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An Environmental Framework for Preliminary Industrial Estate Site Selection using a Geographical Information System

P. Rachdawong[a*] and S. Apawootichai[b]

[a] Department of Environmental Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok 10330, Thailand.
[b] The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi 10140, Thailand
* Corresponding author

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Abstract : The task of making decisions on industrial estate site selection based on numerous variables can be greatly simplified by combining geographical information system (GIS) and multi-criteria decision making (MCDM) techniques. Traditionally, there have been two major concerns for initial industrial estate site selection. One was the large number of potential project sites being proposed that must be investigated. Another concern was how the criteria for site evaluation were chosen and quantitatively defined. In this study, a framework was proposed to screen for the most suitable areas for the Supanburi Industrial

Estate Project using selected sets of criteria. Eight criteria (two constraints and six factors) with appropriate ranges were chosen based on literature reviews together with community and expert survey results. Following this, attribute values of the criteria were entered into a multi-criteria decision making scheme with GIS. A suitability map was created using the weighted linear combination (WLC) method to show sites that met all the requirements. The candidate areas with high scores were subjected to further assessment for final decision. In our conclusion it was found that the criteria could effectively function only if the proper information were fed into the GIS application. The GIS analysis could be used to speed up the site selection process and also to enhance public understanding of the project.

Keywords: Industrial estate site selection, Geographical information system, Multi-criteria decision making, Attribute values, Weighted linear combination.

Introduction

Industrial location decisions have long been influenced by economic, technical, and socio-cultural considerations [1]. Criteria relating to the environment were often neglected or ignored in the decision making process. In practice, the environment was conventionally viewed by most industrialists as sources and sinks for inputs and outputs from industrial operations, and was always taken for granted. As natural regenerative capability was surpassed by excessive rates of exploitation, impacts of industrial operations became evident and began to affect the nearby inhabitants adversely. This has usually provoked both fear and anger from local people, NGO groups, and concerned parties in a number of places around the world, especially in developing countries. Thus a number of governments took the initial step of creating special zones for industry, primarily to separate them from heavily populated or affected areas. Government agencies, in charge of regulating industrial site selection, started to consider the inclusion of environmental criteria into the selection process as a measure to lessen potential environmental impacts to local communities.

In Thailand, the Industrial Estate Authority of Thailand (IEAT) is responsible for site selection, planning and management of industrial estates in all areas of the country. Historically, IEAT were faced with two major concerns for initial industrial estate site selection. One was the large number of potential project sites being proposed. This required, as a consequence, a lot of time and effort for feasibility studies and environmental impact assessment (EIA) preparation before the most suitable sites were chosen. Another concern was how the criteria for site evaluation was selected and quantitatively defined.

In this study, a framework was proposed to locate the most suitable areas for Supanburi Industrial Estate by using selected sets of criteria. Supanburi is traditionally an agricultural province to the west of Bangkok and has been proposed by the government as a potential area for industrial development. Criteria with appropriate ranges were chosen based on literature reviews and expert survey. Later, attribute values of the criteria were fed into a multi-criteria decision making scheme with geographical information system (GIS). A suitability map was then created to show potential sites that met all the requirements. This screened information will assist subsequent planners in final decision making.

1. Study Area

Supanburi Province was the target area for this study. It is located on the west bank of the Chao Phraya River in the central plains region of Thailand between latitude 14° 4′ to 15° 5′ north and longitude 99° 17′ to 100° 16′ east [2], and is in the Tha Chin Basin. The province is subdivided into ten districts with total area of 5,354.4 km^2. Topography of the province can be classified into three broad groups; namely mountains and hills in the west (8%), rolling plains in the middle immediately adjacent to the higher area (20%), and the plains to the east (72%).

2. Proposed Industrial Types

Criteria selection for assessment of industrial estate impact on the surroundings was inevitably dependent on the types of industry to be established in the project area. According to the initial study by the IEAT, the industrial estate was to contain four major groups of industries namely: agricultural processing and canning; electronics, car assembly, machinery and equipment; ceramics; and pharmaceutical and medical-related industries. These industries were estimated to produce approximately 8,500 m^3 per day of organic wastewater and 850 m^3 per day of chemical wastewater during operation. Solid and hazardous waste production were estimated to be on an average of 156 and 8 m^3 per day, respectively.

Methodology

There were four steps in developing the framework for preliminary suitable industrial estate site selection as seen in Figure 1. The first step was the GIS software selection. The second step involved the selection of criteria and ranges based on the literature. Both expert and local community opinions were sought, analyzed and computed in the third step to yield relative importance values and subsequently weights for factors. The last step was incorporation of the weights derived from individual and relative importance to the area maps so that the final suitability map could be created.

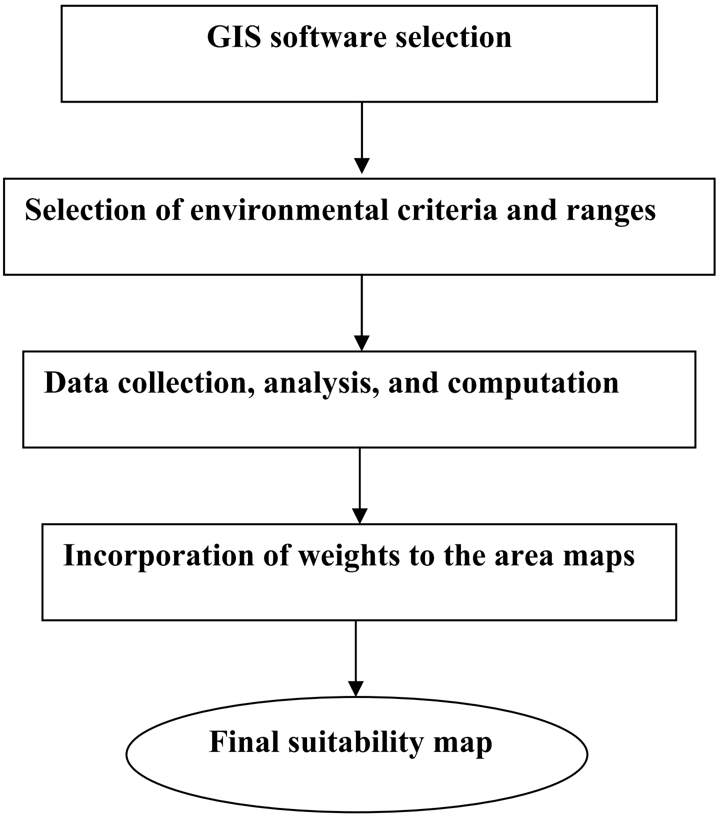

Figure 1. Framework of preliminary industrial estate site selection.

Details of each step are outlined as follows;

1. GIS software selection

A GIS tool should enable collection, reclassification, analysis, and presentation of spatial data sets. In this study, IDRISI (Clark Labs, Clark University, USA), a raster-based GIS software tool was chosen due to the fact that it was designed specifically for multi-criteria evaluation [3] Raster-based format has an enhanced overlay capability and is widely used for site suitability analysis [4].

2. Selection of criteria

There were eight criteria selected. Of the eight, there were two constraints (reserved forest and watershed class) and six factors (elevation, slope gradient, distance from water bodies, soil properties, distance from roads and distance from communities). Selection of criteria was determined by scanning literature relating to industrial estate siting for the aforementioned groups of factories. Types, attribute values, and references for selection are given in Table 1.

Table 1. Eight criteria and associated attribute values.

Type	Acceptable range for industrial estate application	Reference
1. Reserved forest	Not permitted	[5]
2. Watershed class 1 & 2	Not permitted	[5]
3. Elevation	100-700 metres above sea level	[6] [7]
4. Slope gradient	0-10 %	[8]
5. Distance to water bodies	50-1,000 metres	[9]
6. Soil properties	clay texture moderately slow permeability moderately deep	[10] [7] [11]
7. Distance from roads	10-1,000 metres	[9]
8. Distance from communities	800-5,000 metres	[9]

3. Collection, analysis, and computation of data

Two types of data were involved in this study: primary and secondary.

3.1 Primary data collection

Primary data were the data collected directly by researchers. Two types of questionnaire were distributed separately for experts and residents of local communities. For experts, three major questions were asked; 1) if the pre-selected six factors were appropriate and adequate for site assessment study, 2) comparative importance of factors for individual and mixed type of industries, and 3) suitable range of the six factors. For residents, major questions asked were types of pollutants released from selected industries and what the nearest distance they were willing to live by the individual or mix of industries. Details of content and format of questionnaires can be found in [9].

The idea of comparative importance was to compare the relative preference of any two factors at a given time. A higher score would be assigned to a factor with higher importance than the other. To account for the comparative importance of the six factors, a matrix of six factors with nine-point comparative importance scale (15×9) was created as described in the IDRISI Manual [3]. Each entry in the matrix was the percentage of respondents who agreed with the score of importance for each pair of factors, i.e., 41.19% of the respondents who agreed with the fact that elevation and slope are equally important would become an entry in the matrix.

3.2 Primary data analysis and computation

After creation of the comparative importance matrix, calculation to compare pairs was conducted to reduce the dimension of information involved. Entries to the pair-wise comparison matrix were the importance scores corresponding to the median values of percentage voted for comparative importance of each factor pair. Dimensions of the pair-wise comparison matrix were six by six. Weights for each factor were subsequently extracted from the matrix of pair-wise comparison in the same fashion as for eigenvalue computation. Finally, each factor weight would be assigned for each layer of mapping procedure.

3.3 Secondary data

Secondary data were from various government agencies. They were map layers of six environmental factors and two constraints.

4. Integration of collected field data with geographical information system

Integration of the data with GIS is shown graphically in Figure 2, with details as follows.

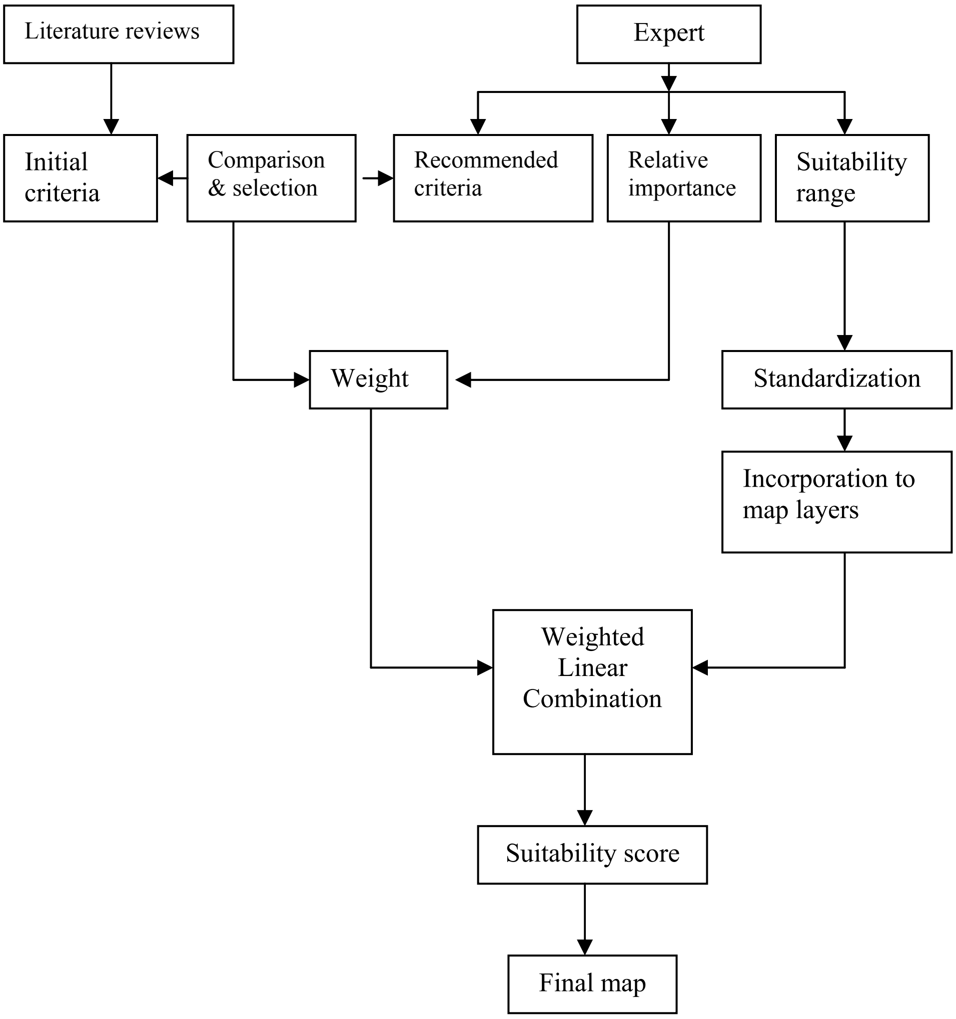

Figure 2. Integration of data with geographical information system.

4.1 Suitability functions

To calculate the suitability score, the range of each factor needs to be on the same scale or standardization [3] and [12]. For constraints, the value of one was assigned to desirable areas whereas the value of zero was assigned to undesirable areas. For the six factors, a standardized scale from 0 to 255 was used to transform acceptable ranges of values. However, functional relationship of scales and attribute values was different depending on the nature of each factor to attenuate concentration of pollutants from points of discharge.

4.2 Final map creation

Weighted linear combination was used to summarize the total score of all attribute values for a particular area of interest. Each total score was obtained by multiplying the factor weight by the standardized scores for the map of specific factors and then summing the products for all maps considered. After the overall scores for the whole geographical area were computed, the areas with high scores were then subjected to further assessment for final decision. More details on this procedure can be found in [12].

Results and Discussion

1. Comparative importance

Comparative importance for each factor is given in Table 2. In order to select a score of importance for each combination, statistic measures of central tendency were used. The middle value of frequency or median was accepted as the all-important scale of combinations instead of mean or mode [13] because the sample size of experts was small and the frequency of surveyed opinion could not be considered a normal distribution. If mode was chosen for this case, it might create a biased estimate. To avoid the effect of extreme value, the mean was also not used in this study. From Table 2, the median value of relative importance of elevation and distance from communities criteria (the fifth row) indicated that elevation was moderately less important than distance from communities and it was supported by 18% of the experts surveyed. On the other hand, it could be said that distance from communities was moderately more important than elevation. Most of the median values were quite similar to the mode while few were different.

2. Comparison of pairs

According to the matrix of pair-wise comparison shown in Table 3, the most important factor was distance to water bodies, which was considerably more important than soil and elevation factors and was moderately more important than the distance from communities factor. The second most important factor was slope, which was moderately more important than the soil factor; and distance from communities, which was moderately more important than elevation and soil factors.

Table 2. Percentage of comparative importance of environmental factors for four types of industries.

Column Factor	extremely less import. (1/9)	very strongly less import. (1/7)	strongly less import. (1/5)	moderately less import. (1/3)	equally important 1	moderately more import. 3	strongly more import. 5	very strongly more import. 7	extremely more import. 9	Row Factor
elevation	0.00	5.88	17.65	11.76	*41.19*	5.88	5.88	5.88	5.88	slope
elevation	11.76	11.76	*29.42*	5.88	11.77	11.76	5.89	5.88	5.88	water body
elevation	0.00	0.00	11.76	11.76	*29.42*	5.88	23.53	17.65	0.00	soil property
elevation	0.00	17.65	17.65	5.88	*29.42*	5.88	5.88	11.76	5.88	road
elevation	17.65	5.88	23.54	*17.65*	11.76	5.88	0.00	5.88	11.76	community
slope	5.88	17.66	5.88	5.88	*35.30*	11.76	0.00	11.76	5.88	water body
slope	5.88	0.00	0.00	0.00	41.18	*5.88*	17.65	29.41	0.00	soil property
slope	5.88	5.88	5.88	5.88	*35.30*	5.88	17.66	11.76	5.88	road
slope	0.00	11.76	5.88	5.88	*29.42*	11.76	17.66	11.76	5.88	community
water body	5.88	5.88	0.00	5.88	17.66	11.76	*5.88*	23.53	23.53	soil property
water body	5.88	5.88	0.00	5.88	*41.19*	5.88	11.76	17.65	5.88	road
water body	5.88	0.00	0.00	0.00	23.53	*23.53*	17.65	17.65	11.76	community
soil property	5.88	17.66	11.76	11.76	*35.30*	5.88	5.88	0.00	5.88	road
soil property	0.00	29.42	11.76	*23.54*	11.76	11.76	0.00	5.88	5.88	community
road	0.00	5.88	0.00	23.54	*29.42*	11.76	11.76	11.76	5.88	community

Distance from roads was equally important to all factors whereas the least important factors were soil and elevation factors. Most experts thought more of natural features than of public facilities. These findings were similar to those concerned with the siting of a landfill [14]. Weights computed from IDRISI denoted the same trend in that the distance to water bodies factor had the highest weight of 0.3164. While weights of slope and distance from communities factors were quite similar (0.1783 and 0.1757, respectively). The lowest weights were for elevation and soil factors with the scores of 0.0970 and 0.0787, respectively. The distance from roads factor with a weighted score of 0.1540, showed similar importance to the rest of the factors.

Table 3. Lower half triangle of pair-wise comparison matrix of environmental factors.

Factor	Elevation	Slope	Distance to water bodies	Soil properties	Distanc e from roads	Distance from communities
Elevation	1					
Slope	1	1				
Distance to water bodies	5	1	1			
Soil properties	1	1/3	1/5	1		
Distance from roads	1	1	1	1	1	
Distance from communities	3	1	1/3	3	1	1

3. Suitability functions and standardized scores

Functional relationships of standardized scores and actual values of ranges were quite different depending on the mechanisms for each factor to attenuate pollutant concentrations. Information on functional relationship on attribute values of the six factors and standardized scores are given in Table 4.

Table 4. Information showing functional relationship of the six factors.

Type	Functional relationship	Reasons
1. Elevation	Linear monotonic decrease	Indicating less desirable areas with increasing altitude
2. Slope gradient	Discrete decrease	Same as elevation
3. Distance to water bodies	Increasing and decreasing sigmoidal	Compromising environmental attenuation and economic return
4. Soil properties	Discrete decrease	Same as elevation
5. Distance from roads	Increasing and decreasing sigmoidal	Compromising environmental attenuation and economic return
6. Distance from communities	Continuous increase	Indicating more desirable areas with increasing altitude

Standardized criteria maps for six factors were also created based on the above information. For example, the criteria maps with standardized scores for distance from roads and communities are shown in Figures 3 and 4, respectively.

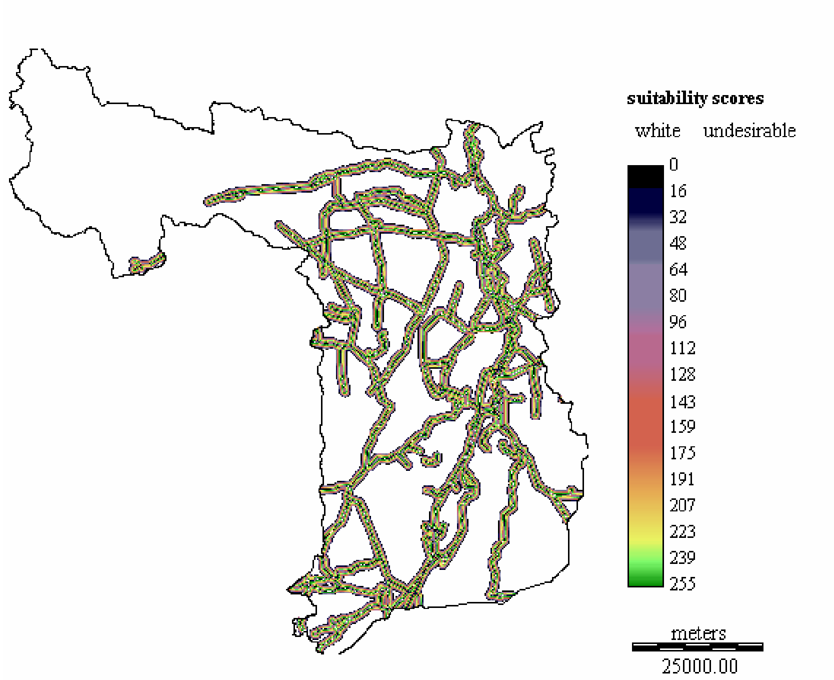

Figure 3. Standardized distance from roads criterion map.

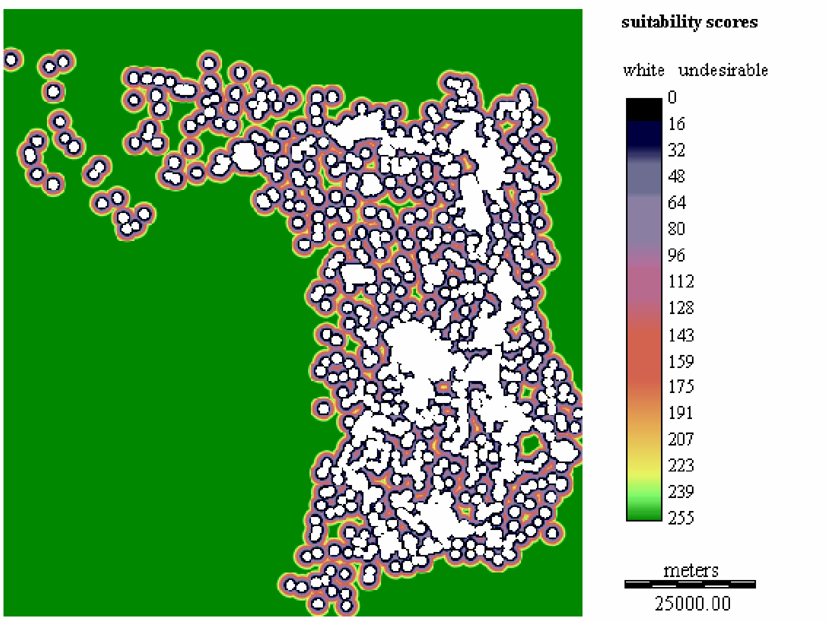

Figure 4. Standardized distance from communities criterion map.

4. Final map creation

The results in the form of final map indicated not only the factors that were included in the framework of Figure 1, but also areas with high acceptance total scores (more than 90% of the total score, which was specified as the suitability score threshold). According to the 90% suitability score threshold, there were 24 sites with the total area of 218.41 hectares that met all the requirements (Figure 5).

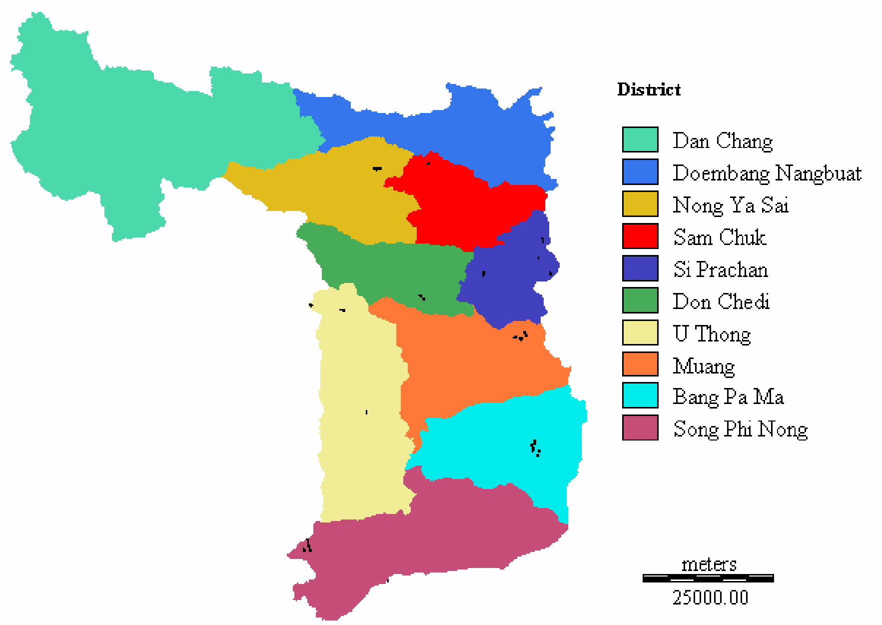

Figure 5. Suitable areas for establishing an industrial estate based on 90% of suitability thresholds.

Conclusion

Combining the concept of multiple criteria and GIS for industrial estate site selection was realized showing similarities to the site selection of sewage, hazardous waste, and radioactive waste disposal sites [6], [7] and [15]. The actual work was carried out in a few days, compared with manual analysis, which could be expected to take over several months. A small number of potential sites were proposed for decision-making. In addition, the whole procedure was clear and easy to understand and could be used to inform the general public. In the case that there is a dispute over the site selection process, the IEAT could debate quantitatively on the significance of criteria and re-evaluate for a new choice of location with ease. The results of analysis depended on both geographical information and value judgment, thus qualified data and procedures such as Delphi Technique [16] and [17] are necessary. In cases where the framework is to be applied in other locations, the attribute values of criteria should also be changed to reflect the new site characteristics and types of industry to be established.

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