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Study of environmental risk management by multivariable analysis of pattern structure *

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Abstract — This paper introduced a new framework of environmental risk management methodology by the concept of pattern recognition with multivariable analysis (PRMA). The purpose of this study is to develop an ideal pattern structure relationship for environmental risk management by multivariable analysis. The PRMA use the pattern structure with characteristic matrix and estimate the relationship by the multivariable analysis method. The candidate indexes of each pattern can be selected from the most important factors of the summary of literature review. Based on the given approach, the link between the environmental events, the ecosystem change, the economic loss, and the response measure system can be evaluated. The improvement of risk response and the quality of management system could be upgraded by this system. Besides, the methodology can also be served as a basis for the future development of environmental risk response system design.

Keywords: pattern recognition, risk management, environmental protection, pollution

1 Introduction

Environmental risk management is an important tool today because it can reduce much economic loss for society. To prevent the damage and loss from the environmental event such as the natural disaster or environmental pollution, certain response measure has to be done before or after the event. However, the environmental phenomenon is very complex and not easy to predict. A proper measure for risk management is usually very hard on design. Therefore, to know more precisely about the actual phenomenon is an important subject for the environmental risk management.

Environmental risk is the actual or potential effects on living organisms and environment by discharge, effluent, emission, etc., from man-made source or the natural disaster, which arising out of the organization's activities. The characteristic of environmental risk needs to be studied further since the environmental problem has become more important recently. Many studies had been done about the environmental risk management. However, a systematic approach by the pattern recognition has not been found yet. This paper suggests a systematic approach by multivariable analysis in the pattern structure of environmental risk.

Recently, researchers have spent more effort in studiing the risk encountered in the management process. (Makuil et al., 2010 [10]; Choi et al., 2010 [4]; Mojtahedi et al., 2009 [11]; Wang and Elhag, 2006 [18]). Some of them were interested in the project management risk study. (Carr and Tah, 2001 [1]; Chapman and Ward, 2004 [2]; Patrick, Zhang and et al., 2007 [12]; Raftery, 1999 [13]; Savic and Kayis, 2006 [15]; Hillson, 2002 [9].) Some were interested in the product risk management. (Cooper, 2003 [5]; Coppendale, 1995 [6]; Mojtahedi et al., 2008 [11].) While some were focused in the construction risk management (Flanagan and Norman, 1993 [8]; Chapman, 2001 [3]; Thevendran and Mawdesley, 2004 [17]).

For environmental risk, we need to develop a new tool to clearly describe the phenomenon. The "pattern recognition" technique is "the act of taking in raw data and taking an action based on the category of the pattern" (Duda et al., 2001 [7]; Schuermann, 1996 [16]). Pattern recognition aims to classify data (pattern) based either on a prior knowledge or on statistical information extracted from the patterns. The patterns to be classified are usually groups of measurements or observations, defining points in an appropriate multi dimensional space. In this paper, the concept of pattern recognition technique was introduced to identify the pattern of environmental data set for risk management. Four types of pattern structures were defined in this paper to construct the framework of pattern recognition and a multivariable analysis method was derived in this paper to estimate the relationship between each pattern.

2 Data flow of pattern structure in the environmental events

The pattern recognition is the approach to integrate all the important factors within the environmental process. There is a multi dimensional relationship among the functional areas such as environmental events, ecosystem change, economic loss, and response measure.

In this paper, the pattern relationship is defined as how each pattern can influence other pattern. This will be calculated by the multi variable analysis (MA) in this paper. Four types of pattern were defined in this paper as the following: (1) Characteristic types of environmental events. (2) Characteristic types of ecosys-

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tem change. (3) Characteristic types of economic loss. (4) Characteristic types of response measure.

The level of relationship between each pattern should be well known for the system engineers. The higher degree of relationship between the environmental event and the ecosystem change or economic loss reveals that we need to pay more attention to the Possible consequences. Therefore, the pattern of response measure needs to be more carefully designed.

The PRMA determines the total relationships for each pattern and environmental factors. These data are usually obtained from the empirical observation and statistical results. Therefore, the data flow for the pattern is important. It is also helpful for the system engineers to find the best responding activities that could reduce or minimize environmental risk in advance. Fig. 1 shows the general framework of environmental risk management derived in this paper.

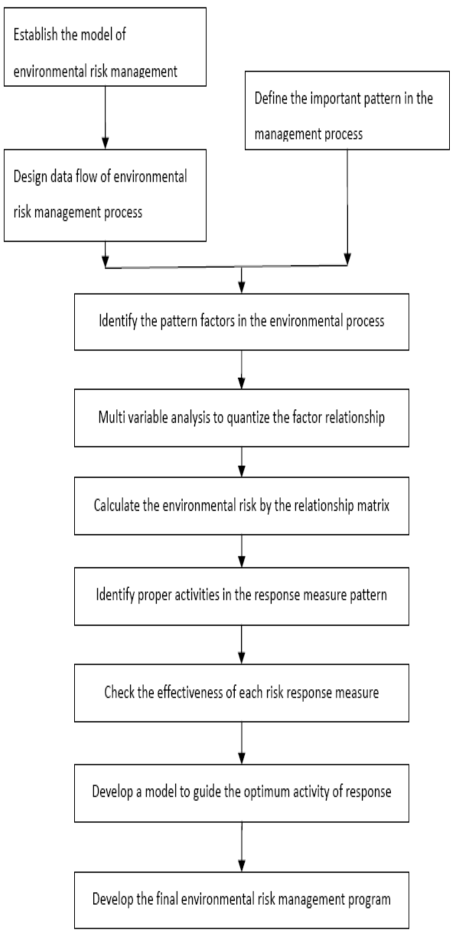

Fig. 1 The framework of environmental risk management

The framework suggests establishing the model of environmental risk management. Firstly, to define the important pattern in the management process, then design data flow of pattern in the environmental risk management process. Combine the above results to identify the pattern in the environmental process. Then, use the multivariable analysis to quantify the relationship and calculate the environmental risk by the relationship matrix. Consequently, identify the proper activities in the response measure pattern and check the effectiveness of each risk response measure to develop a model to guide the optimum activity of response. The final environmental risk management program can be obtained from the above procedure.

3 Environmental risk and engineering management

3.1 Pattern structure of environmental risk

Fig. 2 shows the ideal structure of PRMA. In this figure, we may consider the subject under the following category: (1) natural disaster itself; (2) change in ecosystem; (3) loss in economic system; (4) response for risk management.

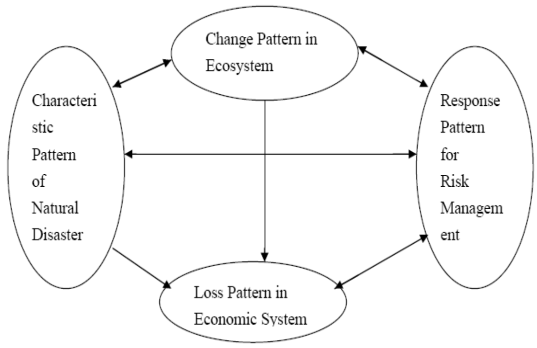

Fig. 2 Pattern structure of environmental risk and its management

From this framework, the engineers can manage more systematically for a risk management project under various levels of risks. The arrows in the figure represents the direction of influence. For example, the change pattern in ecosystem will influence the loss pattern in ecosystem. Also, the characteristic pattern of environmental event will influence the loss pattern in economic system.

3.2 Characteristic pattern of environmental event

An environmental event refers to any observable occurrence or extraordinary occurrence of environmental phenomenon, such as air pollution, river and ocean pollution, typhoon, earthquake, flood, etc. There are a lot of variables that represents the environmental events. For example, the natural of earthquake could be described by the following factors:

- Strength,
- Location,
- Frequency,
- Time,
- Duration.

3.3 Change pattern in ecosystem

The environmental event may cause the change of ecosystem. The change will induce the environmental risk. There are a variety of risk types due to the ecosystem change in the environment. By the previous researchers, those risks can be described as the following factors:

- Land use and property;
- Social and economic;
- Noise and vibration;
- Visual amenity and urban design;
- Traffic;
- Soil and geology;
- Surface and ground water;
- Flora fauna;
- Air quality;
- Aboriginal heritage;
- Non-indigenous heritage;
- Hazard;
- Resources and waste.

3.4 Loss pattern in economic system

Both the environmental event itself and the change of ecosystem will cause the loss of economic system. The loss pattern in economic system includes the following factors:

- Housing damage;
- Personal injury and death;
- Agricultural Loss;
- Roads and bridges damage;
- Indirect economic loss;
- Post-disaster reconstruction costs.

3.5 Response pattern for risk management

Response measure is the activity we take to avoid the damage of ecosystem and the loss of economic system. All the proper measures combine together to form the response pattern of risk management. The factors of response pattern in risk management system includes the following factors:

- Reinsurance compensation;
- Super fund;
- Major disaster securities market;
- Social public disclosure;
- Education and training;
- Emergency Response;
- Human resource.

4 Definition of each pattern in environmental risk management

(1) Define the pattern of environmental event

For an environmental event, there exists a characteristic pattern defined by $\boldsymbol{X}$,

$$\boldsymbol{X} = (x_1, x_2, \cdots, x_n)^T. \quad (1)$$

(2) Define the pattern of environmental change

For an ecosystem, there exits a change pattern defined by $\boldsymbol{C}$.

$$\boldsymbol{C} = (c_1, c_2, \cdots, c_n)^T. \quad (2)$$

(3) Define the pattern of economic loss

For an economic system, there exits a loss pattern defined by $\boldsymbol{L}$.

$$\boldsymbol{L} = (l_1, l_2, \cdots, l_n)^T. \quad (3)$$

(4) Define the pattern of risk management

For a risk management system, there exits a response pattern defined by $\boldsymbol{R}$.

$$\boldsymbol{R} = (r_1, r_2, \cdots, r_n)^T. \quad (4)$$

5 A multivariable model and estimating of the environment risk

The relationship between each pattern leads to a matrix that represents the degree of influence factors. The coefficients of this matrix are the basis for managing the environmental risk.

5.1 Link between environmental events and change in ecosystem

$$\begin{aligned} c_1 &= a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n + d_1, \\ c_2 &= a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n + d_2, \\ &\cdots \\ c_n &= a_{n1}x_1 + a_{n2}x_2 + \cdots + a_{nn}x_n + d_n. \end{aligned} \quad (5)$$

The above linear system can be represents by matrix as

$$\begin{pmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \cdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_3 \end{pmatrix} + \begin{pmatrix} d_1 \\ d_2 \\ \vdots \\ d_n \end{pmatrix}. \quad (6)$$

Define

$$\boldsymbol{D} = (d_1, d_2, \cdots, d_n)^T. \quad (7)$$

The above linear equation can be rewritten as matrix equation as

$$\boldsymbol{C} = \boldsymbol{AX} + \boldsymbol{D}, \quad (8)$$

where $\boldsymbol{C}$ represents the total change in the change pattern, $\boldsymbol{AX}$ is the individual contribution of each parameter in the change pattern.

Theorem 1. *The characteristic pattern of environmental events will influence the change pattern in ecosystem, and the change pattern in ecosystem will also influence the characteristic pattern of environmental events.*

From theorem 1, we rewrite the equation to

$$\begin{aligned} c_1 =& a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n + a_{1(n+1)}c_1 + a_{1(n+2)}c_2 \\ &+ \cdots + a_{1(n+m)}c_m + \delta_1, \\ c_2 =& a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n + a_{2(n+1)}c_1 + a_{2(n+2)}c_2 \\ &+ \cdots + a_{2(n+m)}c_m + \delta_2, \\ &\cdots \\ c_n =& a_{n1}x_1 + a_{n2}x_2 + \cdots + a_{nn}x_n + a_{n(n+1)}c_1 + a_{n(n+2)}c_2 \\ &+ \cdots + a_{n(n+m)}c_m + \delta_n, \\ x_1 =& a_{(n+1)1}x_1 + a_{(n+1)2}x_2 + \cdots + a_{(n+1)n}x_n \\ &+ a_{(n+1)(n+1)}c_1 + a_{(n+1)(n+2)}c_2 + \cdots + a_{(n+1)(n+m)}c_m \\ &+ \delta_{n+1}, \\ x_2 =& a_{(n+2)1}x_1 + a_{(n+2)2}x_2 + \cdots + a_{(n+2)n}x_n \\ &+ a_{(n+2)(n+1)}c_1 + a_{(n+2)(n+2)}c_2 + \cdots + a_{(n+2)(n+m)}c_m \\ &+ \delta_{n+2}, \\ &\cdots \\ x_m =& a_{(n+m)1}x_1 + a_{(n+m)2}x_2 + \cdots + a_{(n+m)n}x_n \\ &+ a_{(n+m)(n+1)}c_1 + a_{(n+m)(n+2)}c_2 + \cdots \\ &+ a_{(n+m)(n+m)}c_m + \delta_{n+m}. \end{aligned} \quad (9)$$

The above linear system can be represents by matrix as:

$$\begin{pmatrix} u_1 \\ u_2 \\ \vdots \\ u_n \\ u_{n+1} \\ u_{n+2} \\ \vdots \\ u_{n+m} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} & a_{1(n+1)} & a_{1(n+2)} & \cdots & a_{1(n+m)} \\ a_{21} & a_{22} & \cdots & a_{2n} & a_{2(n+1)} & a_{2(n+2)} & \cdots & a_{2(n+m)} \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} & a_{n(n+1)} & a_{n(n+2)} & \cdots & a_{n(n+m)} \\ a_{(n+1)1} & a_{(n+1)2} & \cdots & a_{(n+1)n} & a_{(n+1)(n+1)} & a_{(n+1)(n+2)} & \cdots & a_{(n+1)(n+m)} \\ a_{(n+2)1} & a_{(n+2)2} & \cdots & a_{(n+2)n} & a_{(n+2)(n+1)} & a_{(n+2)(n+2)} & \cdots & a_{(n+2)(n+m)} \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ a_{(n+m)1} & a_{(n+m)2} & \cdots & a_{(n+m)n} & a_{(n+m)(n+1)} & a_{(n+m)(n+2)} & \cdots & a_{(n+m)(n+m)} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \\ c_1 \\ c_2 \\ \vdots \\ c_n \end{pmatrix} \begin{pmatrix} \delta_1 \\ \delta_2 \\ \vdots \\ \delta_n \\ \delta_{n+1} \\ \delta_{n+2} \\ \vdots \\ \delta_{n+m} \end{pmatrix}. \quad (10)$$

Define

$$\boldsymbol{U} = (c_1, c_2, \cdots, c_n, x_1, x_2, \cdots, x_n)^T. \tag{11}$$

and

$$\Delta = (\delta_1, \delta_2, \cdots, \delta_n, \delta_{n+1}, \delta_{n+2}, \cdots, \delta_{n+m})^T. \tag{12}$$

The above linear equation can be rewritten as matrix equation as:

$$\boldsymbol{U} = \boldsymbol{AX} + \Delta, \tag{13}$$

where $\boldsymbol{U}$ represents the total change in the change pattern, $\boldsymbol{AX}$ is the individual contribution of each parameter in the change pattern.

5.2 Link between environmental events and loss in economic system

$$\begin{aligned} l_1 &= a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n + \beta_1, \\ l_2 &= a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n + \beta_2, \\ &\cdots \\ l_n &= a_{n1}x_1 + a_{n2}x_2 + \cdots + a_{nn}x_n + \beta_n. \end{aligned} \tag{14}$$

The above linear system can be represents by matrix as

$$\begin{pmatrix} l_1 \\ l_2 \\ \vdots \\ l_n \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \cdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix} + \begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{pmatrix}. \tag{15}$$

Define

$$\boldsymbol{B} = (b_1, b_2, \cdots, b_n)^T. \tag{16}$$

The above linear equation can be rewritten as matrix equation as

$$\boldsymbol{L} = \boldsymbol{AX} + \boldsymbol{B}, \tag{17}$$

where $\boldsymbol{L}$ represents the total loss in the loss pattern, $\boldsymbol{AX}$ is the individual contribution of each parameter in the loss pattern.

Theorem 2. *The characteristic pattern of environmental events will influence the loss pattern in economic system, and the loss pattern in economic system will not influence the characteristic pattern of environmental events.*

Theorem 3. *The characteristic pattern of ecosystem change will influence the loss pattern in economic system, and the loss pattern in economic system will not influence the characteristic pattern of ecosystem change.*

From theorem 2 and theorem 3, we rewrite the equation to

$$\begin{aligned} l_1 =& a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n + a_{1(n+1)}c_1 + a_{1(n+2)}c_2 \\ &+ \cdots + a_{1(n+m)}c_m + \beta_1', \\ l_2 =& a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n + a_{2(n+1)}c_1 + a_{2(n+2)}c_2 \\ &+ \cdots + a_{2(n+m)}c_m + \beta_2', \\ \cdots& \\ l_n =& a_{n1}x_1 + a_{n2}x_2 + \cdots + a_{nn}x_n + a_{n(n+1)}c_1 + a_{n(n+2)}c_2 \\ &+ \cdots + a_{n(n+m)}c_m + \beta_{n+m}'. \end{aligned} \tag{18}$$

5.3 Link between environmental events and management system

$$\begin{aligned} r_1 &= a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n + \gamma_1, \\ r_2 &= a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n + \gamma_2, \\ &\cdots \\ r_n &= a_{n1}x_1 + a_{n2}x_2 + \cdots + a_{nn}x_n + \gamma_n. \end{aligned} \tag{19}$$

The above linear system can be represents by matrix as

$$\begin{pmatrix} r_1 \\ r_2 \\ \vdots \\ r_n \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \cdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix} + \begin{pmatrix} \gamma_1 \\ \gamma_2 \\ \vdots \\ \gamma_n \end{pmatrix}. \tag{20}$$

Define

$$\boldsymbol{G} = (\gamma_1, \gamma_2, \cdots, \gamma_n)^T. \tag{21}$$

The above linear equation can be rewritten as matrix equation as

$$\boldsymbol{R} = \boldsymbol{AX} + \boldsymbol{G}, \tag{22}$$

where $\boldsymbol{R}$ represents the total response in the risk management pattern, $\boldsymbol{AX}$ is the individual contribution of each parameter in the risk management pattern.

5.4 Overall description of the environmental risk management model

Theorem 4. *The characteristic pattern of environmental events will influence the response pattern for risk management, and the response pattern for risk management will also influence the characteristic pattern of environmental events.*

Theorem 5. *The change pattern in ecosystem will influence the response pattern for risk management, and the response pattern for risk management will also influence the change pattern in ecosystem.*

Theorem 6. *The loss pattern in economic system will influence the response pattern for risk management, and the response pattern for risk management will also influence the loss pattern in economic system.*

From theorem 4 and theorem 5 and 6, we rewrite the equation to a more general form. Since there are four different groups of variable, it is too complicated to write the equation with these four groups of variables, therefore we define a new variable φ to represent the parameters among these four patterns.

$$\Psi = (\varphi_1, \varphi_2, \cdots, \varphi_n)^T. \tag{23}$$

$$\begin{aligned} \varphi_1 &= \tau_{11}x_1 + \tau_{12}x_2 + \cdots + \tau_{1n}x_n + \varepsilon_1, \\ \varphi_2 &= \tau_{21}x_1 + \tau_{22}x_2 + \cdots + \tau_{2n}x_n + \varepsilon_2, \\ &\cdots \\ \varphi_n &= \tau_{n1}x_1 + \tau_{n2}x_2 + \cdots + \tau_{nn}x_n + \varepsilon_n. \end{aligned} \tag{24}$$

The above linear system can be represents by matrix as

$$\begin{pmatrix} \varphi_1 \\ \varphi_2 \\ \vdots \\ \varphi_n \end{pmatrix} = \begin{pmatrix} \tau_{11} & \tau_{12} & \cdots & \tau_{1n} \\ \tau_{21} & \tau_{22} & \cdots & \tau_{2n} \\ \vdots & \cdots & \cdots & \vdots \\ \tau_{n1} & \tau_{n2} & \cdots & \tau_{nn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix} + \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{pmatrix}. \tag{25}$$

Define

$$\boldsymbol{E} = (\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_n)^T, \tag{26}$$

and

$$\boldsymbol{\Lambda} = \begin{pmatrix} \tau_{11} & \tau_{12} & \cdots & \tau_{1n} \\ \tau_{21} & \tau_{22} & \cdots & \tau_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tau_{n1} & \tau_{n2} & \cdots & \tau_{nn} \end{pmatrix}. \tag{27}$$

The above linear equation can be rewritten as matrix equation as

$$\Psi = \boldsymbol{\Lambda X} + \boldsymbol{E}, \tag{28}$$

where Ψ represents the total response pattern in the risk management system, $\boldsymbol{\Lambda X}$ is the individual contribution of each parameter in the risk management pattern.

6 Conclusion and future research

In this paper, we suggested the PRMA as a tool for systematic approach of environmental risk management. Four types of characteristic pattern were defined in this paper to represent the environmental risk management. We determined the relationship of each pattern by multivariable analysis. By this model, a suitable response measure could be identified. Therefore, this study offers an ideal way for environmental risk management in the early stage or for the post examination. However, this study is still in the beginning phase, many fields could be expanded as described in the following. First, it is suggested having more precisely of the data about the patterns. Second, try to develop a new algorithm to estimate the relationship between each pattern. Third, find a quantitative way to calculate the risk. Finally, have more case study data for this model.

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