. The bidding may consist of either a single round or multiple rounds. The final bid under single-round bidding will generally be lower than that with multiple-round bidding, because contenders do not have a second chance to topple other contenders' bids. This mechanism generally does not require the operators to pay 3G permit fees or frequency usage fees. The rationales are the same as those in the auction mechanism, because the fees could have been reflected in the bids. The main difference between the "Auction" and "tender" mechanisms is that the former does not screen contenders and there are multiple rounds of bidding, while the latter does screen contenders and there is generally a single round of bidding.

2.1.4. The beauty contest with fixed fee mechanism

This mechanism uses a selection committee to decide the candidate licensees who will pay a fixed 3G-license fee to the government. As in the beauty contest mechanism, the licensees must still pay annual 3G permit and frequency usage fees. This system is, however, different from the beauty contest system in that the former needs to pay a license fee while the latter does not.

2.1.5. The fees for each mechanism

The major differences among the four 3G licensing mechanisms lie in how selection decisions are made and the different kinds of fees that each has to render during the 15-year license period. Some fees are due when the 3G licenses are awarded and others are annual recurrent fees. The unpredictability of the bid result is due to competition among auction contenders. The license fee, the 3G-permit fee, and the frequency usage fee are either a fixed amount mandated by the government or can be calculated from the equations in the rate structure, which increase only when the 3G business grows. These fees have much less risk than auction bids. Fees that different governments collect under the different 3G licensing mechanisms are illustrated in Table 1.

2.2. Comparison of 3G licensing mechanisms

The advantages and disadvantages of the four categories of 3G licensing mechanisms are compared in

Table 1
Government Income from alternative 3G licensing mechanisms

Government income	Licensing mechanism			
	Auction	Tender	Beauty contest with fixed fee	Beauty contest
Auction bid	Yes	Yes	No	No
License fee	No	No	Yes	No
3G permit fee	No	Yes	Yes	Yes
Frequency usage fee	No	No ^a	Yes	Yes
Sales tax	Yes	Yes	Yes	Yes
Income tax	Yes	Yes	Yes	Yes

^a Taiwan DGT adopted the tender policy; however, the operators are required to pay the annual frequency usage fees.

Table 2. The selection of a 3G licensing mechanism will have a profound influence, not only on consumers and 3G operators, but also on the domestic mobile telecommunications industry.

3. Constructing a multi-criteria decision-making model

3.1. The model

When making a multi-objective decision, its impact on multiple dimensions must be considered [3]. Each dimension has its own multiple evaluation criteria, which form a hierarchical multi-tier problem structure [4]. Many scholars use the Analytic Hierarchy Process (AHP) method [7,8] to deal with strategy selection problems. A fuzzy notion was introduced into the AHP method [2,6,9,10]. Instead of asking the survey respondents to select a specific utility score, this notion allows a range of utility scores; this was used to study the marketing strategies of the information service industry [11] and to analyze the strategy choices of IC companies in Taiwan [5]. Here, we use the fuzzy AHP method to select multi-criteria 3G licensing strategies.

We learned why different countries chose one 3G licensing mechanism over others and brainstormed with domestic regulators/scholars in the telecommunications arena to determine what is expected from a good 3G licensing mechanism. Then, we decided on the three top-level goals that a 3G licensing mechanism must accomplish.

Under government goals, we defined four evaluation criteria that can be used to measure to what extent the goal is satisfied: (1) whether 3G licensing gen-

erates significant fiscal income; (2) whether the 3G spectrum is utilized effectively; (3) whether the licensee selection process is fair and impartial; and (4) whether the result of 3G licensing can benefit Taiwan's domestic telecommunications industry.

Under consumer goals, we also defined four evaluation criteria: (1) whether the quality of 3G services is good; (2) whether the tariff of 3G services is reasonable; (3) whether the functions of 3G services are useful; and (4) whether 3G services can be deployed quickly and widely.

Under the goal of selecting competent operators, we defined four evaluation criteria: (1) whether the operators have the financial capabilities; (2) whether the operators have the technical capabilities; (3) whether the operators have the management capabilities to operate 3G businesses successfully; and (4) whether the operators can cope with foreign competition.

A multi-criteria decision-making model with three first-tier goals, and four second-tier evaluation criteria is shown in Fig. 1.

3.2. Solution to this multi-criteria decision-making model

We use the MCDM model to evaluate four 3G licensing mechanisms to determine how well each of them to meet the 12 criteria.

We convened five groups of experts in Taiwan; they are the most knowledgeable in 3G technologies and services. These included telecom service operators; telecom equipment manufacturers; scholars in telecommunications engineering; scholars in non-technical fields such as management, economics, and law; and government officials and researchers.

Table 2
A comparison of the advantages and disadvantages of 3G licensing mechanisms

Licensing Mechanism	Advantages	Disadvantages	Suggestions and Supporting Regulations
Auction	<p>Free market decides the value of 3G license</p> <p>Spectrum resource is utilized effectively Generates substantial income for government</p> <p>Attracts foreign investment and technology inflow</p> <p>Improves Taiwan's image in telecommunications liberalization</p>	<p>Operator's financial burden and operational costs are high</p> <p>Impedes the development of 3G services Cost structure is higher than that of 2G operation. 3G is at a disadvantage in competing against 2G Higher costs result in a higher tariff to consumers</p> <p>Unable to support domestic telecommunications industry If 3G prospers beyond expectations, government income cannot increase Is difficult to maintain objectivity and impartiality in the selection process</p>	<p>Auction based on promise of a percentage of future 3G revenue instead of a fixed payment of cash could reduce operators' risk. Auction price is paid over the license period There should be a security deposit for auction participants</p> <p>Auction winners should be allowed to sell or lease their 3G frequencies to other parties.</p>
Beauty contest	<p>3G permit and frequency usage fees could be adjusted with reference to 3G profitability and license fees paid License fee could be determined by a panel of manufacturers, officials, scholars, researchers, and other experts Could require 3G licensees to meet specific targets and requirements</p>	<p>Does not reflect the market value of the 3G spectrum</p> <p>Criteria and fairness of the selection process may be challenged</p>	<p>Establishes open and fair selection procedure</p> <p>3G permit fees and frequency usage fees could be adjusted with reference to 3G profitability Extra credit could go to applicants who purchase equipment from domestic manufacturers Require 3G licensees to meet specific targets and requirements</p>
Tender	<p>Operator's financial burden is lower than that of auction policy</p> <p>Has advantages of beauty contest and the fairness in selection of auction Minimizes resource depletion</p> <p>Facilitates government policy implementation (e.g., sharing of base station and antenna facilities) License fees also generate significant income to government Government can support domestic telecom industry Minimizes operator's uncertainty risks</p>	<p>Difficult to maintain objectivity and impartiality in the selection process</p> <p>Unable to assess a 3G license's true market value</p> <p>Criteria and fairness of the selection process may be challenged</p>	<p>3G permit and frequency usage fees could be adjusted with reference to its profitability and license fees. License fee should be determined by a panel of manufacturers, officials, scholars, etc. Require 3G licensees to meet specific targets and requirements</p>
Beauty contest with fixed license fee	<p>Has most of the advantages of beauty contest License fees also generate income to government Government can support domestic telecom manufacturers Fixed license fee causes no risk of uncertainty to operators</p>	<p>Has similar disadvantages to beauty contest but to a lesser extent If the license fee is too high, it could still impede the operators' investment in 3G</p>	<p>The license fee should be determined by an impartial panel Adopt similar suggestions given for beauty contest</p>

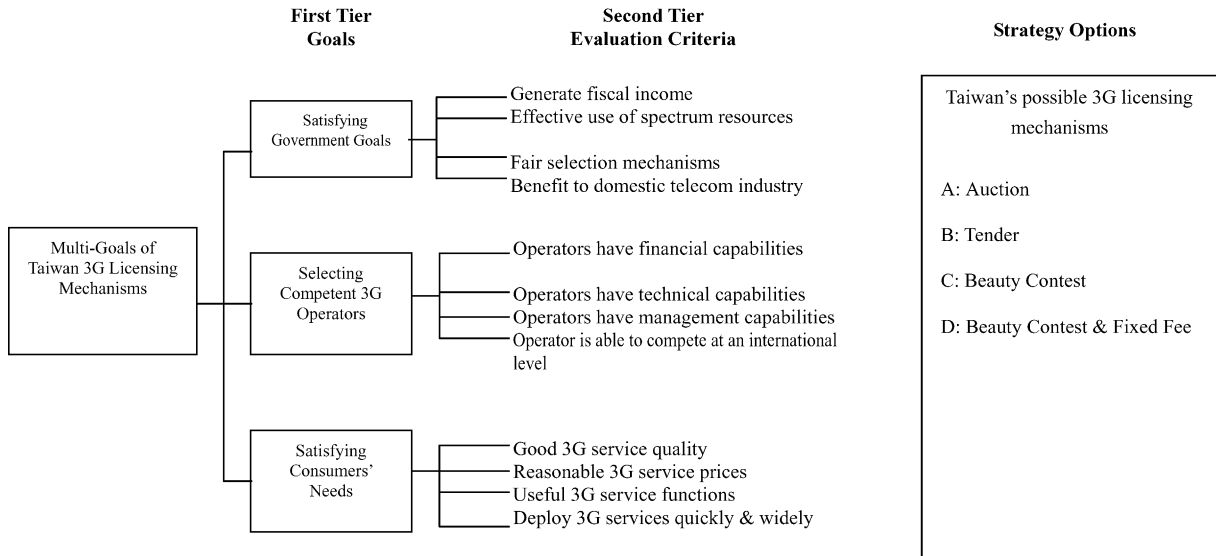


Fig. 1. A multi-criteria decision-making model for evaluating Taiwan 3G licensing mechanisms.

In the survey, we asked subject n of survey group i about his/her perception of the ratios of relative importance between pairs of the twelve multi-criteria. A set of twelve weighting factors associated with the twelve multi-criteria can therefore be derived as follow:

Let \vec{V}_n be the vector of weighting factors of subject n in group i

$$\vec{V}_n = (v_{n1}, v_{n2}, \dots, v_{n12}) \tag{1}$$

where v_{nj} is the weighting factor for the j th evaluation criterion by subject n . Averaging \vec{V}_n among all subjects within group i generates an overall set of weighting factors for group i . Assume there are N_i subjects in group i .

Let \vec{W}_i be the vector of weighting factors of survey group i .

$$\vec{W}_i = \sum_{n=1}^{n=N_i} \frac{\vec{V}_n}{N_i} \tag{2}$$

$$\vec{W}_i = (w_{i1}, w_{i2}, \dots, w_{i12}) \tag{3}$$

where w_{ij} is the weighting factor for the j th evaluation criterion by the i th group. We repeated this process for each of the five groups.

For the four 3G licensing mechanisms, we wish to derive, from each subject, a utility score that represent

the level of satisfaction for each of the twelve multi-criteria. We asked each subject to select one out of five linguistic variables from: “very highly effective”, “highly effective”, “fairly effective”, “low effective”, and “very low effective” as a way to measure the level of satisfaction for a criterion. Because the perception or the interpretation of these linguistic variables is likely to be different for each subject, this study used the notion of triangular fuzzy numbers (TFN) to represent each survey subject’s perception of the linguistic variables [1]. We asked each survey subject to assign a fuzzy range of utility scores between 0 and 100 with lower estimate LE, medium estimate ME, and Upper estimate UE. We adopted the Center of Area (COA) method [12,13] to convert the fuzzy range of utility scores to a non-fuzzy utility score (NFUS). We used the following method: The utility scores constitute a 12×4 matrix \vec{S}_n , where s_{nj}^k is the utility score of the j th evaluation criterion for licensing mechanism k by user n .

$$\vec{S}_n = \begin{bmatrix} s_{n1}^A & s_{n1}^B & s_{n1}^C & s_{n1}^D \\ s_{n2}^A & s_{n2}^B & s_{n2}^C & s_{n2}^D \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ s_{n12}^A & s_{n12}^B & s_{n12}^C & s_{n12}^D \end{bmatrix} \tag{4}$$

The utility score matrix \vec{S}_n of subject n will be multiplied by the vector of weighting factors of its group, \vec{W}_i , to get \vec{U}_n , where u_n^k is the utility score weighted by the weighting factors of group i for licensing mechanism k by subject n .

$$\vec{U}_n = \vec{W}_i \times \vec{S}_n = (u_n^A, u_n^B, u_n^C, u_n^D) \quad (5)$$

Averaging \vec{U}_n among all subjects within group i generates an overall set of utility scores T_i ,

$$\vec{T}_i = \sum_{n=1}^{n=N_i} \frac{\vec{U}_n}{N_i} = (t_i^A, t_i^B, t_i^C, t_i^D) \quad (6)$$

where t_i^A is the utility score of licensing mechanism k by group i . The licensing mechanism with the highest utility score is the most favored licensing mechanism by that subject.

The survey experts' opinions about 3G licensing mechanisms will provide valuable references to Taiwan DGT with respect to selecting a licensing mechanism for 3G services.

4. Evaluation results of the MCMD model

Ideal survey candidates for evaluating 3G licensing mechanisms are people who are familiar with the subject. The background or sources of the survey candidates included:

1. The National Telecommunications Project Office of Taiwan keeps a correspondence database of over 200 e-mail addresses of people who constantly receive a bi-weekly newsletter concerning the latest telecommunications developments from the project office. This group consisted of specialists in every field of telecommunications in Taiwan, e.g., operators, manufacturers, government officials, scholars, and researchers.
2. A total of 35 professors of telecommunications engineering from National Taiwan University and National Chiao-Tung University.
3. A group of 20 of professors in industrial economics, management, law, and regulatory policy.
4. Ten selected experts in the telecommunications industry.
5. Thirty-five members from the Bell Laboratory Alumni Club in Taiwan.

This survey was intended to be comprehensive and cover most perspectives of every relevant types of experts in 3G licensing. Although some people might have received duplicate questionnaires from more than once source, they responded only once. We received 76 responses with 7 discarded because they were incomplete, so 69 were complete and acceptable resulting in a 23% return rate.

Among the 69 survey respondents, 18 were from the telecom manufacturing sector; 15 were from the telecom service sector; 10 were university professors from non-technical areas; 9 were university professors in telecommunications engineering departments, and the remaining 17 were from government, research, and other organizations. In addition to assessing the preferred 3G licensing mechanism for each of the five groups, the preferences of all the survey respondents as a whole was also studied. Based on the survey responses a fuzzy MCDM model was constructed.

4.1. Opinion of the telecom manufacturers group

4.1.1. Weighting factors

The manufacturers surveyed included domestic and international manufacturers in Taiwan. The weighting factors for the first-tier goals are: (1) the goal of satisfying consumers' needs (0.527); (2) the goal of selecting competent operators (0.276); and (3) The goal of reaching government objectives (0.107). The importance of satisfying consumers' needs was five times higher than that of reaching government objectives. The priorities of the evaluation criteria used to measure how well customers' needs are satisfied are: (1) deploying 3G services quickly & widely (0.317); (2) having a reasonable 3G service tariff (0.242); (3) having good 3G service quality (0.241); and (4) having useful 3G functions (0.201). The weighting factors of the 12 evaluation criteria for the telecom manufacturers group are shown in Table 3.

In order to reach the goal of selecting competent 3G operators, telecom manufacturers place the greatest importance on the management's ability to run a successful 3G business. Regarding reaching the goal of satisfying government's objectives, telecom manufacturers place the greatest importance on the ability to benefit Taiwan's domestic telecommunications industry.

Table 3
Weighting factors by telecom manufacturers group

Goals	Evaluation criteria		
	Weighting factors of goals	Weighting factors of evaluation criteria within a goal	Weighting factors of evaluation criteria across goals
The goal of reaching government objectives	0.107		
Generate a significant amount of fiscal income		0.210 (2)	0.041 (11)
Effective use of spectrum resources		0.207 (3)	0.042 (10)
Fair and impartial licensee selection procedures		0.185 (4)	0.037 (12)
Benefit to domestic telecommunications industry		0.397 (1)	0.078 (6)
The goal of selecting competent operators	0.276		
Financial capability of operators		0.216 (2)	0.061 (7)
Technical capability of operators		0.212 (4)	0.059 (9)
Management capability of operators		0.356 (1)	0.098 (5)
Ability to cope with foreign competition		0.216 (3)	0.060 (8)
The goal of satisfying consumers' needs	0.527		
Good 3G Service quality		0.241 (3)	0.127 (2)
Reasonable 3G service tariff		0.242 (2)	0.128 (3)
Useful 3G service functions		0.201 (4)	0.105 (4)
Deploy 3G services quickly & widely		0.317 (1)	0.167 (1)

Note: The numbers in parentheses represent the order of importance.

4.1.2. Utility scores of four licensing mechanisms

The vector of weighting factors by the telecom manufacturers group is denoted as \vec{W}_1 :

$$\vec{W}_1 = (0.041, 0.042, 0.037, 0.078, 0.061, 0.059, 0.098, 0.060, 0.127, 0.128, 0.105, 0.167)$$

If we multiply \vec{W}_1 by the score matrix \vec{S}_n of subject n in the telecom manufacturers group, it is possible to calculate the utility scores of the four licensing mechanisms for subject n . Averaging the utility scores of the four licensing mechanisms by all survey subjects in the telecom manufacturers group, we may derive the group's utility scores for each of the licensing mechanisms listed in Table 4.

Table 4
Utility scores by telecommunication manufacturers group

3G licensing mechanisms	Utility scores (rankings)
A. Auction	49.2 (4)
B. Tender	59.7 (2)
C. Beauty contest	60.9 (1)
D. Beauty contest with fixed fee	53.9 (3)

4.1.3. Opinion on alternative licensing mechanisms

The telecom manufacturer group rated beauty contest the highest, with tender second, beauty contest with fixed fees third, and auction last. Choosing the beauty contest mechanism, which does not need to pay a high bid price or license fee to the government at the beginning of 3G operation, reflects telecom manufacturers' concern that a high auction bid or high 3G license fee will jeopardize 3G operators' financial capability to invest in and operate 3G services.

4.2. Opinion of the telecom operators group

4.2.1. Weighting factors

The telecom operators here included mobile and fixed-line operators in Taiwan. The weighting factors for the first-tier goals are: (1) satisfying consumers' needs (0.516); (2) selecting competent operators (0.296); and (3) reaching government objectives (0.189). Thus the importance of satisfying consumers' needs is greater than the combined importance of the other two goals. The priorities of the evaluation criteria used to measure how customers' needs are

Table 5
Weighting factors by telecom operators group

Goals	Evaluation criteria		
	Weighting factors of goals	Weighting factors of evaluation criteria within a goal	Weighting factors of evaluation criteria across goals
The goal of reaching government objectives	0.189		
Generate a significant amount of fiscal income		0.091 (4)	0.017 (12)
Effective use of spectrum resources		0.287 (3)	0.054 (11)
Fair and impartial licensee selection procedures		0.310 (2)	0.058 (10)
Benefit to domestic telecommunications industry		0.311 (1)	0.059 (9)
The goal of selecting competent operators	0.296		
Financial capability of operators		0.228 (3)	0.068 (7)
Technical capability of operators		0.216 (4)	0.064 (8)
Management capability of operators		0.275 (2)	0.081 (6)
Ability to cope with foreign competition		0.279 (1)	0.083 (5)
The goal of satisfying consumers' needs	0.516		
Good 3G Service quality		0.306 (1)	0.158 (1)
Reasonable 3G service tariff		0.230 (3)	0.119 (3)
Useful 3G service functions		0.266 (2)	0.137 (2)
Deploy 3G services quickly & widely		0.197 (4)	0.102 (4)

satisfied are: (1) 3G services have good quality (0.306); (2) 3G services have useful functions (0.266); (3) 3G services are reasonably priced (0.230); and (4) deploying 3G services quickly & widely (0.197). The weighting factors of the twelve evaluation criteria for the telecom operators group are listed in Table 5.

In order to meet the goal of selecting competent 3G operators, existing telecom operators value their ability to cope with foreign competition the most. They value this because Taiwan is about to join the WTO, and therefore the domestic telecommunications market shall be open to international telecom operators. Regarding reaching government objectives, telecom operators deem benefiting Taiwan's domestic telecom industry the most important criterion.

4.2.2. Utility scores of the four licensing mechanisms

The vector of weighting factors by telecom operators group is denoted as \vec{W}_{II} :

$$\vec{W}_{II} = (0.017, 0.054, 0.058, 0.059, 0.068, 0.064, 0.081, 0.083, 0.158, 0.119, 0.137, 0.102)$$

When we multiply \vec{W}_{II} by the score matrix \vec{S}_n of subject n in the telecom operators group, we can

calculate the utility scores of the four licensing mechanisms by subject n . Averaging the utility scores of the four licensing mechanisms by all survey subjects in the telecom operators group, we may derive this survey group's utility scores for each of the four licensing mechanisms, see Table 6.

4.2.3. Opinion on alternative licensing mechanisms

The telecom operators group rated beauty contest the highest, beauty contest with fixed fees second, tender third, and auction last. The utility score of auction is only 38.42, which is well below those of the other three licensing mechanisms. This shows that Taiwan telecom operators are very concerned about the negative impact caused by potentially high auction bids.

Table 6
Utility scores by telecom operators group

3G licensing mechanisms	Utility scores (rankings)
A. Auction	38.4 (4)
B. Tender	61.4 (3)
C. Beauty contest	69.2 (1)
D. Beauty contest with fixed fee	64.1 (2)

4.3. Opinion of the non-technical scholars group

4.3.1. Weighting factors

The non-technical scholars surveyed in this study included university professors in the field of management, law, and economics, etc. The weighting factors for the first-tier goals are: (1) satisfying consumers' needs (0.582); (2) selecting competent operators (0.260); and (3) reaching government objectives (0.157). The importance of satisfying consumers' needs is twice as important as the goal of selecting competent operators and almost four times as important as the goal of reaching government objectives. The priorities of the evaluation criteria used to measure how customers' needs are satisfied are: (1) 3G services have good quality (0.391); (2) 3G services are reasonably priced (0.262); (3) 3G services have useful functions (0.212); and (4) Deploy 3G services quickly & widely (0.135). The weighting factors of the twelve evaluation criteria for the non-technical scholars group are listed in Table 7.

In order to meet the goal of selecting competent 3G operators, non-technical scholars most value management capability to operate a successful 3G business. Regarding reaching the goal of satisfying government objectives, the non-technical scholars also deem ben-

efiting domestic telecom industry the most important criterion.

4.3.2. Utility scores of the four licensing mechanisms

The vector of weighting factors by non-technical scholar group is denoted as \vec{W}_{III} :

$$\vec{W}_{III} = (0.021, 0.049, 0.034, 0.054, 0.044, 0.056, 0.084, 0.075, 0.228, 0.153, 0.124, 0.079)$$

When we multiply \vec{W}_{III} by the score matrix \vec{S}_n of subject n for the non-technical scholars group, we can calculate the utility scores of the four licensing mechanisms by subject n . Averaging the utility scores of the four licensing mechanisms by all survey subjects in the non-technical scholars group, we may derive this survey group's utility scores of the four licensing mechanisms, see Table 8.

4.3.3. Opinion on alternative licensing mechanisms

The non-technical scholars group rated beauty contest the highest, beauty contest with fixed fees second, tender third, and auction last. The utility score of auction is substantially below those of the other three licensing mechanisms and shows that

Table 7
Weighting factors by non-technical scholars group

Goals	Evaluation criteria		
	Weighting factors of goals	Weighting factors of evaluation criteria within a goal	Weighting factors of evaluation criteria across goals
The goal of reaching government objectives	0.157		
Generate a significant amount of fiscal income		0.132 (4)	0.021 (12)
Effective use of spectrum resources		0.312 (2)	0.049 (9)
Fair and impartial licensee selection procedures		0.213 (3)	0.034 (11)
Benefit to domestic telecommunications industry		0.346 (1)	0.054 (8)
The goal of selecting competent operators	0.260		
Financial capability of operators		0.169 (4)	0.044 (10)
Technical capability of operators		0.215 (3)	0.056 (7)
Management capability of operators		0.324 (1)	0.084 (4)
Ability to cope with foreign competition		0.290 (2)	0.075 (6)
The goal of satisfying consumers' needs	0.582		
Good 3G Service quality		0.391 (1)	0.228 (1)
Reasonable 3G service tariff		0.262 (2)	0.153 (2)
Useful 3G service functions		0.212 (3)	0.124 (3)
Deploy 3G services quickly & widely		0.135 (4)	0.079 (5)

Table 8
Utility scores by non-technical scholars group

3G licensing mechanisms	Utility scores (rankings)
A. Auction	55.6 (4)
B. Tender	68.8 (3)
C. Beauty contest	71.5 (1)
D. Beauty contest with fixed fee	69.2 (2)

non-technical scholars are very concerned about the negative impact, which may be caused by potentially high auction bids.

4.4. Opinion of technical scholars group

4.4.1. Weighting factors by technical scholars group

The technical scholars included university professors in the fields of telecommunications and electrical engineering. The weighting factors for the first-tier goals are: (1) satisfying consumers' needs (0.571); (2) selecting competent operators (0.233); and (3) reaching government's objectives (0.169). The importance of satisfying consumers' needs is much higher than the other two. The priorities of the evaluation criteria used to measure how customers' needs are satisfied are: (1) 3G services have useful functions (0.310); (2) 3G

services have good quality (0.274); (3) 3G services are reasonably priced (0.249); and (4) deploy 3G services quickly & widely (0.165). The weighting factors of the twelve evaluation criteria for the technical scholars group are shown in Table 9.

In order to meet the goal of selecting competent 3G operators, technical scholars emphasize operators' capability to cope with foreign competition the most. Regarding reaching the goal of satisfying government objectives, the technical scholars put special emphasis on the effective use of spectrum resources as most important (Table 9).

4.4.2. Utility scores of four licensing mechanisms

The vector of weighting factors by technical scholars group is denoted as \vec{W}_{IV} :

$$\vec{W}_{IV} = (0.031, 0.070, 0.049, 0.047, 0.048, 0.061, 0.055, 0.069, 0.157, 0.142, 0.177, 0.094)$$

When we multiply \vec{W}_{IV} by the score matrix \vec{S}_n subject n in the technical scholars group, we can calculate the utility scores of the four licensing mechanisms by subject n . Averaging the utility scores of the four licensing mechanisms by all survey subjects in the technical scholars group, we may derive

Table 9
Weighting factors by technical scholars group

Goals	Evaluation criteria		
	Weighting factors of goals	Weighting factors of evaluation criteria within a goal	Weighting factors of evaluation criteria across goals
The goal of reaching government objectives	0.169		
Generate a significant amount of fiscal income		0.158 (4)	0.031 (12)
Effective use of spectrum resources		0.360 (1)	0.070 (5)
Fair and impartial licensee selection procedures		0.246 (2)	0.049 (9)
Benefit to domestic telecommunications industry		0.238 (3)	0.047 (11)
The goal of selecting competent operators	0.233		
Financial capability of operators		0.206 (4)	0.048 (10)
Technical capability of operators		0.261 (2)	0.061 (7)
Management capability of operators		0.237 (3)	0.055 (8)
Ability to cope with foreign competition		0.297 (1)	0.069 (6)
The goal of satisfying consumers' needs	0.571		
Good 3G service quality		0.274 (2)	0.157 (2)
Reasonable 3G service tariff		0.249 (3)	0.142 (3)
Useful 3G service functions		0.310 (1)	0.177 (1)
Deploy 3G services quickly & widely		0.165 (4)	0.094 (4)

Table 10
Utility scores by technical scholars group

3G licensing mechanisms	Utility scores (rankings)
A. Auction	63.6 (2)
B. Tender	65.7 (1)
C. Beauty contest	62.1 (4)
D. Beauty contest with fixed fee	62.5 (3)

this survey group’s utility scores of the four licensing mechanisms, see Table 10.

4.4.3. *Opinion on alternative licensing mechanisms*

The technical scholars group rated tender the highest, auction second, beauty contest with fixed fees third, and beauty contest last. Although the utility scores of the four licensing mechanisms are quite close, the survey results show that the technical scholars are very skeptical of the fairness and impartiality in the decision-making process of a selection committee in the beauty contest mechanism.

4.5. *Opinion of the undesignated survey group*

4.5.1. *Weighting factors*

All survey respondents who do not belong to the previous four groups were placed into the undesignated

group, which therefore consists of government regulators, researchers, etc. The weighting factors for the three first-tier goals are: (1) satisfying consumers’ needs (0.422); (2) selecting competent operators (0.294); and (3) reaching government objectives (0.283). The priorities of the evaluation criteria used to measure how customers’ needs are satisfied are: (1) 3G services have good quality (0.297); (2) 3G services are reasonably priced (0.294); (3) 3G services have useful functions (0.237); and (4) deploy 3G services quickly & widely (0.173). The weighting factors of the twelve evaluation criteria for the undesignated group are in Table 11.

In order to meet the goal of selecting competent 3G operators, the undesignated group places the most importance on operators’ capability to cope with foreign competition. Regarding reaching the goal of satisfying government objectives, the undesignated group emphasizes the effective use of spectrum resources as the most important criterion.

4.5.2. *Utility scores of four licensing mechanisms*

The vector of weighting factors by the undesignated group is denoted as \vec{W}_V :

$$\vec{W}_V = (0.031, 0.070, 0.048, 0.047, 0.056, 0.071, 0.072, 0.096, 0.125, 0.124, 0.101, 0.073)$$

Table 11
Weighting factors by the undesignated group

Goals	Evaluation criteria		
	Weighting factors of goals	Weighting factors of evaluation criteria within a goal	Weighting factors of evaluation criteria across goals
The goal of reaching government objectives	0.283		
Generate a significant amount of fiscal income		0.250 (2)	0.031 (12)
Effective use of spectrum resources		0.388 (1)	0.070 (8)
Fair and impartial licensee selection procedures		0.205 (3)	0.048 (10)
Benefit to domestic telecommunications industry		0.157 (4)	0.047 (11)
The goal of selecting competent operators	0.294		
Financial capability of operators		0.190 (4)	0.056 (9)
Technical capability of operators		0.243 (2)	0.071 (7)
Management capability of operators		0.241 (3)	0.072 (6)
Ability to cope with foreign competition		0.326 (1)	0.096 (4)
The goal of satisfying consumers’ needs	0.422		
Good 3G Service quality		0.297 (1)	0.125 (1)
Reasonable 3G service tariff		0.294 (2)	0.124 (2)
Useful 3G service functions		0.237 (3)	0.101 (3)
Deploy 3G services quickly & widely		0.173 (4)	0.073 (5)

Table 12
Utility scores by the undesignated group

3G licensing mechanisms	Utility scores (rankings)
A. Auction	45.7 (4)
B. Tender	58.7 (3)
C. Beauty contest	65.3 (1)
D. Beauty contest with fixed fee	65.1 (2)

When we multiply \bar{W}_V by the score matrix \bar{S}_n of subject n in the undesignated group, we can calculate the utility scores of the four licensing mechanisms by subject n . Averaging the utility scores of the four licensing mechanisms by all survey subjects in the undesignated group, we may derive this survey group's utility scores of the four licensing mechanisms, see Table 12.

4.5.3. Opinion on alternative licensing mechanisms

The undesignated group rated beauty contest the highest, beauty contest with fixed fees second, tender third, and auction last. Choosing the beauty contest mechanism, reflects the undesignated respondents' concerns that a high auction bid or high 3G license

fee will jeopardize 3G operators' financial capability to invest in and operate 3G services.

The utility scores of beauty contest and beauty contest with fixed fee are very close and they are higher than those of tender and auction. This shows that survey respondents in the undesignated group favor non-auction type licensing mechanisms to auction type licensing mechanisms.

4.6. The overall opinion of all survey respondents

4.6.1. Weighting factors

All of the survey respondents were finally considered as one group. The weighting factors for the three first-tier goals are then: (1) satisfying consumers' needs (0.521); (2) selecting competent operators (0.270); and (3) reaching government objectives (0.209). The importance of satisfying consumers' needs is greater than the combined importance of the other two. The priorities of the evaluation criteria used to measure how customers' needs are satisfied are: (1) 3G services have good quality (0.291); (2) 3G services are reasonably priced (0.258); (3) 3G services have useful functions (0.239); and (4) deploy 3G services quickly & widely (0.211). The weighting

Table 13
Weighting factors by the group of all survey respondents

Goals	Evaluation criteria		
	Weighting factors of goals	Weighting factors of evaluation criteria within a goal	Weighting factors of evaluation criteria across goals
The Goal of Reaching Government Objectives	0.209		
Generate a significant amount of fiscal income		0.177 (4)	0.037 (12)
Effective use of bandwidth resources		0.314 (1)	0.066 (7)
Fair and impartial licensee selection procedures		0.227 (3)	0.048 (10)
Benefit to domestic telecommunications industry		0.282 (2)	0.059 (9)
The goal of selecting competent operators	0.270		
Financial capability of operators		0.209 (4)	0.057 (11)
Technical capability of operators		0.235 (3)	0.063 (8)
Management capability of operators		0.302 (1)	0.082 (5)
Ability to cope with foreign competition		0.253 (2)	0.068 (6)
The goal of satisfying consumers' needs	0.422		
Good 3G Service quality		0.297 (1)	0.125 (1)
Reasonable 3G service tariff		0.294 (2)	0.124 (2)
Useful 3G service functions		0.237 (3)	0.101 (3)
Deploy 3G service coverage quickly		0.173 (4)	0.073 (5)

Table 14
Utility scores by the group of all survey respondents

3G licensing mechanisms	Utility scores (rankings)
A. Auction	45.9 (4)
B. Tender	57.1 (3)
C. Beauty contest	61.6 (1)
D. Beauty contest with fixed fee	59.1 (2)

factors of the twelve evaluation criteria for the group of all survey respondents are shown in Table 13.

In order to meet the goal of selecting competent 3G operators, the respondents valued management capability to operate 3G services successfully. Survey respondents deem effective use of spectrum resources a most important evaluation criterion.

4.6.2. Utility scores of four licensing mechanisms

The vector of weighting factors by all survey respondents is denoted as \vec{W}_{VI} :

$$\vec{W}_{VI} = (0.037, 0.066, 0.048, 0.059, 0.057, 0.063, 0.082, 0.068, 0.125, 0.124, 0.101, 0.073)$$

The product of \vec{W}_{VI} and the score matrix \vec{S}_n of any subject n calculates the utility scores of the four licensing mechanisms by subject n . Averaging the utility scores of the four licensing mechanisms by all subjects, we may derive the utility scores of the four licensing mechanisms, see Table 14.

4.6.3. Opinion on alternative licensing mechanisms

Overall, the survey respondents rated beauty contest the highest, beauty contest with fixed fee

second, tender third, and auction last. The utility scores of the three former-runner licensing mechanisms are quite close and significantly higher than the utility score of auction. This survey result shows that a majority of survey respondents are not in favor of auction to be Taiwan's 3G licensing mechanism.

5. Conclusions

Selecting 3G licensees is a complex problem involving consumers, operators, and telecom regulators, each of whom have different objectives and interests. We constructed a multi-criteria decision-making model to evaluate four 3G licensing alternatives. The model defines three first-tier goals. Each of these goals has associated evaluation criteria that can be used to measure the level of fulfillment of the goals.

In this study, about 300 experts and scholars in the Taiwan telecommunications arena were surveyed to find out their priorities with respect to these goals and evaluation criteria. The 69 survey respondents can be categorized into five groups.

The opinions of survey respondents in each of the five groups as well as the aggregation of all respondents were analyzed. The utility scores of the four licensing mechanisms are summarized in Table 15.

The key findings from each group of survey respondents are:

1. There is consensus among all survey groups regarding the priorities of the three first-tier goals

Table 15
Utility Scores of Four 3G licensing mechanisms by Six Survey Groups

Survey Groups	3G licensing mechanisms			
	Auction	Tender	Beauty contest	Beauty contest with fixed fees
Telecom manufacturers group	49.2 (4)	59.7 (2)	60.9 (1)	53.9 (3)
Telecom operators group	38.4 (4)	61.4 (3)	69.2 (1)	64.1 (2)
Non-technical scholars group	55.6 (4)	68.8 (3)	71.5 (1)	69.2 (2)
Technical scholars group	63.6 (2)	65.7 (1)	62.1 (4)	62.5 (3)
Undesignated group	45.7 (4)	58.7 (3)	65.3 (1)	65.1 (2)
Group of all survey Respondents	45.9 (4)	57.1 (3)	61.6 (1)	59.1 (2)

Note: The numbers in the parentheses are rankings within the same survey group.

with respect to 3G licensing. The ranking is: (1) satisfying consumers' needs; (2) selecting competent operators; and (3) reaching government objectives. In most cases, the importance of pursuing satisfaction of consumer needs is much higher than that of the other two.

2. Generating a significant amount of fiscal income for the government is considered the least important evaluation criterion. The weighting factor is as low as 0.037 by all survey respondents: all groups ranked it last, except one group ranked it 11th. This clearly shows a consensus in Taiwan's telecommunications arena that contributing to the fiscal income of the government should not be an objective for 3G licensing.
3. All survey groups, except for scholars in telecommunications engineering, are strongly opposed to a multiple-round auction as Taiwan's 3G licensing mechanism. Even for that group, the tender mechanism is preferred.
4. The telecom manufacturers, operators, and non-technical scholars stressed the importance of helping the domestic telecom industry in selecting a 3G licensing mechanism in Taiwan. They favor beauty contest or beauty contest with fixed license fee, because a selection committee could incorporate measures that can benefit the domestic telecom industry in their selection process.
5. Scholars in non-technical fields are more concerned about the operators' management ability to run a successful 3G business while scholars in telecommunications engineering are more concerned about the effective use of the spectrum and are more skeptical of the fairness and impartiality of selection decisions made by members of the selection committee. That is probably why they prefer to rely on the highest bids to award 3G licenses.

This 3G licensing multi-criteria decision-making model has demonstrated its applicability to the evaluation process. It has also revealed the concerns and preferences of experts and scholars in Taiwan's telecommunications arena. The results of this study could serve as a reference for telecommunication authorities.

Auctions of 3G licensing in Europe have generated significant incomes for the government. However, there are arguments that the huge auction fees may negatively impact the ability of mobile operators to invest in 3G infrastructures.

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