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RISK MANAGEMENT OF VULNERABILITY THROUGH FUZZY COGNITIVE MAP

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ABSTRACT

Risk management has been one of the vital concerns for financial institutes. This paper introduced concepts of "vulnerability" and "recoverability" to construct a fuzzy cognitive mapping (FCM) for risk management. Aside from exploring the exposures types and the degree of impact attributing to each of such exposures for financial institutes in Taiwan, it was also used to find out the factors affecting the exposure of financial institutes and the relations among the factors. The result of the analysis shows that organizational culture, risk appetite, and internal audit are the most crucial factors affecting the vulnerability of financial institutes. This research provides an exposure assessment system and recommendation to carry out a healthier financial institution management. It also expands financial research into a new field that enriches the vision for financial risk assessment.

KEYWORDS: *Risk Management, Fuzzy Cognitive Map, Vulnerability*

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INTRODUCTION

The financial crisis has always been the most unfortunate event that financial institutes do not want to encounter. The most well-known financial crisis in recent years shall be the Financial Crisis of 2007-2008 (also known as the 2008 Financial Crisis, subprime crisis, the credit crisis and the Financial Tsunami). The event refers to the liquidity crisis arising from investors started to lose confidence in the value of the pledged securities due to the outbreak of subprime crisis since August 9, 2007. The situation gradually got out of control in September 2008 and led to the shutdown of multiple large-scale financial institutes, or taken over by the government, eventually gave rise to the global financial disaster. During the financial crisis, financial institutes around the world were affected, including financial companies in Taiwan. With unforeseen and enormous financial turmoil, many financial companies experienced considerable impact, resulting in the drop in stock price. Even though those financial institutes have their recovery after a series of changes and adjustments, the crisis highlights the importance that the financial institutes shall take risk management as one of the most significant business issues.

With the impact of internationalization and globalization, the rapid changes of the time and the increase of the diversified demands of customers, enterprises are currently experiencing severe turbulence in operation. Taiwan's financial industry is facing a trend of the external environment with radical changes and an era of fast-transforming information technology. Therefore, operators in the financial sector must equip themselves with a certain

degree of understanding and reflection ability towards the operating risks in the external environment to provide adequate and concrete reformation plans during a financial crisis.

Financial industry participants must formulate a risk identification system for in its status, prepare an adequate operating strategy, according to all types of risk to efficiently minimize the impact when the company is facing such risks, and ensure the competitive advantages of the company. In other words, with the changing operating environment and the fierce competition in the market, how to further construct the risk map through financial risk identification shall become an essential subject for managers of financial institutes.

In response to the complex changes in the environment, financial organizations shall have the flexibility to adapt to the obscure environmental changes. When pursuing effective reflection of changes as a flexible entity, the enterprise will inevitably encounter the similar challenges of transformation; as such, how to further carry out the task of risk identification and formulate proper responding strategy according to different types of risks shall become the core subject for the operation of financial institutes. In respect to research on such issues, certain scholars consider that a relatively flat and agile structure or a team-oriented culture with broader authorization shall be adopted, to respond to the transforming demand of the environment, or to adjust the organization structure in time to comply with the new system for achieving the goal of globalized competitive strength. Care for the risk type and plans for minimizing risk impact are currently the most critical management task for many enterprises. Without transformation, the work of managers would remain unchanged and straightforward, and all the planning becomes easy; without uncertainties in the environment, the organization structure would not have to readjust, all the results for all the plans could predict precisely, and the decision process would become naturally smooth. However, it is far from the truth. Transformation is an inevitable process for all the organizations.

RESEARCH MODEL

Previously, the difficulties for applying system dynamics lie in the over-complicated relations among the variables within the system, and such ties were hard to express with accuracy. To overcome such restrictions, Axelrod proposed the cognitive maps theory in 1976, the concept mainly aimed at the resolving the non-structural problems. The method utilizes the causal diagram to establish the correlation among variables where the variables are the nodes in the system setting, and the correlations are the arcs connecting the nodes. The structure of cognitive maps is a series of the network instead of the singly linked tree structure. The construction step initially uses different variables and their connections to represent the event status, then forms the network with correlated elements and the degree of impact, exhibiting the positive or negative correlation between the variable only with plus or minus sign. FCM is used for analyzing the causal diagram among uncertainties; it builds the linkage between fact, patterns, value, and targets, to analyze the interaction and production of complex incidents. In the structure of FCM, the interplay among variables possesses the fuzzy feature and the positive and negative causal relations; therefore, FCM is a nonlinear dynamical system with feedback characteristics. FCM is used to enhance the application of the cognitive map. The feature is that FCM can deal with the relations between variables that are difficult to be defined in the cognitive map, emphasizing its privilege of only requiring a fuzzy relation. Issues that many decision-makers need to process usually possess the characteristics of multiple attributes, where the existing relations among the attribute may either be conflicting or related (Kosko, 1993). How to solve decision-making issues of such complexity has become one of the most challenging topics among decision methods. In recent years, FCM has achieved treasurable results regarding the research on complex social, economic issues through utilizing quantitative mathematical

model as the analytical approach. Currently, the FCM method has been widely applied in many fields, such as business decision (Wei *et al.*, 2008), urban planning (Xirogiannis *et al.*, 2004), enterprise resource planning (Bueno *et al.*, 2008), and e-commerce operation performance (Lee *et al.*, 2003).

For FCM, the operation mode for the entire cognitive map makes use of the level of correlation of variables (numerical value), which is first represented by the matrix method and represents the behavior of the changes in the behavior of the entire system by way of a mathematical matrix calculus. Then, filter each variable value after the matrix calculus through the mathematical form of threshold functions. The filtered results of such value shall serve as the present status after the effect of interplay within the system. The setting for changing the scale of each variable value is based on the type of threshold function, that is, the type of a threshold function represents the operation type for the associative model of the entire system. The purpose of FCM is to solve non-structural problems, to provide references for managers regarding decision making. The cognitive map method may use the causal diagram to establish the relations between the variables, and the primary elements shall be nodes and arcs. Variables represent nodes, and the lines linking variables shall be the arcs. Figure 1 shows a typical straightforward concept for FCM. As shown in figure 1, $X_1 \rightarrow X_3$, $X_3 \rightarrow X_4$, $X_4 \rightarrow X_1$, X_1, X_3, X_4, those three variables would form an iterative loop.

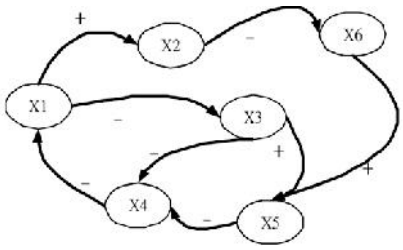

Figure 1: Fuzzy Cognitive Map

The establishment of FCM can be divided into the questionnaire survey method and the document coding method. Questionnaire survey method would gather experts in the field of specific to form a discussion group and discuss with each of the variables in the cognitive map, to ensure the variables worthy of taking into account as well as whether such variables would be affected by other secondary variables. Subsequently, it requires the experts to discuss and confirm the association and effect between variables, thus getting a relatively comprehensive picture of the initial cognitive map through organized, systematic analysis of relations in between variables by the above-mentioned experts. In terms of document coding method, the researchers shall firstly by collect related documents based on the specific issues, then further narrowing down useful information by way of sorting, induction and comparison, thus choosing variables relevant to the system association structure and build the network structure and relations of cognitive map in the form of a causal diagram.FCM operation program shall firstly establish a structure with causal relations in between each related variable, then convert the causal relations between variables into the expressive flow table, thus defining the qualitative and quantitative relation with the function and eventually carry out the simulation of dynamic changes. The operation form for FCM can be divided into the steps as follow:

- **Construct the Target System:** The target system constructed shall include nodes (system variables) and the causal link in between nodes (associations). Node Ci represents the phenomenon variables or a fuzzy set (similar to the neurons of the neural network) that adds up the input of nonlinear conversion for an output value. The Causal Link expresses the positive and negative causal relations of between Nodes C_i and C_j with plus or minus sign. However, the definition of the relations in FCM is not simply the positive and negative relations in

the cognitive map, but the influence of the number of factors in the range of [-1,1]. Such system combines the recommendations from experts, decides the input variables for the system according to features of issues, and analyses the causal links (the association between variables) to construct the feedback loop diagram and causal feedback relations matrix for the system.

- **Set the Initial Value:** Initial value shall be recognized with detailed definition and by rational stakeholders and experts before the systematic adoption. In FCM, the scale of the initial value of each system variable will be converted to the range of [0,1], but it must be a rational number to avoid errors in matrix operation.The initial value can be distinguished by the data type of the system variables. Most quantitative variable data can be represented by the quantity or ratio scale, where ratio scale can satisfy the status for the initial value, but the quantitative scale requires the setting of caps through the normalization to convert the data into the ratio scale
- **Select the Threshold Value:** Threshold value can prevent the value of Node $C_i$exceeding its defining domain. The threshold functions defined by the scholars include Bivalent, Trivalent, Logistic Signal Function, Unipolar Sigmoid, etc. The selection of the threshold functions influences the results of the inferences.
- **System Operation:** Operating system for FCM requires an initial construction of structures in between each associated variable by causal relations, then convert such causal relations into an expressive flow table for the characters of variables. And eventually, carry out the operation and the simulations of the changes. Form (1) explains the structure of iterative computations within FCM.

$$x_i(t) = f \cdot \left(\sum_{\substack{j=1 \\ j \neq i}}^{n} x_j(t-1) w_{ji}\right), f = \frac{1}{1+e^{-\lambda x}} \quad (1)$$

In Form (1), $x_i(t)$ represents the status of Variable i in Phase t, with the value within 0 to 1. The closer of Variable x_i to 1 show a better status of the Variable (or worse status, subject to the definition of the Variable). w_{ji} is the weight for the effect of Variable j on Variable i. The absolute value of w_{ji} shall be less than 1; a positive value represents the positive effect of Variable j on Variable i, where a negative value represents the negative effect of Variable j on Variable i, higher value means more significant effect. From Form (1), we can tell that the status of Variable x_i in Phase t is subject to the status of all the variables under Variable x_i in Phase t f is the transform function, it ensures keeping the value range of variables within the initial settings after iterative computations within FCM, converting the value of xi (t) to between 0 and 1. This paper has chosen Logistic Signal Function as the transforming function, the typical setting for its parameter λ ranging within 0.2-5 (Ghazanfari *et al*., 2007 ; Kim *et al*., 2008 ; Papageorgiou and Groumpos, 2005). The setting of λ is related to the numbers of variables and the complexity among variables within FCM. Researchers may decide the value of λ according to the feature set of the FCM. In this research, the value of λ is set at 3.

MODEL CONSTRUCTION AND ANALYSIS

To understand the relevant management factors and affecting factors in the case study in the face of financial crisis, this section introduced factors of vulnerability and recoverability, as well as related vulnerable factors, with their description are set out in Table 1 and Figure 2. We can says the interaction between factors from Figure 2 by the direction of arrows, which represents the relationship between the officer and the affected. Then, carry out the expert questionnaire survey. First, give a summary to respondents on the scope and purpose of this research and describe the definition and content of each variable. After confirming the definition and content of these 8 affecting factors, proceed to the filling step,

and requires experts to assess the status for these 8 factors, the provide the status of such factors and the influence weight among variables in the questionnaire form provided by this researcher. The status value of the factors is restricted to rational numbers, rounding to 2 decimal places ranging within {0~1}, and the influence weight between factors shall be limited to rational numbers rounding to 2 decimal places ranging within {-1~1} according to FCM. This paper has collected questionnaire information from 8 experts in the financial risk sector. For the reason that all experts may belong to financial institutes carrying different roles and functions in the service system, and to avoid the effect of extremum, this paper calculates the geometric average of the information provided by experts as matrix needed for the model variables. See Table 2.

According to the initial value of the status variables and the influence weight matrix among variables, carry out repeated operation calculation through the analysis step described in the Form (1) to arrive at the dynamic changes of variables through time within the system. Experts in the survey said that international financial institutes generally require approximately a week to prepare and react to the effect when encountering changes in the external environment that call for change. During the week, the system would carry out (1) meetings to confirm the operation, content of the change; (2) operation, adjustment by relevant units; (3) announcement to the units and commencement of new operational implementation. Also, for research on operations of financial institutes, Wang et al. Have set the managerial implications for each repeated calculation in FCM as one week. Therefore, considering the recommendation from experts in the survey and research documents, this paper has set the managerial implications for each repeated calculation in as one week. Figure 3 explains the final status for dynamic changes of the system and status variables. Figure 3 shows that most of the variables in FCM have arrived at a stable status after 8 times of repeated calculations; therefore, it refers to the status may become stable after approximately two months. Figure 3 describes the status changes of the variables in the system. Figure 3 shows that risk appetite has decreased from 0.5 to 0.43; compliance with regulations has increased from 0.55 to 0.96; operation management has increased from 0.6 to 0.95; organizational culture has increased from 0.6 to 0.71; internal audit has changed from 0.4 to 0.54; communication frequency has increased from 0.3 to 0.59; external connectivity has increased from 0.33 to 0.63; and vulnerability has decreased from 0.6 to 0.15.

Table 1: Description of Vulnerable Factors for the Studying Case

Code	Variables	The Description of the Variable Content
$\mathbf{X_1}$	Risk appetite	Risk appetite refers to the attitude of a company when facing financial risks. The increase of risk appetite indicates the willingness of the financial institutes to take up higher exposures for higher returns
$\mathbf{X_2}$	Compliance with regulations	The financial companies' extent of compliance with the relevant financial regulations. Where a company of high compliance concerning the regulations, the exposure to the law may be further reduced, however, it may cause rigid decisions and less flexibility of the company
$\mathbf{X_3}$	Operation management	Refers to professionalism and consistency of staff performance in the daily course of operation of a company. Poor performance on operation management may lead to operational risks arising from human error
$\mathbf{X_4}$	Organization culture	Organization culture refers to a combination of the highest target standard, basic concept and code of conduct of that gradually formed through a long-term existence and development and is organization-specified and followed by most of the member within the organization. Healthy organization culture is beneficial to the operation performance and the resistance to exposures of the company
$\mathbf{X_5}$	Internal audit	Optimized internal audit function of financial institutes is advantageous to the improvement on the operation management of such institutes, reduce the possibility of human error in management and operation flow that may lead to financial exposures
$\mathbf{X_6}$	Communication	Refers to the meeting and communication frequency between members of the financial

	frequency	institutes in daily operation. When operation bottleneck occurred, the frequency of communication, meeting, and negotiation increases.
X_7	External connectivity	Refers to the connectivity between financial institutes and the external environment, including the connection with government and other related industries or companies. The higher the external connectivity, the higher the chance for maintaining flexibility or grasping further information on market changes, thus strengthen the resistance to exposure of financial institutes
X_8	Vulnerability	The vulnerability of financial institutes refers to the original status of the system before the occurrence of disasters, which serves as the structural factor regarding the resistance of the financial system to the disaster

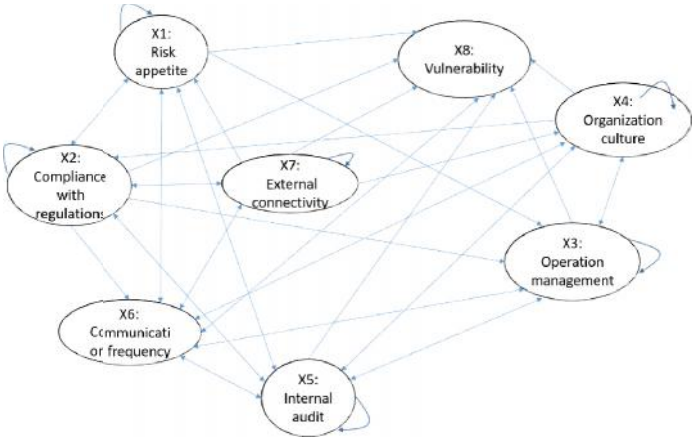

Figure 2: Research Model

This paper further discussed on which variable shall be the principal influence factor in FCM through using the Sensitivity Model and analyzed the influence and influence weight of each variable. The positivity or negativity of factors influence is not the focus of sensitivity analysis; therefore, the influence weight of variables shows in the matrix of the sensitivity analysis are their absolute value. The results for the matrix of sensitivity analysis after the conversion are set out in Table 2 and Figure 4.

Table 2: Analysis Matrix of FCM

Variables	Code	x1	x2	x3	x4	x5	x6	x7	x8	AS	Q
Risk appetite	X_1	0.65	0.30	0.30	0.00	0.40	0.00	0.00	0.50	2.15	1.89
Compliance with regulations	X_2	0.50	0.85	0.30	0.00	0.10	0.26	0.74	0.40	3.15	1.88
Operation management	X_3	0.00	0.00	0.35	0.20	0.27	0.30	0.00	0.30	1.42	1.75
Organization culture	X_4	0.00	0.20	0.20	0.85	0.30	0.53	0.50	0.73	3.31	1.85
Internal audit	X_5	0.30	0.30	0.40	0.20	0.15	0.50	0.00	0.20	2.05	1.22
Communication frequency	X_6	0.24	0.00	0.20	0.30	0.00	0.00	0.50	0.50	1.74	2.39
External connectivity	X_7	0.20	0.23	0.00	0.30	0.00	0.10	0.30	0.74	1.87	2.04
Vulnerability	X_8	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.00	0.70	3.37
RS		1.89	1.88	1.75	1.85	1.22	2.39	2.04	3.37	Q=AS/RS	

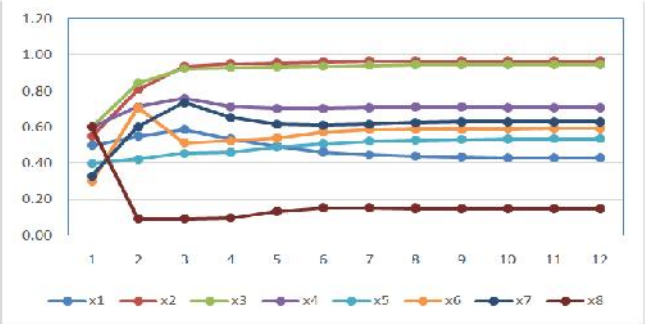

Figure 3: Analysis Results of FCM

In Table 2, AS (Active Sum) represents the value of the sum of all the influence weight regarding one factors influence on other factors. For example, the AS value 3.15 of Factor X2 (compliance to regulations) represents the sum of all the influence weight regarding Factor X_2' s influence on Factor X_1 ~X_8. Higher AS value refers to factor may have more impact on other factors. Table 4 shows that the top 3 factors with the highest AS value are "organizational culture," "compliance to regulations," and "risk appetite" in order, respectively. PS (Passive Sum) represents the value of the sum of all the influence weight regarding the exposure of one factor from other factors. For example, the PS value 1.85 of Factor X_4 (organizational culture) represents the sum of all the influence, the influence weight regarding the exposure of Factor X_4 from Factor X_1 ~X_8. Higher PS value means the factor may have a higher exposure to influence from other factors. The 3 factors with the highest PS value are "external connectivity," "communication frequency," and "risk appetite" in order, respectively.

To include the factors' exposure to influence from other factors and the influence of other factors into consideration, this study used Q value (Q=AS/PS) to discuss the features of different factors. The higher Q value indicates that the factor can affect others, smoothly without being affected. The result of the Q value sets out in Table 4. According to AS and PS, we acknowledge that, if a variable locates further away from the base point on the sensitivity analysis figure, it indicates the variable can easily affect or be easily affected by others. Q value is used to represent the area size of the variable on the figure. The results of the sensitivity analysis of Factors X_1~X_8 set out in Figure 4.

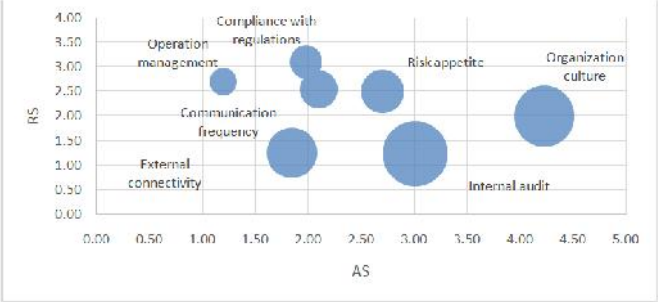

Figure 4: Analysis Results of Sensitivity Analysis

CONCLUSIONS AND RECOMMENDATION

Generally, when the environment changes and for corporates to achieve sustainable development and breakthrough the current situation, except for transformation such as internal structure adjustment or modification for organization target for corporate, an open, evolving condition and healthy interaction and interdependency with the environment may as well be beneficial for corporate to form a new corporate operational model. Therefore, scholars began

to focus on the trend of applying arguments from the new scientific model to explore the phenomenon “joint evolution of corporate and environmental” in recent years. Many studies show that all the risk events encountered by corporate imply the premises of learning and open-up for evolution Also, under the obscure condition, with the mechanism of collaborative competition and joint evolves, companies shall carry out organization transformation and adjustment accordingly. As such, this paper studies the issue of operational risk identification and assessment for financial institutes and construct the FCM basing on vulnerability and recoverability. Factors affecting vulnerability include risk appetite, compliance with regulations, operation management, organization culture, internal audit, communication frequency and external connectivity. Through the construction and dynamic analysis of FCM, the result of which shows that "organization culture," “compliance to regulations,” and “risk appetite” are the main factors affecting the vulnerability of financial institutes. If the finance authority can require financial institutes to comply with relevant financial regulations and review the organization culture and variables, such as risk appetite, of financial institutes themselves, the exposure of financial institutes can be managed efficiently, thus reducing the vulnerability of financial institutes.

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