Optimal Developing Strategies of Nanotechnology in Taiwan

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ABSTRACT

Since nanotechnology has been applied in various fields, it has attracted enormously worldwide investments. In the meanwhile, according to the reports of US National Science Foundation in 2002, the annual production value of nanotechnology related industries would reach one thousand billion dollars within 10-15 years. Given the bright prospect of nanotechnology in global trend, countries have undertaken numerous studies to catch the opportunity. Facing the competitions from Mainland China, Korea and several other countries, Taiwan government is eyeing on foresight strategies of nanotechnology with traditional industries in order to put effort on maintaining current leading position in the manufacturing sectors. However, Taiwan's nano-companies mostly focus on developing nano-composite products, and most products are still at developing stage or pilot stage. As regards other infrastructure development, the government still lacks an explicit goal and developing policies. Therefore, this research tends to propose an optimal executing order of developing policies in nanotechnology domain. By using the multi-objective compromise optimization method which integrating AHP with TOPSIS, we can conduct a priority of government policies executing. The optimal policies of nanotechnology could be applied by companies as their alternative developing strategies and also commissioned for enhancing the global competitive position of Taiwan.

Keywords: nanotechnology, multi-objective compromise optimization, analytic hierarchy process, government policy

1 INTRODUCTION

Richard Feynman, one of the Nobelists on Physics, firstly proposed the concept of Nanotechnology in 1959. Nano is the one tenth of 10 trillion meter. According to US National Science Foundation reports in 2002, annual production value of Nanotechnology related industries could reach a thousand billion US dollars within 10-15 years. It has attracted huge investments worldwide. Taiwan's Hsinchu Nanotechnology Applied Research Center is listed as one of the major national projects at "Challenge 2008: The Focuses of National Developing Programs" proposed by Taiwanese government. More than 71 million US dollars will be invested during 2003 to 2008. On the other hand, facing the competitions from Mainland China and Korea, as well as the developed countries such as US and Japan who are aggressively enlarging the difference of their technology advantage, Taiwan has to confront the issues how to integrate the nanotechnology with the traditional industries to continue taking the leading position in the global manufacturing.

In this study, we would like to introduce fuzzy hierarchical analytic process with simple additive weighted method to derive the synthetic values with respect to criteria of development strategies for Taiwan's nanotechnology industry. Furthermore, we would employ TOPSIS method to evaluate these proposed strategies.

Thereinafter, fuzzy hierarchical analytic process for multi-criteria decision making problems is introduced in Section 2. The multiobjective compromise optimization method is described in Section 3. The evaluation of emerging industrialized technology and development strategies for nanotechnology industry are demonstrated in Section 4. Finally, some concluding remarks are summarized in Section 5.

2 FUZZY ANYLYTIC HIERARCHY PROCESS

AHP is a popular technique often used to model subjective decision-making processes based on multiple attributes (Saaty, [8,9]). Application of AHP in MCDM environments involves defining a common hierarchy of criteria, specifying pairwise comparisons by members of the group and aggregating those pairwise comparisons for the entire group. Saaty used the principal eigenvector of the comparison matrix to find the comparative weights among the criteria of the hierarchy systems. Here, we employ Buckley's method [2] to derive analytic hierarchy process by allowing fuzzy numbers for the pairwise comparisons, and find the fuzzy weights and fuzzy performance; in this section we briefly review concepts for fuzzy hierarchical evaluation model.

The hierarchical analytic process can decompose a complicated policy decision problem from a higher hierarchy topic into many smaller items for a more quantitative/qualitative analysis. The evaluators must establish a hierarchical system for analysis and evaluation in the multiple criteria decision-making problem. Keeney and Raiffa [5] suggest that five principles must be followed when criteria are being formulated: (1) Completeness, (2) Operationality, (3) Decomposability, (4) Nonredundancy, and (5) Minimum size.

Considering the evaluation of criteria entails diverse and meanings, we cannot assume that each evaluated criterion is of equal importance. Hwang and Yoon [3,4] summarized many methods that can be employed to determine weights such as the eigenvector method, weighted least square method, entropy method, AHP, as well as linear programming techniques for multidimension of analysis preference (LINMAP). However, the selected approach depends on the nature of the problems.

Buckley [2] considered a fuzzy positive reciprocal matrix $\tilde{\mathbf{A}} = [\tilde{a}_{ij}]$, extending the geometric mean technique to define the fuzzy geometric mean of each row $\tilde{r}_i$ and fuzzy weight $\tilde{w}_i$ corresponding to each criterion as follows:

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{im})^{1/m}; \; \tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_m)^{-1} \quad (1)$$

Where $\oplus$ and $\otimes$ express the addition and multiplication operation of fuzzy numbers, respectively [13].

In addition, we request the evaluators choose a performance value for each feasible strategies corresponding to considered criteria based on their subjective judgments. When we determined the criteria weights and performance values of feasible strategies corresponding to criteria, the next step is to aggregate the synthetic value for each strategy. In this study, we utilize the fuzzy geometric mean method to determine the criteria weights and integrate the performance value through participated evaluators. In order to provide easy-to-follow process for MCDM problems, here we simplify the process to conduct the synthetic values employing simple additive weighted method to integrate the criteria weights with performance values for each strategy.

The result of the fuzzy synthetic decision reached by each strategy is a fuzzy number. Therefore, it needs to defuzzify the fuzzy numbers for getting the preferred order of the strategies. In previous works the procedure of defuzzification had to locate the best nonfuzzy performance (BNP) value. Methods of such defuzzified fuzzy ranking generally include three kinds of method, mean of maximal, center of area (COA), and a -cut [11,13]. Utilizing the COA method to determine the BNP is a simple and practical method, the BNP value of the triangular fuzzy number (LR_i, MR_i, UR_i) can be found by as follows:

$$BNP_i = [(UR_i - LR_i) + (MR_i - LR_i)]/3 + LR_i, \forall i \quad (2)$$

3 MULTI-OBJECTIVE COMPROMISE OPTIMIZATION METHOD

With a given reference point, the MCDM problem can then be solved by locating the alternatives or decision points that are the closest to the reference point. Therefore, the problem becomes how to measure the distance to the reference point. Generally, the global criteria method measures the distance by using Minkowski's L_p -metric. The L_p metric defines the distance between two points, f_j and f_j^* (the reference point), in n-dimensional space as:

$$L_p = \left\{ \sum_{j=1}^{k} (f_j^* - f_j)^p \right\}^{1/p}, \text{ where } p \ge 1 \quad (3)$$

Distance L_p $(p = 1, 2, ..., \infty)$ are especially operationally important, the distance L_p decreases as p increase, i.e., $L_1 \ge L_2 \ge \cdots \ge L_\infty$. Specifically, for $p = 1$, it implies equal weights for all these deviations, L_1 called the Manhattan distance; for $p = 2$, it implies that these deviations are weighted proportionately with the largest deviation having the largest weight, L_2 called the Euclidean distance. Ultimately, while $p = \infty$, it implies the largest deviation completely dominates the distance determination, L_∞ usually called the Tchebycheff metric, is the shortest distance in the numerical sense [10]. That is,

$$L_\infty = \max_j \left\{ \left| f_j^* - f_j \right| \middle| j = 1, ..., k \right\} \quad (4)$$

Considering the incommensurability nature among objectives or criteria, Yu and Zeleny [12] normalized the distance family of Eq. (8) to remove the effects of the incommensurability by using the reference point. The distance family then becomes as follows:

$$L_p = \left\{ \sum_{j=1}^{k} \left(\frac{f_j^* - f_j}{f_j^*} \right)^p \right\}^{1/p}, \text{ where } p \ge 1 \quad (5)$$

Hwang and Yoon [3,4] proposed TOPSIS approach to solve multiple attribute decision making problems (MADM) by using the concept of optimal compromise solution. Lai et al. [6] further extended the concept of TOPSIS for MADM problems and developed a methodology for solving multiple objective decision making (MODM) problems. In their study using the normalized distance family from Eq. (10) with the ideal solution being the reference point, the problem as Eq. (8) becomes how to solve the following auxiliary problem:

$$\min_{x \in X} \quad L_p = \left\{ \sum_{j=1}^{k} \left(\frac{f_j^* - f_j}{f_j^* - f_j^-} \right)^p \right\}^{1/p} \quad \text{where } p = 1, 2, ..., \infty \quad (6)$$

where f_j^* is the best value of corresponding j-th criterion, f_j^- is the worst value of corresponding j-th criterion, and $\boldsymbol{f}^* = \left(f_1^*, ..., f_j^*, ..., f_k^* \right)$ is the vector of positive ideal solution, $\boldsymbol{f}^- = \left(f_1^-, ..., f_j^-, ..., f_k^- \right)$ is the vector of negative ideal solution, respectively. The value chosen for p reflects the way of achieving a compromise by minimizing the weighted sum of the deviations of criteria from their respective reference points.

With the concept of optimal compromise solution, the best alternative or decisions of TOPSIS method are those that have the shortest distance from the positive ideal solution as well as have the farthest distance from the negative ideal solution.

The TOPSIS procedure consists of the following steps:

1. Calculate the normalized decision matrix. The normalized value r_{ij} is calculated as:

$$r_{ij} = f_{ij} / \sqrt{\sum_{j=1}^{J} f_{ij}^2}, \quad j = 1,...,k; \; i = 1,..,n \tag{7}$$

2. Calculate the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as:

$$v_{ij} = w_j r_{ij}, \quad j = 1,...,k; \; i = 1,...,n \tag{8}$$

where w_j is the weight of the *j*-th attribute or criterion, and $\sum_{j=1}^{k} w_j = 1$.

3. Determine the ideal and negative-ideal solution.

$$A^* = \{v_1^*, ..., v_k^*\} = \{(\max_j v_{ij} \mid i \in I'), (\min_j v_{ij} \mid i \in I'')\};$$

$$A^- = \{v_1^-, ..., v_k^-\} = \{(\min_j v_{ij} \mid i \in I'), (\max_j v_{ij} \mid i \in I'')\}$$

where I' is associated with benefit criteria, and I'' is associated with cost criteria.

4. Calculate the separation measures, using the k-dimensional Euclidean distance. The separation of each alternative from the positive ideal solution is given as:

$$D_i^* = \sqrt{\sum_{j=1}^{k} (v_{ij} - v_j^*)^2}; \; i = 1,...,n \tag{9}$$

Similarly, the separation from the negative ideal solution is given as:

$$D_i^- = \sqrt{\sum_{j=1}^{k} (v_{ij} - v_j^-)^2}; \; i = 1,...,n \tag{10}$$

5. Calculate the relative closeness to the ideal solution. The relative closeness of the alternative a_i with respect to A^* is defined as:

$$C_i^* = D_i^- / (D_i^* + D_i^-); \; i = 1,...,n \tag{11}$$

Rank the preference order of alternatives based on values of parameter C_i^*.

4 EMPIRICAL CASE

According to the report of technology commercial capability which issued by 3I Group [1], the results indicated that US, Japan, Germany and UK are on the top four in terms of nano-technology industrialization. US got the top three in all areas. Japan and Germany have more advantages than US in electronic and chemical technologies. In Asia, other than Japan, both Taiwan and Korea are among the top five in electronics and manufacturing sectors.

Taiwan's nano-companies mostly focus on developing the nano-composite products, technologies are either from own-developing or from domestic technology transfers. Most products are still at developing stage or pilot stage. The major research institute generating the technology is ITRI, which has had developed products in LCD, LED, Light Storage, IC Packaging, Energy Storage, Chemical and Biotech.

The development strategies of nanotechnology in Taiwan can be structured into three phases. The first phase is the goal, which is the overall objective. The second phase includes nine aspects of industrialized technology for analysis. The last phase includes eight strategic action plans in order to implement the evaluated aspects (Figure 1).

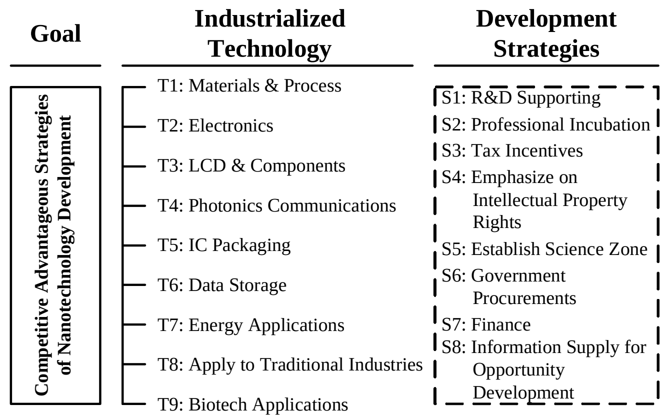

Figure 1: Hierarchical Frame of Evaluation Model

After establishing the hierarchical frame of evaluation model shown in Figure 1, we have 26 participated evaluators supporting this study, nine from industry sector, six from governmental sector, six from academia and five from research institutes. Fuzzy AHP technique utilized to determine the relative weights of considered criteria from evaluators' subjective judgment. The weights from each criterion in the proposed strategy can therefore be determined. We aggregate their own subjective judgments by fuzzy geometric mean method and then conduct the final fuzzy weights, we further utilize fuzzy AHP to derive the aggregated weights of industrialized technology that from subjective judgment of evaluators and then rank the development priority of these technologies, computing the defuzzified BNP values followed that proposed by Opricovic and Tzeng [7] as shown in Table 1.

	Industry Sector		Government Sector		Academic Sector		Research Sector		Aggregation	
	Weigh	Rank	Weigh	Rank	Weigh	Rank	Weigh	Rank	Weigh	Rank
T1	0.159	2	0.204	1	0.204	1	0.195	1	0.189	1
T2	0.113	4	0.093	7	0.117	4	0.060	9	0.096	6
T3	0.167	1	0.106	6	0.114	5	0.158	2	0.138	2
T4	0.100	5	0.120	2	0.067	8	0.065	8	0.089	8
T5	0.119	3	0.066	9	0.107	6	0.073	7	0.092	7
T6	0.090	6	0.116	4	0.132	2	0.111	5	0.111	3
T7	0.081	9	0.112	5	0.052	9	0.109	6	0.088	9
T8	0.084	8	0.066	8	0.123	3	0.116	3	0.096	5
T9	0.085	7	0.118	3	0.084	7	0.113	4	0.099	4

Table 1: Normalized BNP Values of Criteria

To determine the performance value of each strategy, the evaluators can define their own individual range for the linguistic variables employed in this study according to their subjective judgments within a fuzzy scale. In order to make more clearly comprehensive in considered criteria with strategies for readers, we express the nonfuzzy performance value of strategies with respect to evaluated criteria and show as Table 2.

	S1	S2	S3	S4	S5	S6	S7	S8
T1	84.256	72.551	73.333	76.435	58.710	57.306	72.180	79.512
T2	71.856	74.384	69.519	75.791	61.588	50.872	63.031	74.872
T3	74.713	70.235	71.706	75.460	62.195	49.996	65.544	77.543
T4	73.312	69.786	66.578	74.904	61.093	50.850	65.271	75.273
T5	70.035	70.588	66.734	75.129	60.388	50.009	60.736	70.155
T6	71.910	73.533	66.482	76.486	61.617	50.832	63.129	72.533
T7	67.319	64.571	63.821	70.361	58.176	51.748	65.189	66.413
T8	71.484	68.737	74.092	72.768	62.253	56.919	71.113	78.195
T9	77.707	73.914	70.887	74.619	67.289	53.867	70.133	71.813

Table 2: BNP Values of Performance Values

When we determined the criteria weights and performance values of evaluated criteria and feasible strategies, the next step is to integrate the synthetic utility for each strategy. Here we employ simple additive weighted method to integrate the nonfuzzy criteria weights with nonfuzzy performance values for each strategy, the results as shown in Table 3.

	S1	S2	S3	S4	S5	S6	S7	S8
T1	15.738	13.552	13.698	14.277	10.966	10.704	13.483	14.852
T2	7.115	7.365	6.884	7.505	6.098	5.037	6.241	7.414
T3	10.389	9.767	9.971	10.493	8.649	6.952	9.114	10.783
T4	6.645	6.325	6.034	6.789	5.537	4.609	5.916	6.822
T5	6.661	6.714	6.347	7.146	5.743	4.756	5.777	6.672
T6	7.882	8.060	7.287	8.383	6.754	5.572	6.919	7.950
T7	5.863	5.624	5.559	6.128	5.067	4.507	5.678	5.784
T8	6.778	6.518	7.026	6.900	5.903	5.397	6.743	7.415
T9	7.605	7.234	6.937	7.303	6.585	5.272	6.863	7.028

Table 3: Nonfuzzy Synthetic Values of Strategies

Following the procedure as mentioned in Section 3, we derive distance from the positive ideal solution (S^+) and from the negative ideal solution (S^-) of each strategy. Finally, we further compute the relative closeness as Eq. (14) and then assign the preferred order to each strategy according to their closeness index (Table 4).

	S^+	S^-	Closeness	Rank
S1	0.00315	0.01614	0.83664	3
S2	0.00460	0.01485	0.76328	4
S3	0.00595	0.01301	0.68635	5
S4	0.00199	0.01781	0.89940	1
S5	0.01142	0.00773	0.40361	7
S6	0.01878	0.00000	0.00000	8
S7	0.00834	0.01082	0.56467	6
S8	0.00282	0.01674	0.85595	2

Table 4: Preferred Order Derived by TOPSIS

We can conduct the preferred order of development strategies of industrialized nanotechnology of Taiwan as follows: Emphasize on Intellectual Property Rights (S4) > Information Supply for Opportunity Development (S8) > R&D Supporting (S1) > Professional Incubation (S2) > Tax Incentives (S3) > Finance (S7) > Establish Science Zone (S5) > Government Procurements (S6).

5 CONCLUSIONS

Nanotechnology is an emerging industry that includes many areas. Nano now is still in the stage of science development and the market orientation can change human life. If government can refer to above optimal policy orders of nanotechnology in the future, it would be helpful for enhancing the global competitive position of Taiwan. Secondly, to find nano material applications is always very time consuming and can't be guaranteed for the success. As a result, many newcomers fail to survive due to the failure of finding the market at early stage. Even for some commercialized products, the company is still looking for the market direction. Once the market direction is mistakenly taken, the production plan has to be changed. Therefore, the above order can also be applied as companies' alternative developing strategies to avoid the failure of expanding market.

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