

# A decision support model for the selection of nanotechnology with good performance and necessity

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Nanotechnologies are being developed rapidly and driving economic growth. Among so many nanotechnology alternatives, selecting a nanotechnology with good performance and necessity is important and difficult. In this study, we propose a decision support model composed of AHP/DEA-AR(analytic hierarchy process/data envelopment analysis-assurance region) and AHP(analytic hierarchy process)rating method to evaluate nanotechnologies accurately and systematically. The proposed model evaluates performance of nanotechnology alternatives by AHP/DEA-AR and necessity of nanotechnology alternatives by AHP rating method, and calculates each alternative's combined score by adding each alternative's performance value and necessity value. The alternative with the highest combined score is selected as nanotechnology with good performance and necessity.

In this study, we select 6 criteria for selecting nanotechnology with good performance and necessity. Experts rate nanotechnology alternatives in terms of the 6 criteria. The 6 criteria are classified as criteria for performance and criteria for necessity, R&D capability, ease of production, marketability and technical extension are criteria for performance. Urgency and government support are criteria for necessity. To evaluate the performance of nanotechnology alternatives, we normalize the ratings to criteria for performance first, then, we use AHP pairwise comparison to set AR (assurance region) for using DEA-AR. After setting AR, we employ DEA-AR to evaluate performance of nanotechnology alternatives. The evaluation result is performance value (DEA score). To assess the necessity of nanotechnology alternatives, we use AHP rating method instead of AHP pairwise comparison, because the number of alternatives is large, so the pairwise comparison is impracticable. The assessment result is necessity value (AHP score). We add a nanotechnology alternative's DEA score and AHP score to get the alternative's combined score. After calculating each nanotechnology alternative's combined score, we rank the combined scores from the largest to lowest. At last, we select the nanotechnology alternative with the highest combined score as the nanotechnology with good performance and necessity. A case of nanotechnology is used to illustrate the proposed model. The result shows that the proposed model provides a systematical and objective evaluation to alternatives and is a reasonable method for nanotechnology selection.

Key words: nanotechnology, technology selection, performance evaluation, necessity evaluation

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## 1. Introduction

Nanotechnology, a technology in high-technology, knowledge-based sectors, has become the potential economic engines driving regional and national job and wealth creation (Kautt, 2007). Nanotechnology can be defined as the science and engineering involved in the design, synthesis, characterization and application of materials and devices whose lowest functional organization in at least one dimension is on the nanometer scale (one-billionth of a meter) (Sahoo et al., 2007). It was first discussed in the late half of the 20th century, technically by Fynman (1960) and commercially by Drexler (1986), and had been applied in fields of engineering, physics, chemistry, medical science and biology. New materials, products and services based on nanotechnology have been and will be developed in a wide range of applications for high benefits. The number of companies, the market volume of products, and the volume of R&D in the field of nanotechnology has also substantially increased in recent years (Roco, 2005). In such a circumstance, in order to realize effective R&D investment, selecting competitive nanotechnology to invest in from various alternatives is important and necessary for either companies or countries.

In order to select a nanotechnology which has good performance and necessity, we pro-

pose a decision support model composed of AHP/DEA-AR (Analytic Hierarchy Process/Data Envelopment Analysis-Assurance Region) and AHP rating method. In the proposed model, we use AHP/DEA-AR on the experts' rating data to evaluate the performance of nanotechnology alternatives, and use AHP rating method on the experts' ratings to evaluate the necessity of nanotechnology alternatives. Data envelopment analysis (DEA) is a non-parametric linear programming based technique to evaluate the relative efficiency of decision-making units (DMUs) that use multiple inputs to produce multiple outputs (Chang, 2011). DEA can be used for evaluating efficiency of DMU such as ports, banks, hospitals and so on (Alirezaee and Afsharian, 2007; Lim et al., 2011; Park and Lee, 2011). When selecting a suitable technology among multiple technology alternatives, technology alternatives should be evaluated against the various pre-defined criteria (Lamb and Gregory, 1997). Some criteria can be categorized as the inputs and outputs for using DEA. Inputs are required resources of developing a technology. Outputs are results of applying a technology. After identifying inputs and outputs, DEA can be used in technology selection to evaluate efficiency of technology alternatives. Some studies have employed DEA to select efficient technology (Moutaz, 1995; Lee et al., 2011). But there are some problems in the existing methods. First, basic DEA models such as

DEA-CCR, DEA-BCC, cannot analyze ordinal rating data (qualitative data collected through survey) accurately. Second, the existing methods using basic DEA models (DEA-CCR model or DEA-BCC model) are not excellent in confirming the most efficient technology. DEA-CCR and DEA-BCC always select many efficient technology alternatives to make selection of the most efficient technology difficult. In order to solve the problems, instead of using basic DEA models, in this study, we use DEA-AR on ordinal rating data to evaluate efficiency of nanotechnology alternatives as performance of nanotechnology alternatives. DEA-AR model is developed based on basic DEA model to avoid the unreasonable weight distribution (Thompson et al., 1986). DEA-AR has also showed good performance in evaluating ordinal (rating) data collected through surveys to experts in technology selection (Taylor et al., 1997; Seifert and Zhu, 1998; Takamura and Tone, 2003; Kong and Fu, 2012). Analytic hierarchy process (AHP) is designed to solve complex problems involving multiple criteria. When there are a large number of alternatives and pair-wise comparison is impracticable, AHP rating method is particularly useful (Sueyoshi et al., 2009). In this study, because of large number of technology alternatives which are independent with each other, we use AHP rating method to calculate priority of nanotechnology alternatives to assess an alternative's necessity. In this study, we

select 6 criteria for evaluating nanotechnology alternatives accurately. The 6 criteria are classified into 4 criteria for performance and 2 criteria for necessity. The 4 criteria for performance are evaluated by DEA-AR model. For using DEA-AR model reasonably, the assurance region(AR) should be set in advance by using AHP method, so AHP/DEA-AR is employed. The 2 criteria for necessity are evaluated by AHP rating method. Each nanotechnology alternative is finally evaluated by combining the alternative's performance score (DEA score) and necessity score (AHP score). The combined score of nanotechnology alternatives are the basis of nanotechnology selection. The nanotechnology alternatives has highest combined scores are selected as nanotechnology with good performance and necessity.

The remainder of this study is structured as follows. Section 2 introduces nanotechnology's background; section 3 introduces technology selection; section 4 introduces DEA-AR model and AHP rating method; section 5 describes the procedures of the decision support model; section 6 conducts proposed model on nanotechnology selection; section 7 offers conclusion.

## II. Background of nanotechnology

Nanotechnology was first discussed technically by Fynman (1960) and commercially by

Drexler (1986). It is also defined as the first research initiative of the 21st century. Nanotechnology-related investments (Shapira and Youtie, 2011; Teece, 2011), created platforms and infrastructures have brought more than 2,000,000 articles and over 1,000,000 patents (Mangematin and Errabi, forthcoming; Youtie and Shapira, 2008b). Current development of nanotechnology have been in a situation: nanotechnology based products, devices and services are on the markets and production capabilities has been invested by large companies (Fiedler and Welpe, 2010, 2011; Huang et al., 2011; Newbert et al., 2007; Palmberg, 2008). Nanotechnology has been seen an engine to technology development, science development, production innovation and social innovation (Kautt et al., 2007). Therefore, as mentioned before, nanotechnology is also a hot topic and discussed at different perspectives. For example, Genet et al. (2012) discussed the patterns of technology transfer in nanotechnology. Allarakhia and Walsh (2012) proposed a method to manage, select, analyze and design large consortia which is central to commercial progress in the field of nanotechnology. Raesfeld et al. (2012) assessed the commercial performance of 169 nanotechnology research projects, and discussed the determinants of the potential collaboration project performance. Battard (2012) discussed the formation of nanocenters and argues that research groups dedicated to

nanotechnology are technological hubs where scientists with multiple backgrounds converge in order to conduct research at the nanoscale. Arora and Gambardella (1994) pointed out nanotechnologies are changing the "technology of technological change" in biotechnology, but affecting different scientific fields and different industries.

### III. Review of technology selection

Technology selection is a process that involves identifying and evaluating technology alternatives and choosing among them (Shen et al., 2010). In this process, information about technology alternatives should be collected through many channels and the alternatives should be evaluated against each other or some criteria (Lamb and Gregory, 1997). Due to the increasing number and complexity of technology, technology selection is becoming more and more difficult (Torkkeli and Tuominen 2002). A systematic assessment of technology is necessary to overcome the difficulties of technology selection (Efstathiades et al., 2000).

In technology selection, AHP (Saaty, 1980) is a widely used method of solving multi-criteria problems (Tran and Daim, 2008). many researchers have used AHP to research technology selection. For example, AHP was used to help selecting the promising access

technology under the criteria of cost, quality and speed (Malladi and Min, 2005). A healthcare technology assessment application using AHP was presented (Sloane, 2004). AHP was integrated with scenario analysis techniques to evaluate hydrogen fuel processor technologies (Winebrake and Creswick, 2003). Ramanujam and Saaty (1981) proposed a method which employed AHP to select imported technology for the less developed countries. Hajeeh and Al-Othman (2004) used AHP to select the most appropriate seawater desalination technology. AHP was used to identify criteria and obtain their relationship and weights to select the proposed OLED technology (Shen et al., 2010). Chin cheng (2012) used the 'fuzzy AHP' method to develop a valuation method for selecting new materials technology. Some researches also use DEA in technology selection. For example, Moutaz (1995) proposed a two-phase decision method for technology selection problems. A novel practical common weight multi-criteria decision-making (MCDM) DEA approach was proposed for technology selection (Karsak and Ahiska, 2005). But in researches above, they used basic DEA models for technology selection, so the number of efficient technology is more than 1. This is difficult for decision makers to select only one efficient technology. In this research, instead of basic DEA models, we use DEA-AR to evaluate efficiency of technology alternatives more accurately.

In previous studies on technology selection,

most researchers used AHP or DEA alone, but the combined AHP and DEA method has been applied in many fields. Bowen (1990) suggested a two-step process of integrating DEA and AHP in site selection. Takamura and Tone (2003) presented a site evaluation model based on AHP and DEA method for relocating Japanese government agencies out of Tokyo. Shang and Sueyoshi (1995) proposed a unified framework using AHP and DEA for the selection of the most appropriate flexible manufacturing system (FMS) for a manufacturing organization. Zhang and cui (1999) developed a project evaluation system using DEA and AHP method to manage investments in the various parts (sub-systems) of the State Economic Information System (SEIS) of China. Sinuany-stern et al. (2000) presented an AHP and DEA methodology for fully ranking organizational units with multiple inputs and multiple outputs. Ertay et al. (2006) suggested a similar decision-making methodology based on the DEA and AHP for evaluating facility layout design. The combined use of AHP and DEA can yield more valid results, but seldom used on technology selection. In this study, we propose a decision model which combines AHP/DEA-AR and AHP rating method for selecting nanotechnology with good performance and necessity.

The previous studies on technology selection method usually focused on dealing with cardinal data, not ordinal data (Saen, 2006). In

general, however, technology selection is conducted by carrying out surveys to several experts and then evaluating ordinal rating data collected through surveys. Thus, it is essential to have the technology selection method which can accurately analyze ordinal rating data. Some or all of the criteria in technology evaluation may be ordinal (qualitative), and should be treated as such (Saen, 2006). The addition of subjective judgements to the purely quantitative approach can provide a more realistic evaluation process (Sharon, 2008). In this study, technology alternatives are rated in ordinal data by experts.

#### IV. DEA-AR and AHP rating method

##### 4.1 DEA-AR

DEA is a popular mathematical programming methodology based on the efficiency frontier (Charnes et al. 1978). DEA evaluates the relative efficiencies of a homogeneous set of decision making units (DMUs) having multiple inputs and outputs. A DMU is considered relatively inefficient if its efficiency score is less than 1. The degree of inefficiency for a DMU is measured relative to a set of more efficient DMUs. However, a DMU identified as being efficient does not imply absolute efficiency. It is only relatively efficient to

other DMUs that are being considered.

DEA-CCR model is introduced as the most basic DEA model (Charnes et al. 1978). When there are  $n$  DMUs utilizing  $m$  inputs and producing  $s$  outputs, the relative efficiency score of a test DMU  $k$  can be calculated by equations as follows:

$$\max \sum_{r=1}^s v_r y_{rk} \tag{1}$$

$$s.t. \sum_{i=1}^m u_i x_{ik} = 1, \tag{2}$$

$$\sum_{r=1}^s v_r y_{rj} - \sum_{i=1}^m u_i x_{ij} \leq 0, \quad \forall j, \tag{3}$$

$$u_i \geq \epsilon, v_r \geq \epsilon, \quad \forall i, r \tag{4}$$

Where  $y_{r,k}$  is the amount of output  $r$  yielded by DMU  $k$ ,  $x_{i,k}$  is the amount of input  $i$  consumed by DMU  $k$ ,  $v_r$  is the weight given to output  $r$ ,  $u_i$  is the weight given to input  $i$ ,  $y_{r,j}$  is the amount of output  $r$  consumed by DMU  $j$ ,  $x_{i,j}$  is the amount of input  $i$  consumed by DMU  $j$ , and  $\epsilon$  is a positive non-Archimedean infinitesimal.

DEA-AR model is developed based on DEA-CCR model (Thompson et al., 1986). In basic DEA model, the weights are not fixed in advance, but derived from the data. Each DMU chooses the assigned weights. In this case, an efficient DMU may be weighted a single input and a single output with the other inputs and outputs being weighted zero

(Kong and Fu, 2012).

The DEA-AR model can vary weights within a region by imposing constraints on the relative magnitudes of the weights for special items (Kong and Fu, 2012). For every pair  $(y_{r1k}, y_{r2k})$  of measurement (input and output) the ratio  $\frac{w_{r1}}{w_{r2}}$  should be bounded by  $L_{r1,r2}$  and  $U_{r1,r2}$ . Here,  $y_{r1k}$  and  $y_{r2k}$  are the  $r1$ -th and  $r2$ -th measurement of DMU  $k$ .  $w_{r1}$  and  $w_{r2}$  denotes the weight of  $y_{r1k}$  and  $y_{r2k}$ .  $L_{r1,r2}$  and  $U_{r1,r2}$  are the lower and upper bounds of the ratio. This constraint limits the region of weights to some special area. The equation is

$$L_{r1,r2} \leq \frac{w_{r1}}{w_{r2}} \leq U_{r1,r2} \quad r1 \neq r2 \quad (5)$$

By adding Equation (5) into the equation of DEA-CCR model (Equation (1)), we can obtain the DEA-AR model.

#### 4.2 AHP rating method

Analytic hierarchy process (AHP) is designed to solve complex multiple criteria decision making (MCDM) problems (Saaty, 1980). The AHP has two measurement modes, absolute (rating method) and relative (pairwise comparison) (Saaty, 1994). The AHP rating method differs from AHP pairwise comparison. AHP pairwise comparison sets up a comparison matrix at each level by comparing pairs of criteria, or pairs of alternative at the lowest

level. AHP rating method defines a set of intensity (or categories) levels that serves as a base to evaluate the performance of the alternatives in terms of each criteria and/or sub-criteria (Duarte and De Souza, 2005). In the AHP rating method, the evaluation is performed by intensity levels (categories) attributed to each sub-criteria related to each alternative instead of evaluating the alternatives by pair-wise comparisons.

The procedure of AHP rating method is as follows: (1) get experts' subjective ratings on the necessity of criteria; (2) make pair-wise comparison of the ratings to get the weights of criteria; (3) fix the number of element level, use pair-wise comparison to derive the original score for each level and normalize them by dividing each original score by the highest value among them; (4) obtain elements priorities under each criteria to generate the final values of the alternative priorities.

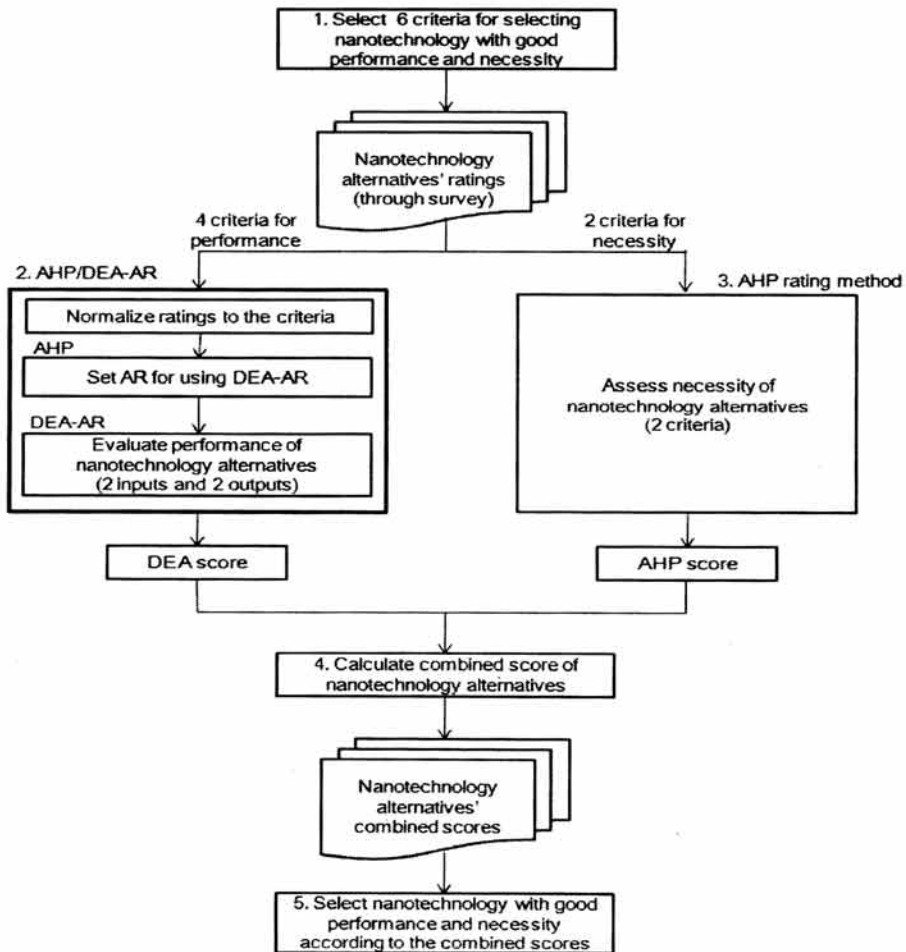
The main advantage of AHP rating method is decreasing the number of comparisons necessary when there are a large number of alternatives and pair-wise comparison is impracticable (Schoner et al., 1993; Schenkerman, 1994; Sueyoshi et al., 2009; Taghipour et al., 2010). In this study, because there are too many alternatives, we use AHP rating method to prioritize necessity of nanotechnology alternatives.

## V. A decision support model for nanotechnology selection

In order to provide an effective selection of nanotechnology, in this study, we propose a decision support model composed of AHP/DEA-AR and AHP rating method considering the 6 criteria to select nanotechnology with

good performance and necessity. Figure 1 shows the process of the proposed model.

As shown in Figure1, there are 5 main steps in the whole procedure of the proposed model: (1) select 6 criteria (introduced in 5.1) for selecting nanotechnology with good performance and necessity; (2) After getting the experts' ordinal ratings to nanotechnology alternatives in terms of the 6 criteria, we



〈Figure 1〉 The process of the proposed model

determine 4 criteria as criteria for evaluating performance, and employ AHP/DEA-AR on ordinal ratings of the 4 criteria (2 inputs and 2 outputs)' ratings to evaluate performance of nanotechnology alternatives. In this step, we should normalize experts' ordinal ratings to the 4 criteria first, then use AHP pairwise comparison to set assurance region for using DEA-AR. After that, we use DEA-AR on 4 criteria' ordinal ratings to evaluate the performance of nanotechnology alternatives. The calculated efficiency value of a nanotechnology alternative is defined as DEA score: (3) we determine the remaining 2 criteria as criteria for assessing necessity, and use AHP rating on the ordinal ratings of the 2 criteria to calculate the necessity of nanotechnology alternatives. In this study, the calculated priority value of a nanotechnology alternative is defined as AHP score: (4) calculate the combined score of each nanotechnology alternatives by adding each alternative's DEA score and AHP score: (5) select nanotechnology which has good performance and necessity according to the combined scores of nanotechnology alternatives.

### 5.1 Select 6 predefined criteria

Nanotechnology is one of emerging technologies, evaluating these emerging technologies, some factors should be considered: the technology required R&D capability level:

degree of ease of production; whether the technology is profitable; whether the technology can be extended technically; whether the technology is urgently needed by the market or society; whether the technology is supported by government need to be considered carefully. Therefore, we select R&D capability, ease of production, marketability, technical extension, urgency and government support as the criteria for selecting nanotechnology with good performance and necessity. In the 6 criteria, R&D capability is the required R&D capability of a technology, ease of production is the ease of using a technology to producing products, marketability is the marketability of a product using a technology, technical extension is a technology's extension to other products or fields, urgency means the market or society's urgent need to a technology, government support means government's support to a technology. In the process of a survey, experts rated nanotechnology alternatives in terms of the 6 criteria.

After getting experts' ratings to nanotechnology alternatives in terms of the 6 criteria, In the 6 criteria, R&D capability and ease of production are resources of applying a nanotechnology, marketability and technical extension are results of applying a nanotechnology, so we determine the 4 criteria as input 1(R&D capability), input 2(ease of production), output 1(marketability) and output 2(technical extension). The other 2 criteria

(Urgency and government support) are related with the necessity of nanotechnology alternatives.

### 5.2 Apply AHP/DEA-AR to evaluate performance

In this step, we use AHP/DEA-AR on the ordinal ratings of the 4 criteria to evaluate performance of nanotechnology alternatives. First, in order to bring the ordinal ratings to the 4 criteria used for DEA-AR to a common scale, normalization is needed. In this study, we normalize ordinal ratings of the 4 criteria (2 inputs and 2 outputs) with the method proposed by Roll and Golany (1993). According to their method, each rating value is divided by the mean of the ratings to the criteria. For example, to  $n$  nanotechnology alternatives, the ratings to the  $s$ -th output

are  $y_{s1}, \dots, y_{sn}$ , the mean is  $\bar{y}_s = \frac{\sum_{j=1}^n y_{sj}}{n}$ , the normalized value of  $n$ -th nanotechnology alternative's  $s$  the output's rating is  $\frac{y_{sn}}{\bar{y}_s}$ .

After normalization, we use AHP pairwise comparison to set reasonable weight region (Assurance Region) for using DEA-AR model. The procedure of setting assurance region is as follows: (1) conduct surveys to  $m$  experts and elicited their subjective judgements ( $m$  sets of ratings) on the importance of the 2 inputs and 2 output; (2) use pair-wise comparison in AHP to get the weights of inputs and outputs; (3) calculate each expert's input

weight ratio and output weight ratio and find the highest and the lowest values of each weight ratio; (4) set upper and lower bound of inputs and outputs' weights region (as shown in equation (6)).

$$II_{i,k} \leq \frac{u_i}{u_k} \leq IU_{i,k} \tag{6}$$

In equation (6),  $u_i$  is the weight of input  $i$ ,  $u_k$  is the weight of input  $k$ .  $\frac{u_i}{u_k}$  is the input weight ratio.  $II_{i,k}$  is the lowest value among the  $m$  sets of input weight ratio, and set as the lower bound of the inputs' weights' region.  $IU_{i,k}$  is the highest value among the  $m$  sets of input weight ratio, and set as the upper bound of the inputs' weights' region. The upper and lower bound of the outputs' weights' region should be set by the same way.

After getting the upper and lower bounds of inputs and outputs' weights' region, we employ DEA-AR model to evaluate the performance of nanotechnology alternatives (DEA score).

### 5.3 Apply AHP rating method to assess necessity

Based on the ratings collected through the surveys to  $m$  experts, we use AHP rating method because the number of nanotechnology alternatives is generally large, and accordingly makes their pair-wise comparisons almost

impracticable. As the result of AHP rating method, the necessity of nanotechnology alternatives are calculated.

In this step, we use the  $m$  experts' ratings to the importance of criteria to derive weights of criteria. The number of intensity levels are fixed in advance and levels of each criteria varies (e.g., from "very high" to "very low"). Then, we use pair-wise comparison to derive the original score for each level and normalize them by dividing each original score by the highest value among them. After applying AHP rating method, the necessity of nanotechnology alternatives (AHP score), is calculated.

#### 5.4 Calculate combined scores

After applying AHP/DEA-AR in 5.2 and AHP rating method in 5.3, we can get each nanotechnology alternative's DEA score and AHP score. In this step, we use DEA score and AHP score to calculate combined score for each nanotechnology alternatives. In this study, in order to consider the performance and necessity equally when selecting nanotechnology, we set the weight of performance and weight of necessity as 1:1. Generally, when selecting technology, except special circumstances, performance and necessity are important factors which should be equally considered and used.

A nanotechnology alternative's combined score is the sum of the alternative's DEA

score and AHP score. The combined score determines a nanotechnology alternative's selected priority.

#### 5.5 Determine nanotechnology with good performance and necessity

After calculating each nanotechnology alternative's combined score, all nanotechnology alternatives are ranked from the largest to lowest according to their combined scores. nanotechnology alternatives with the highest combined score should be selected as nanotechnology with good performance and necessity.

## VI. Empirical study

We apply the proposed model to nanotechnology for illustration. In the first step of the model, we select 6 criteria (R&D capability, ease of production, marketability, technical extension, urgency and government support) in advance for selecting nanotechnology with good performance and necessity and invite 3 experts to rate 243 nanotechnology alternatives based on the 6 criteria on a five-point scale (1 being a "very low" and 5 being a "very high" level) to get the ratings. After classifying the 6 criteria into 4 criteria (R&D capability, ease of production, marketability and technical extension) for performance and 2

criteria(urgency and government support) for necessity, we normalize the ratings of the 4 criteria and use a software called Expert choice 11.5 to apply AHP to calculate the AR region, and then use a software called DEA solver to apply DEA-AR model to normalized ratings of the 4 criteria (2 inputs and 2 outputs) to evaluate performance of nanotechnology alternatives and get DEA score of each nanotechnology alternatives. In the third step, we use Expert choice 11.5 to apply AHP rating method to the ratings of the 2 criteria to assess the necessity of nanotechnology alternatives and get AHP score of each nanotechnology alternatives. In the fourth step, we calculate combined score of nanotechnology alternatives by adding each nanotechnology alternative's DEA score and AHP score. after getting all nanotechnology alternatives' combined scores, in the last step, we select nanotechnology with good performance and necessity according to the combined scores. In the following contents, we will show the main results of the illustration.

### 6.1 Performance of nanotechnology alternatives

At first, we need to normalize experts' ra-

tings to the 2 inputs and 2 outputs (4 criteria). In the first step of normalization, we should calculate the 4 criteria's mean value. The R&D capability's mean value is 3.64, the ease of production's mean value is 3.67, the marketability's mean value is 3.81, the technical extension's mean value is 3.86. Then, we use each nanotechnology alternative's rating values to divide the corresponding criteria's mean value to get the normalized values. For example, if a technology's R&D capability rating is 3.8, the normalized value will be  $3.8/3.64=1.044$ .

After normalization, we use AHP pairwise comparison to calculate the weights of inputs and outputs and set assurance region (AR) for the inputs' weights and outputs' weights according to their ratios. To calculate the weights of inputs and outputs, we conducted a survey to 3 experts and collected their ratings to the necessity of the 2 inputs and 2 outputs. All the ratings were made on a five-point scale (1 being a "very low" and 5 being a "very high" level).

Table 1 shows the 3 experts' ratings to the necessity of the 2 inputs and 2 outputs. Then we make pair-wise comparisons of the ratings

<Table 1> Experts' ratings to the necessity of 2 inputs and 2 outputs

		Expert 1	Expert 2	Expert 3
Input	R&D capability(Input1)	4.5	4	4
	Ease of production(Input2)	3	3	2
Output	Marketability(Output1)	4	4.5	3.5
	Technical extension(Output2)	2	3	2.5

to get the weights of inputs and outputs. After getting the weights of inputs and outputs, we should calculate each expert's inputs' weights ratio and outputs' weights ratio. Then, we need to find the lowest and highest values of each weight ratio and construct the lower and upper bound values of assurance region (AR). Table 2 shows the lower and upper bounds of assurance region (AR):

〈Table 2〉 The lower and upper bounds of assurance region (AR)

	Lower	Middle	Upper
Input1/Input2	1.33	1.5	2.0
Output1/Output2	1.38	1.5	2.0

In Table 2, among the ratios of inputs' weights, 1.33 is the lowest value, and used as the lower bound of inputs' weights' region in DEA-AR. 2.0 is the highest value, and used as the upper bound of inputs' weights' region in DEA-AR. Among the ratios of outputs' weights, 1.38 is the lowest value, and used as the lower bound of outputs' weights' region in DEA-AR. 2.0 is the highest value, and used as the upper bound of outputs' weights' region in DEA-AR. The weights of inputs and outputs are allowed to vary within the region of the lower and upper bounds. If the number of efficient technology evaluated by DEA is more than the number of expert's aim, we should narrow the assurance region, for example, set 1.5 as the lower bound for

inputs' weights' region, 1.5 as the lower bound for outputs' weights' region and keep the upper bounds of both inputs and outputs' weights' region unchanged to reduce the number of efficient nanotechnology.

After setting the assurance region (AR), we use DEA-AR to evaluate performance of nanotechnology alternatives. Table 3 shows the DEA scores of the 243 nanotechnology (NT) alternatives.

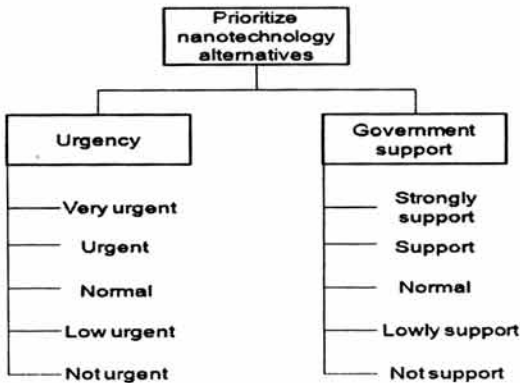
〈Table 3〉 DEA scores of 243 nanotechnology alternatives.

Tech No.	DEA score
NT1	0.696
NT2	1.000
NT3	0.731
NT4	0.729
NT5	0.554
NT6	0.491
NT7	0.859
NT8	0.874
...	...
NT242	0.682
NT243	0.724

## 6.2 Necessity of nanotechnology alternatives

In this study, because the number of nanotechnology alternatives is large, we use AHP rating method rather than AHP pairwise comparison to prioritize nanotechnology alternatives. In order to use AHP rating method, we need to get the weights of criteria and

derive the original score for each level and normalize them. Figure 2 shows the hierarchy for prioritizing nanotechnology alternatives:



〈Figure 2〉 Hierarchy for prioritizing nanotechnology alternatives

As shown in Figure 2, AHP rating method is applied to 2 criteria (Urgency and government support). In this hierarchy, the maximum priority score a nanotechnology alternative could receive is 1.00. The total priority score for each nanotechnology alternative is calculated by adding the each criteria's score. The necessity of a nanotechnology alternative is the priority score of the nanotechnology alternative.

The priority scores (AHP score) of nanotechnology alternatives are calculated after applying AHP rating method. Table 4 shows the AHP scores of the 243 nanotechnology (NT) alternatives.

〈Table 4〉 AHP scores of 243 nanotechnology alternatives

Tech No.	AHP score
NT1	0.625
NT2	1
NT3	0.625
NT4	1
NT5	0.375
NT6	0.497
NT7	1
NT8	1
...	...
NT242	0.625
NT243	0.497

### 6.3 Combined scores of nanotechnology alternatives

Before selecting nanotechnology with good performance and necessity, we need to combine the DEA scores and AHP scores of nanotechnology alternatives. Nanotechnology alternatives' combined scores are shown as follows:

In Table 5, the 243 nanotechnology alternatives are ranked according to the combined scores. NT2 has the highest combined score, and NT5 has the lowest combined score.

### 6.4 Result of selecting nanotechnology with good performance and necessity.

According to the rank of combined scores in Table 5, NT2 technology (Monodisperse metal

〈Table 5〉 Combined scores of nanotechnology alternatives

Rank	Tech No.	DEA score	AHP score	Combined score
1	NT2	1	1	2.000
2	NT45	0.896	1	1.896
3	NT8	0.874	1	1.874
4	NT7	0.859	1	1.859
5	NT181	0.835	1	1.835
6	NT40	0.794	1	1.794
7	NT12	0.789	1	1.789
8	NT180	0.774	1	1.774
	...	...	...	...
242	NT16	0.589	0.375	0.964
243	NT5	0.554	0.375	0.929

oxide magnetic nano-particles technology) has the highest combined score (2.000). The NT2 technology also have high scores in both DEA score and AHP score. Therefore, we select NT2 technology as the nanotechnology with good performance and necessity.

## VII. Conclusion

Recently, nanotechnologies have grown rapidly and had important contributions on helping technology based companies to establish competitive advantages. Selecting a nanotechnology with good performance and necessity is very important. In this study, we propose a decision support model composed of AHP/DEA-AR and AHP rating method to provide systematic evaluation to nanotech-

nology alternatives and select nanotechnology which has good performance and is necessary. In the proposed model, we used AHP/DEA-AR to calculate performance value (DEA score) of nanotechnology alternatives, use AHP rating method to assess necessity (AHP score) of nanotechnology alternatives, and calculate the combined score of each nanotechnology alternative by adding each alternative's DEA score and AHP score. The alternative with the highest combined score is selected as the nanotechnology with good performance and necessity. The selected nanotechnology have high scores in both performance and necessity. The result shows that the proposed model provided a comprehensive analysis that evaluates technology alternatives synthetically and accurately by using an combined AHP/DEA-AR and AHP rating method. Compared with the existing methods, the proposed method used

DEA-AR instead of basic DEA models to analyze ordinal rating data and evaluate technology's efficiency more accurately. The proposed method can also supply more information about the technology alternatives such as technology efficiency than the previous methods of only using AHP method to get the priority of technology alternatives. The proposed method combinedly used the AHP/DEA-AR and AHP rating method to make a deep and comprehensive analysis and evaluation to make the decision making process of technology selection more reasonable and convincing than the existing methods in technology selection.

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## 좋은 퍼포먼스와 필요성을 가지는 나노기술 결정을 위한 통합 접근 방법

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### 요 약

많은 나노기술들이 빠르게 개발되어 경제 성장을 주도하고 있다. 나노기술은 새로운 자료 또는 제품에 활용되기 위해 여러 산업 분야에서 적용되고 있다. 어떤 기업이 많은 나노기술 대안들 중에서 좋은 퍼포먼스를 창출하고 국내외적으로 필요한 나노기술을 선택하는 것은 기업의 비즈니스 상에서 매우 중요하지만 이러한 기술을 선택하는 것은 매우 어렵다. 본 연구는 기업에서 많은 나노기술 대안을 정확하게 평가하기 위해 활용될 수 있는, AHP/DEA-AR(analytic hierarchy process/data envelopment analysis-assurance region) 분석방법과 AHP(analytic hierarchy process) rating 분석방법을 통합한 분석방법을 제안한다. 제안한 통합 분석방법은 나노기술 대안의 기술적용 퍼포먼스를 평가하여 각 대안의 퍼포먼스 점수를 산출하고 동시에 각 기술 대안의 필요성을 평가하여 필요성 점수를 산출하여 각 대안별로 결합 점수를 산출한다.

본 연구에서는 좋은 퍼포먼스와 필요성을 가지는 나노기술을 선정하기 위해, 6가지의 기술평가 및 선정 기준을 설정하여 나노기술 전문가들에게 기술대안들에 대해 서베이를 수행한 후, 6 가지 기준별 각 나노기술 대안의 평가 데이터를 수집하였다. 6 가지 기준들은 기술의 퍼포먼스를 평가하는 기준과 필요성을 평가하는 기준으로 구분된다. 나노기술 대안의 퍼포먼스를 평가하기 위해 전문가의 평가 값을 정규화를 한 후, AHP/DEA-AR 방법을 적용한다. 즉, DEA에서 사용할 수 있는 가중치 범위를 구하기 위해 AHP를 사용하여 AR(assurance region)를 설정한다. AR를 설정한 후, DEA-AR를 사용하여 나노기술 대안들의 퍼포먼스 점수를 구한다. 또한 나노기술 대안의 필요성을 평가하기 위해 AHP rating 방법을 사용하여 나노기술 대안의 필요성 점수를 구한다. 각 기술대안의 퍼포먼스 점수와 필요성 점수를 더해서 각 대안의 결합 점수를 산출하고 가장 높은 결합 점수를 가지는 기술 대안을 최종적으로 좋은 퍼포먼스와 필요성을 가지는 나노기술로 선택한다. 실제 나노기술 선정 사례에 본 연구에서 제안한 방법을 적용한 결과, 제안된 방법이 나노기술 대안을 객관적으로 평가하고 기술선택을 합리적으로 수행할 수 있음을 확인하였다.

주제어: 나노 기술, 기술 선정, 퍼포먼스 평가, 필요성 평가

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