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Factor assessment of the environmental impact for Tainan Technology Industrial Park in Taiwan

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Abstract

To deeply comprehend the environmental impact factors of the Tainan Technology Industrial Park on southern Taiwan, a multi-objective decision support method is developed and the factors based on six categories are considered. Firstly, the Delphi method is adopted to acquire the opinions of experts. The questionnaire is designed to facilitate sound decision-making by using both empirical data and subjective judgment. Secondly, according to the reply answer of questions to establish the hierarchy diagram and factor assessment by the AHP (analytic hierarchy process) method. The pairwise comparisons are carried out to quantify the assessment factors and establish the priorities. Thirdly, the consistency index is calculated and evaluates the contribution to objectives based on the weighting values of impact factors. During the construction and development of Tainan Technology Industrial Park, there are eight important impact factors. Once the project is finished, there are seven major impact factors. Based on the priority of these factors, it can be a guideline on the environment protection of land development.

1 Introduction

The problems generated by the development of industrial area were numerous and complicated, which include the air pollution, noise vibrations, illegal dump of construction wastes and the improper disposition of sewage during the construction process, and the environmental impact over the surrounding area after the construction was finished. Due to the concentration of urban population, the industrial areas are developed in the suburbs in order to accommodate the commuters.

In the comprehensive assessment technique field of environmental impact factors, the weighting is the major method and the weighting is even one of the essential steps. However, the dominant authority and personal bias of experts may cause certain tendencies during the weighted process. The selection of assessment method, therefore, is a key factor to the outcome of assessment and the confidence of the public. The Delphi method is one of the most popular weighted method [1]. By means of anonymous questionnaires, it allows the opinions of respondents to be modified and tend to consistency without the hampers in a face-to-face group discussion and the influence of the dominant authority. Nevertheless, the traditional Delphi method must be executed two or three times at least, and the consumption of time, labor and other resources cannot be overlooked, and a consensus is not guaranteed. The modified Delphi method, created to steer consensus in a particular direction, is to look for the correlation among the factors and the environmental impact categories. The factors, which can be merged in a category, are discovered by analysis and the outcome will be provided to the participants for reference in order to accelerate the convergence process.

In the design of weighted assessment scale, the pairwise comparisons method was adopted to be the measuring scale for Delphi method and to modify the opinions by the qualitative mode. The traditional Delphi method was adopted to do investigation by questionnaires in order to select the environmental impact factors, which will be the basis for the environmental impact analysis while a public construction project is proceeding and in the aftermath.

Following the finding of the impact factors, they could be decided the priorities by the Analytic Hierarchy Process (AHP), then selecting the best area for development. There is the Fuzzy Hierarchy Analytic method for selecting the best area for development, and for the optimum seeking of weighted impact factors; Wang investigated the priorities of the developing strategies for city-planning related subjects in 1993. By combining the traditional Delphi method and the Analytic Hierarchy Process addressed by Professor Saaty [2], selecting Tainan Technology Industrial Park as the object of study, the research involves the analysis of the priority weighting of the impact factors for the surrounding environment during construction and the operation afterward. The result is expected to supply a definite basis for the forecasting analysis of environmental impact, and to achieve everlasting both-win situation in the aspects of environmental protection and economic developments.

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2 The Delphi method

The Delphi method, originally developed at the RAND Corporation in early 1950s, is based on a structured process for collecting and distilling knowledge from a group of experts by means of a series of questionnaires. With lacking of complete data and clear situation, it represents a useful communication device among a group of experts and thus facilitates the formation of a group judgment. The method has been widely used to analyze the complicated problems and enhance the quality of strategic decisions. It may offer the distinct advantages as follows. (1) It can collect the data from different levels and overcome the disadvantage of conventional group discussion. (2) The diversification of the participants is favorable to enhance the strictness of the conclusion for a specific subject and to keep it unbiased [1]. (3) The experts are encouraged to reconsider their opinions by feedback regarding the statistical response of the previous questionnaires. Therefore, the significance of the method is to combine expert opinions by controlled feedback from questionnaires and to enable each participant to have an equal input. The shortcomings of the method involve the controversy of the selection of a panel [3] and the incontrollable retrieval time of questionnaires. Another major concern is that there is no explicit description for the consensus generated from the decision-making process, and therefore, the definition of consensus should be judged by researchers first in order to conduct research effectively. The steps of Delphi method are described as follows:

(1) Formation of a research team: Formation of a research team with various backgrounds would be beneficial to undertake the supervision and progression of the complex and diversified projects. Since the research belongs to a small-scale project, the research workers are responsible for the proceeding of Delphi method and the research team is engaged in the strict supervision and in consultation with the experts with a specialty relative to the subject.

(2) Selection of a panel: The professionals and technicians with more than five-year practical experience in the related fields of environmental science, environmental engineering, water resource engineering, soil and water conservation, civil engineering, industrial safety and hygiene.

(3) Development of questionnaires: The initial questionnaires of Delphi method should be derived from the open collection of opinions. Based on the exploration of environmental reports of Tainan Technology Industrial Park and related literatures, the first round structured questionnaires was edited by the researchers. The contents involve the explanation of matters concerned, the communication mode, the illustration and the opinion additions and revisions. The synthesis of the panelists' views will form the basis of the input of successive rounds.

(4) Execution of questionnaires investigation: The investigation of Delphi questionnaires should be conduct at least three or four times but twice will be satisfying if the consensus is reached or two opposing extremes are identified in the second round [4, 5].

The opinion of experts are categorized by {1-extremely important/ significant}, {2-important}, {3-no opinion}, {4-unimportant}, {5-extremely unimportant}, and the qualities and quantities are equally weighted in statistical analysis.

3 Analytic hierarchy process method

The Analytic Hierarchy Process (AHP) is adopted with the Delphi method to quantify the impact factors of the surroundings in the development process of Tainan Technology Industrial Park and in the aftermath in this research. It is an analytical tool, supported by simple mathematics, enables people to explicitly rank tangible and intangible criteria against each other for the purpose of resolving conflict or setting priorities. It has been formalized by Saaty in 1970s and used in a wide variety of problem areas. The process involves structuring a problem from a primary objective to secondary levels of objectives.

3.1 Construction of a pairwise comparison matrix

Once these hierarchies have been established, a pairwise comparison matrix of each element within each level is constructed. Participants can weigh each factor against each other factors within each level. Each level is related to the levels above and below it, and the entire scheme is tied together mathematically. The result is a clear priority statement of an individual or group. Assuming there are n factors, a pairwise comparison matrix of $n(n-1)/2$ elements is shaped. Each comparison is transformed into a numerical value of Saaty's discrete 9-value scale.

After the pair comparisons of decision-making factors, the pattern of pairwise comparison matrix acquired is shown below:

$$A=\left(a_{ij}\right)=\begin{pmatrix} 1 & a_{12} & \cdots & a_{1m} \\ a_{21} & 1 & \cdots & a_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & 1 \end{pmatrix}=\begin{pmatrix} 1 & a_{12} & \cdots & a_{1m} \\ 1/a_{12} & 1 & \cdots & a_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ 1/a_{1m} & 1/a_{2m} & \cdots & 1 \end{pmatrix} \tag{1}$$

While a_{ij} is the importance of the ith factor as compared to the jth one, that represents how much the decision makers value the factors between i and j.

3.2 Computation of the maximum eigenvalue and eigenvector

To check if the A is conformed to the requirement of consistency, λ_{max}, the positive real maximum eigenvalue, and the eigenvector w_i are computed. That is,

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(1) Eigenvector w_i

$$w_i = \left(\prod_{j=1}^{m} a_{ij}\right)^{1/m} \Big/ \sum_{i=1}^{m}\left(\prod_{j=1}^{m} a_{ij}\right)^{1/m} \tag{2}$$

While m represents the number of decision-making factors.

(2) The maximum eigenvalue λ_{max}
A new vector $w_i{'}$ is obtained by multiplied the pairwise comparison matrix A and eigenvector w_i. The average multiple between them is λ_{max}.

$$\begin{pmatrix} 1 & a_{12} & \cdots & a_{1m} \\ a_{21} & 1 & \cdots & a_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & 1 \end{pmatrix} \times \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_m \end{pmatrix} = \begin{pmatrix} w_1' \\ w_2' \\ \vdots \\ w_m' \end{pmatrix} \tag{3}$$

$$\lambda_{max} = (1/m)\times(w_1'/w_1 + w_2'/w_2 + w_3'/w_3 + \cdots + w_m') \tag{4}$$

(3) Consistency testing
For measuring the coincidence for each decision makers before and after the judgment, the consistency of pairwise comparison matrix is tested. The consistency index (C.I.) and consistency ratio (C.R.) for each level are calculated to measure the criterion. The C.I. is defined as below:

$$\text{C.I.} = \frac{\lambda_{max} - m}{m-1} \tag{5}$$

A zero value of C.I. represents that the human judgments is consistent for the relative importance of decision-making criterion. Satty suggested that C.I.$\leqq$0.1 is the tolerable error range. Then the C.I. can be divided by the random index (R.I.) to obtain the value of C.R.; in short, C.R.=C.I./R.I.. If C.R.$\leqq$0.1, it can be assumed that the entire assessment process has reached consistency. Otherwise the pairwise comparison results should be rejected and another reassessment is required.

Table 1: Random index (R.I.) table.

m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

3.3 Computation for the weight of factors

After the computation of the factors' weight for each level, the weight for whole hierarchy can be calculated. Assuming the latter can pass the consistency testing, the substitute plan for the ultimate objective will be decided based on the weighted value for each plans. Total weighed value of the alternative plan can be shown as

$$\mathrm{TW} = \sum_{i=1}^{n} w_i y_{ij} \tag{6}$$

while $i = 1, 2, \cdots, n$ (a total of n decision-making factors), $j = 1, 2, \cdots, m$ (a total of m substitute plans), w_i the weight for the ith decision-making factor, y_{ij} the value for the ith factor of the jth substitute plan.

4 Case study

4.1 Background of study area

To access the environmental impact of the development of public project, the Tainan Technology Industry Park on southern Taiwan is selected for case study. The background of this industry park is described as follows. The region is divided into two areas, east and west, by Lurm River. The former is near 496 hectares and the latter 213. The total area of development is 709 hectares and the location map is shown in Figure 1. The landform of the region is flat and the average altitude is 0.2 (east) and 0.3 (west) meter individually. There are two important culture places, the tumulus and the ancient battlefield. The tourist spots and the popular temples have 5 places. The characteristic plant is mangroves. There are three kinds of mangroves and one of them is on the verge of crisis. A large tract of wetland serves as the midway of birds' moving to a different place. The main land use of east and west area is the salt pond and the fishpond. Around the region, the main use is the dry farmland, fishpond and salt pond.

4.2 Appraisal of environmental impact factors by Delphi method

Through the interview with the residents, the investigation results of the environmental impact questionnaires, and the environmental assessment reports of Tainan Technology Industrial Park [6], a Delphi expert questionnaires is composed. A total of 29 questionnaires are delivered to the experts in a variety of fields including civil engineering, hydraulic engineering, environmental engineering, factory safety, and all of them are retrieved. Based on the outcome of expert questionnaires, the importance of environmental impact factors are appraised successfully for Tainan Technology Industrial Park during construction and the operation afterward, as illustrated in Table 2 and Table 3.

Transactions on Ecology and the Environment vol 63, © 2003 WIT Press, www.witpress.com, ISSN 1743-3541

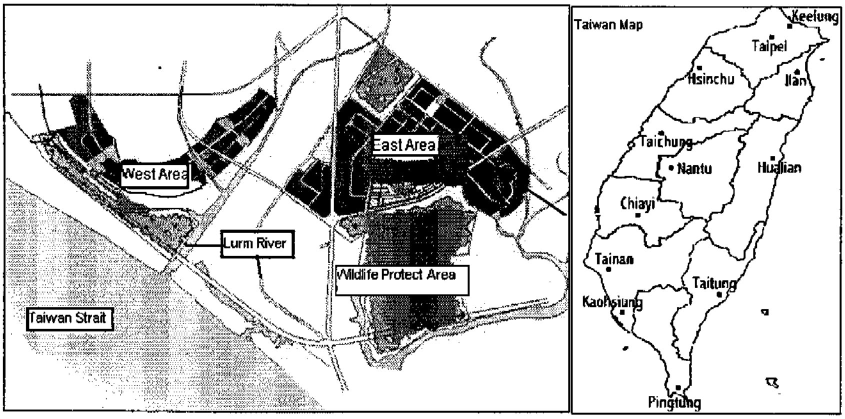

Figure 1: The location map of Tainan Technology Industrial Park.

4.3 AHP optimization analysis of environmental impact factors

A total of 26 and 30 environmental impact factors have appeared for the development and operation process of Tainan Technology Industrial Park by the integration of experts' opinions from various fields. Using AHP questionnaires method, there are 19 panelists invited, that satisfies the requirements for the number of AHP decision maker group, including the experts from related fields, and the technician and the operatives with practical experience.

4.3.1 Analysis of the environmental impact factors in the development process of Tainan Technology Industrial Park

During the development, the importance of impact categories and impact factors are summarized in Table 2.

(1) Weighting analysis of pairwise comparisons for the target level: The factors in the category of public health and safety, with a weighting ratio of 0.233, is most important in the assessment system of environmental impact during the development process, and the next is the environment and ecology categories, whose weighting ratios are 0.212.

(2) Weighting analysis of pairwise comparisons for the second level: Based on the values of weighting ratio, air pollution is the major factor in environment category, whereas there is no significant difference among all the factors in ecology. The supply of water resource is treated as an essential factor in resources category, and this shows the abundant water supply is vital in the development process. In Socioeconomic category, the maximum weighting ratio falls on the employment rate promotion. The destruction of cultural and historic sites is most valued, with a weighting ratio of 0.437, in landscape and culture category. With regard to public health and safety, the most attention is paid to the flood disaster.

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Table 2: AHP analysis of environmental impact factors in the development process of Tainan Technology Industrial Park.

Categories and Factors	Weighting
Environment:	*0.212*
Water Pollution	0.244
Air Pollution	0.245*
Soil Pollution	0.180
Noise	0.122
Machine Vibration	0.111
Traffic Moving Line	0.099
Ecology:	*0.212*
Environmental Green Recovery	0.151
Ecology Protect Area	0.162
Decrease of Primitive Biology Resources	0.247*
Water Saving	0.195
Natural Habitat Area	0.245
Resources:	*0.124*
Water Resource Supply	0.328*
Earth and Stone Resource	0.173
Construction Scrap Reuse	0.142
Energy and Power Supply	0.233
Use the Green Construction Martial	0.124
Socioeconomic:	*0.132*
Feedback Fund	0.183
Employment Rate Promotion	0.374*
Increase of Local Intraindustry	0.270
Public Participation	0.172
Landscape-and-culture:	*0.087*
Destruction of Cultural and Historic Sites	0.437*
Landscape Change	0.334
Unaccommodated vision	0.230
Public health-and-safety:	*0.233**
Environmental Sanitation	0.348
Traffic Accident	0.255
Flood Disaster	0.397*

P.S.: Consistency ratio (C.R.) = 0.005 < 0.1 (pass the test).
*: Relatively maximum value of weighting ratio in each level of AHP.

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Table 3: AHP of the environmental impact factors after the development process of Tainan Technology Industrial Park.

Categories and Factors	Weighting
Environment:	*0.191*
Air Pollution	0.180
Water Pollution	0.206*
Waste Pollution	0.191
Noise	0.086
Machine Vibration	0.081
Traffic Moving Line	0.098
Soil Pollution	0.157
Ecology:	*0.125*
Decrease of Biology Land	0.335*
Species of Bird	0.231
Primitive Flora Change	0.234
Artificial Region for Protection and Recovering	0.200
Resources:	*0.164*
Water Supply	0.343*
Solid Waste Reuse	0.189
Power and Energy Supply	0.285
Human Resources	0.183
Socioeconomic:	*0.167*
Employment Rate Promotion	0.210
Feedback Fund	0.069
Improvment for Local Economy	0.263*
Intervention of Local Inference	0.078
Promotion of Living Standard	0.168
Impacts of Sunrise Intraindustry	0.136
Influence of Nonlocal People Staying	0.077
Landscape-and-culture:	*0.090*
Destruction of Cultural and Historial Sites	0.414*
Landscape Change	0.360
Unaccommodated Vision	0.266
Public health-and-safety:	*0.244**
Risk of Chemical Hazard	0.258
Hazardous Solid Waste	0.260*
Disaster of Factory Accident	0.224
Flood Disaster	0.130
Increase of Traffic Accident	0.127

P.S.: Consistency ratio (C.R.) = 0.009 < 0.1 (pass the test).

*: Relatively maximum value of weighting ratio in each level of AHP.

4.3.2 Analysis of the environmental impact factors after the development process of Tainan Technology Industrial Park

After the development, the importance of impact categories and impact factors are summarized in Table 3.

(1) Weighting analysis of pairwise comparisons for the target level: Since the east region of Tainan Technology Industrial Park has begun functioning, the original land use styles and landscape are no longer visible and the changes due to development are inevitable. The category of public health and safety, with a weighting ratio of 0.244, is considered to be the most important factor, and compared to environment category, ranked second with a ratio of 0.191, the difference is significant. Refer to the "Environmental Impact Report of Development Plan of Tainan Technology Industrial Park" [6], the conclusions are corresponding that the first and foremost impact is in the field of public health and safety. In the report, certain of feasible handling methods are provided for most of the impact categories. The exception is unexpected disaster, which is unpredictable and can only be prevented by proper and cautious control.

(2) Weighting analysis of pairwise comparisons for the second level:

a. In environment category, the most important factor is the pollution of surface water and groundwater.
b. In ecology category, the decrease of habitat area, with a weighting ratio 0.335, has close relationship with the effect of ecology protect area.
c. In resources category, the factor of water resource supply, weighted 0.343, is considered to be vital in industrial manufacturing.
d. In socioeconomic category, once Technology Industrial Park starts operating, the industries with low pollution and high output value will significantly improve local economy and promote employment rate, with a weighting ratio of 0.263 and 0.210, respectively.
e. In landscape and culture, the most valued factor is the destruction of cultural and historic sites.
f. In public health and safety, the jeopardy of pernicious industrial waste and the risk of chemical hazard are taken most seriously since they will cause unredeemable damage.

5 Conclusion remarks

(1) In the process of development, there are eight important impact factors including the water pollution, air pollution, decrease of primitive biology resources, natural habitat area, water resources supply, employment rate promotion, destruction of cultural and historic sites, and flood disaster.

(2) Once the project is finished, the major impact factors are the water pollution, decrease of biology land, water supply, improvment for local economy, destruction of cultural and historial sites, risk of chemical hazard, and hazardous solid waste. Based on the priority of these factors, it can be a guideline on the environment protection of land development.

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