

Applying Fuzzy AHP to Study the KSFs of Information Security Management

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Abstract - The launch of the digital era has made information security management a most significant and critical issue. However, perfect information security management requires certain factors for complete success. This study aims to collect Key Success Factors (KSFs) for information security management through literature review and design of a questionnaire survey. This comprises four major aspects: (1) External dimension, (2) Internal dimension, (3) Technology dimension, and (4) Execution dimension. Based on these, we proceed with categorization and analysis using Fuzzy Analytic Hierarchy Process (Fuzzy AHP or FAHP), which was applied to this study to overcome the seeming failure of general Analytical Hierarchy Process (AHP) in dealing with respondents' impersonal differences in paired comparison.

The ordered ranking of objectives under each aspect is: system, human resource, security function, organization, performance, operation, market, and legislation. The results sifted from the FAHP approach suggest five top key success factors: "Training Plan", "MIS Staffing", "System Structure", "Regulation", and "Maintain Service".

Keywords - Information Security Management, Key Success Factors, Fuzzy Analytic Hierarchy Process

I. INTRODUCTION

It has been recognized that due to the development of information and communication technology, most organizations now heavily rely on information systems to provide effective information for supporting operation and decision activities. This information is valuable and important capital for organizations. Porter and Millar stated that the complete information management keeps an enterprise competitive [1]. Information management also sustains an enterprise's competitive advantage [2], and contributes to its performance [3, 4]; Obviously, the key issue is how to manage information security systems to meet the requirements of all of organizations and achieve organization's goals [5]. Torres et al. also mentioned the importance of information security management to ensure an organization can take advantage of information management, with its criticality, openness and risk [6].

Gordon and Martin analyzed the role of information

security based on the viewpoint of competition systems [7]. They regarded investment in information security to have extreme value, as it could help an organization occupy markets and upgrade competence. Organizations should make appropriate information security management policies in order to keep their information system safe [8, 9]. Information security management issues could be addressed through several dimensions and diverse means [10], but might be concluded to be the combination of information, technology, and people [11]. Another definition is that information security management is the detection and prevention of unauthorized actions from computer system users [12, 13]. There are many factors that will affect the organizational policies for information security management [14]. Austin et al. also pointed out that certain key items should be noted to implement information security management [15].

As discussed above, in order to realize the importance of information security management implementation through study, we use theories, key success factors (KSFs) and Fuzzy AHP. Identification of the KSFs of information security management implementation is a multiple-criteria decision making (MCDM) problem with many quantitative and qualitative attributes. We selected the analytic hierarchy process (AHP) method developed by Saaty [16], as it has been widely applied for affirming the issue of criteria importance [17]. However, conventional AHP uses pairwise comparisons at each level with respect to the importance of criteria for the goal, and judge by using a nine-degree scale. So there is a possibility that the application of Saaty's AHP might have some shortcomings [18].

In addition, respondent considerations on criteria priority and importance always contain ambiguity and multiplicity of meaning. It is also recognized that human assessment of qualitative attributes is always subjective and thus imprecise. Therefore, conventional AHP seems inadequate to explicitly capture the considerations of respondents. In order to model this uncertainty in human preference, fuzzy sets could be incorporated with pairwise comparison as an extension of AHP.

This Fuzzy AHP was formerly proposed to solve the inevitable vagueness incident to AHP, and allows a more accurate description of the decision making process.

In this research, a fuzzy AHP approach is proposed to compensate for the vagueness and uncertainty of the attribute importance determination of respondents. This approach is used because the crisp pairwise comparison of conventional AHP seems too insufficient and imprecise in capturing the degree of importance of respondents' KSF evaluations. Our goal is to discover the KSFs of information security management implementation, and apply Fuzzy AHP to analyze them.

II. LITERATURE REVIEW

A. Key Success Factors (KSFs)

The perspective of KSFs was first proposed by Daniel [19], who stated that most successful organizations possess three to six fundamental elements. An organization that wants to succeed must focus and specialize on these essentialities. Most recently, the KSFs concept has been widely applied to management research. Many researchers apply it, especially in industrial analysis and strategy management where the concept of KSFs is interpreted and extended. This shows KSFs becoming explainable, durable, and consistent [20, 21, 22, 23, 24]

We concur with previous researchers who argued that KSFs are characters, criteria, or variables. If these factors are appropriately supported, maintained, and managed, they would be greatly beneficial to the success of organizations in certain industries [25]. KSFs would be a character, like price competence, and also a criterion, like capital structure or superior customer combination.

B. Fuzzy Analytic Hierarchy Process (FAHP)

The earliest research in fuzzy AHP was argued by van Laarhoven and Pedrycz [26], who compared fuzzy ratios described by triangular membership functions. In this research, Lootsma's logarithmic least square was used to derive local fuzzy priorities. Later, using geometric mean, Buckley determined fuzzy priorities of comparison ratios whose membership functions were trapezoidal [27]. Modifying van Laarhoven and Pedrycz's method, Boender et al. presented a more robust approach to the normalization of local priorities [28]. Taking the perspective, Chang [29] and Mikhailov [30] applied row mean method to obtain priorities for comparison ratios which were fuzzy triangular numbers.

All the aforementioned works compute fuzzy priorities based on arithmetic operations for fuzzy triangular (or trapezoidal) numbers. To be able to use fuzzy arithmetic operations, specific assumptions on the forms of membership functions are required. To date, there are only a limited number of membership-function forms that are computationally manageable. Moreover, the accuracy of the final ranking is inevitably weakened by the series of approximations required during the computation procedure. But the most important criticism on these works has to be their failure to address the issue of consistency.

The issue of consistency in fuzzy AHP was first tackled by Salo [31]. Departing from the fuzzy arithmetic approach, Salo derived fuzzy weights using an auxiliary programming formulation, which described relative fuzzy ratios as constraints on the membership values of local priorities. Expressing relative weights' feasible region in terms of linear inequalities was previously proposed by Arbel [32], and extended in Salo and Hämäläinen [33]. Requiring only quasi-concave and continuous fuzzy comparison ratios, Salo defined consistency in terms of the mean values of the fuzzy ratios (range of values with membership degree equal to one). Here, a fuzzy matrix was considered consistent if there were a set of crisp relative weights within the feasible region defined by the ranges of mean values. When the matrix was not consistent (no crisp weights existed), Salo proposed a simple heuristic which enlarged the feasible region and also guaranteed feasible weights.

After the above literature review, we found the fuzzy AHP method modified problems that might happen in the traditional AHP method, including imprecision, obscurity and disproportion of scales. Therefore, this research decided to use the fuzzy AHP method to study weights of the KSFs of information security management implementation. This is by using triangular fuzzy numbers, group integration, and fuzzy ranking to build fuzzy analytic hierarchy process.

III. FAHP RESEARCH APPROACH

The FAHP research approach for studying the KSFs of information security management is demonstrated in the following steps:

Step 1: Building the Hierarchy Model and Its Criteria

Based on literature review, we used KJ method to build the hierarchy model [34]. After revising both the hierarchy and descriptions of criteria, we finally developed a hierarchy KSFs model (refer to Figure 1). The first level is the goal, the KSFs of information security management. The second level is the four aspects of the KSFs. The third level is objectives which affect the success of information security management. The fourth level represents all involved and relevant criteria.

Step 2: Designing the Questionnaire

Using the hierarchy model built in Step 1, we adopt the concept of AHP to design the questionnaire as pairwise comparison of the relative importance of criteria, using a scale from 1 to 9, to form comparison matrices.

Based on the FAHP analysis, the variables were compared in pairs. The relative importance between two variables, from low to high, was mainly given five ranks: (1) for equally important, (3) for slightly important, (5) for very important, (7) for extremely important, and (9) for absolutely important. Ranks (2), (4), (6), and (8) in were also assigned between these ranks accordingly. In fuzzy sets, the interval value, instead of crisp value, was provided for filling in the questionnaires for the pairwise comparison.

Step 3: Building Fuzzy Converted Judgments $\tilde{M}_{ij}$ Matrices

We used the triangular membership function and cuts to convert the subjective judgments of the respondents to fuzzy judgments. We extracted the judgments of each criterion, objective and aspect, and use the triangular fuzzy number rules on Table I to convert.

Table I . Triangular fuzzy numbers for the pairwise comparison scale

Linguistic Scale	Triangular fuzzy numbers
Equal Important	$\tilde{1} = (1,1,1)$
Between each ranks	$\tilde{2} = (1,2,3)$
Slightly Important	$\tilde{3} = (2,3,4)$
Between each ranks	$\tilde{4} = (3,4,5)$
Very Important	$\tilde{5} = (4,5,6)$
Between each ranks	$\tilde{6} = (5,6,7)$
Extremely important	$\tilde{7} = (6,7,8)$
Between each ranks	$\tilde{8} = (7,8,9)$
Absolutely important	$\tilde{9} = (8,9,10)$

We first formulated all initial individual fuzzy comparison matrices based on the triangular membership function, then used Microsoft Excel to calculate the fuzzy weight.

$$M = [\tilde{M}_{ij}] ; \quad \tilde{M}_{ij} = (L_{ij}, M_{ij}, R_{ij}) ; \quad \tilde{M}_{ij} = 1/\tilde{M}_{ji} , \\ \forall i, j = 1, 2, \dots, n \quad (1)$$

Step 4: Group Integration

We used the geometric approach of Buckley to integrate respondents' judgments into group fuzzy comparison matrices [27]. The formula is as follows:

$$\tilde{m}_{ij} = (1/N) \otimes (\tilde{m}_{ij}^1 \oplus \tilde{m}_{ij}^2 \oplus \dots \oplus \tilde{m}_{ij}^N) \quad (2)$$

Step 5: Calculating Fuzzy Weights

We calculated fuzzy weights $\tilde{w}_i$ through the following formulas:

$$\tilde{Z}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \dots \otimes \tilde{a}_{in})^{\frac{1}{n}}, \forall i = 1, 2, \dots, n \quad (3)$$

$$\tilde{w}_i = \tilde{Z}_i \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \dots \oplus \tilde{Z}_n)^{-1} \quad (4)$$

Step 6: Defuzzication

We took the algorithm developed by Teng & Tzeng to do defuzzication [54]. The equation of the weights of defuzzication, DF_{ij} , is as follows:

$$DF_{ij} = [(R_{ij} - L_{ij}) + (M_{ij} - L_{ij})] / 3 + L_{ij} \quad (5)$$

Step 7: Normalization

The formula of normalization weights NW_i is as follows:

$$NW_i = DF_{ij} / \sum DF_{ij} \quad (6)$$

Step 8: Series of Hierarchical

Through the above steps, we got the weights NW_i of "i" aspect at level 2, and NW_{ij} of "j" objective at level 3 under certain level 2 aspect. NW_{ijk} is the weight of criterion "k" at level 4. If we want to get NW_k , the final weight of "k" criterion under level 1, the top goal of this research, we calculate per series of hierarchical using formula (7).

$$NW_k = NW_i \times NW_{ij} \times NW_{ijk} \quad (7)$$

With above illustration and calculus, we can get the weights to rank the priority of KSFs after series of hierarchical, achieving the goal of this research. This research mainly used Microsoft Excel to process data and analyze the questionnaire.

IV. EVALUATING HIERACHICAL STRUCTURE FOR KSFs

This research found the KSFs of information security management through literature review, then extracted and compiled the KSFs into 25 criteria, as Table II illustrates. Next, we used KJ method to categorize these 25 criteria into 8 objectives, then conducted these 8 objectives into 4 aspects to fulfill the goal, the KSFs of information security management. The 4 aspects are: (1) External Dimension; (2) Internal Dimension, (3) Technology Dimension, and (4) Execution Dimension. KSFs could be inducted from the External and Internal Dimension of the organization, or the condition of the topic [22, 35, 36, 37]. A successful information security management results from the two dimensions Technology and Execution [38, 39, 40]. In this way, we completed the framework of the research hierarchy shown in Figure 1.

(Table II . The criteria of KSFs and relative references)

(Figure 1. The hierarchy model of KSFs of information security management.)

V. DATA ANALYSIS

We released a total of 25 expertise questionnaires and collected results for all. Ten of the respondents are experts in the information security system industry, and the other 15 are information system managers in sizable companies. The following results were obtained through Fuzzy AHP analysis.

A. The Evaluation Results and the Analysis of the Measurement in Level 2

The level 2 aspects are: (1) External Dimension, (2) Internal Dimension, (3) Technology Dimension, and (4) Execution Dimension. The fuzzy weighted values and rankings are shown in Table III.

Table III. The fuzzy weights of the aspects

Aspects	Fuzzy weights	Ranking
External Dimension	0.12	4
Internal Dimension	0.21	3
Technology Dimension	0.38	1

Execution Dimension	0.29	2
CI=0.047 CR=0.049		

Table III states that the Technology Dimension is the most important aspect of the KSFs of information security management. The next in importance was the Execution Dimension. The Internal Dimension is the third most important factor, and the External Dimension is the last.

B. The Evaluation Results and the Analysis of the Measurement in Level 3

The level 3 objectives and their fuzzy weighted values and ranking are shown in Table IV.

Table IV. The fuzzy weights of the objectives

Level 2 Aspects	Level 3			
	Objectives	Fuzzy weights	Ranking	Tests
External Dimension	Legislation	0.46	2	CI=0.046 CR=0.080
	Market	0.54	1	
Internal Dimension	Organization	0.61	1	CI=0.049 CR=0.084
	Operation	0.39	2	
Technology Dimension	System	0.52	1	CI=0.034 CR=0.059
	Security Function	0.48	2	
Execution Dimension	Human Resource	0.65	1	CI=0.046 CR=0.079
	Performance	0.35	2	

C. The Evaluation Results and the Analysis of the Measurement in Level 4

The level 4 criteria and their fuzzy weighted values and ranking are shown in Table V.

(Table V. The fuzzy weights of the criteria)

D. The Weights of Series of Hierarchical

Using Tables 3, 4, and 5, we can calculate the weights after series of hierarchical to rank all criteria in the KSFs of information security management. This is shown in Table VI.

(Table VI. The weights after series of hierarchical)

Table 6 demonstrates the final results from using FAHP to rank the KSFs in order of importance, using the data on the 25 criteria received from respondents. The highest final weight is "Training Plan" under Human Resource, which accounts for about 8.1% and is therefore the most important factor. The second is "MIS Staffing", also under Human Resource, which accounts for 6.6%. The close relationship of these criteria to the "Human Resource" objective could obviously indicate that people are a critical aspect of information security management execution.

The third most important accounted for 6.2%, and is "System Structure" under System and the most important factor at Technology Dimension. However, since Technology Dimension is the most important aspect, its factors are comparatively unremarkable. The fourth most important factor, "Regulation", accounts for 5.5%. We understand that

government policy has some affect on enterprises implementing information security management. The System's "Maintain Service" accounted for 5.3%, and is fifth in the ranking. It seems enterprises rely more on system suppliers' service.

VI. CONCLUSION

This research adopts Fuzzy AHP that ranks the KSFs of information security management per investigation of expert opinions in this field. By using the empirical analysis results, we verified the perspectives of previous research on factors affecting information security systems, and worked out systematic priority of these factors. The results can also be organized and interpreted to form suggestions to relevant people. This Fuzzy AHP approach makes this research capable of precisely disclosing the importance of factors and developing deep knowledge of them.

The research results of the KSFs of information security management analyze the 25 criteria listed previously in this paper, and suggest the more critical success factors for information security management. Although some weights are distributed averagely, we can still realize successful information security management through multi-aspect efforts to achieve the goal without neglecting anyone.

The "Technology Dimension" aspect conclusively takes the first position, and reveals that technology criteria all play considerably important roles in information security management. Although "Execution Dimension" does not rank as high as "Technology Dimension" in aspect comparison, its criteria under the Human Resource objective, "Training Plan" and "MIS Staffing", are the two most important criteria. This shows that reviewing KSFs from different levels may result in different answers, and this is evidently also pointed out by AHP analysis.

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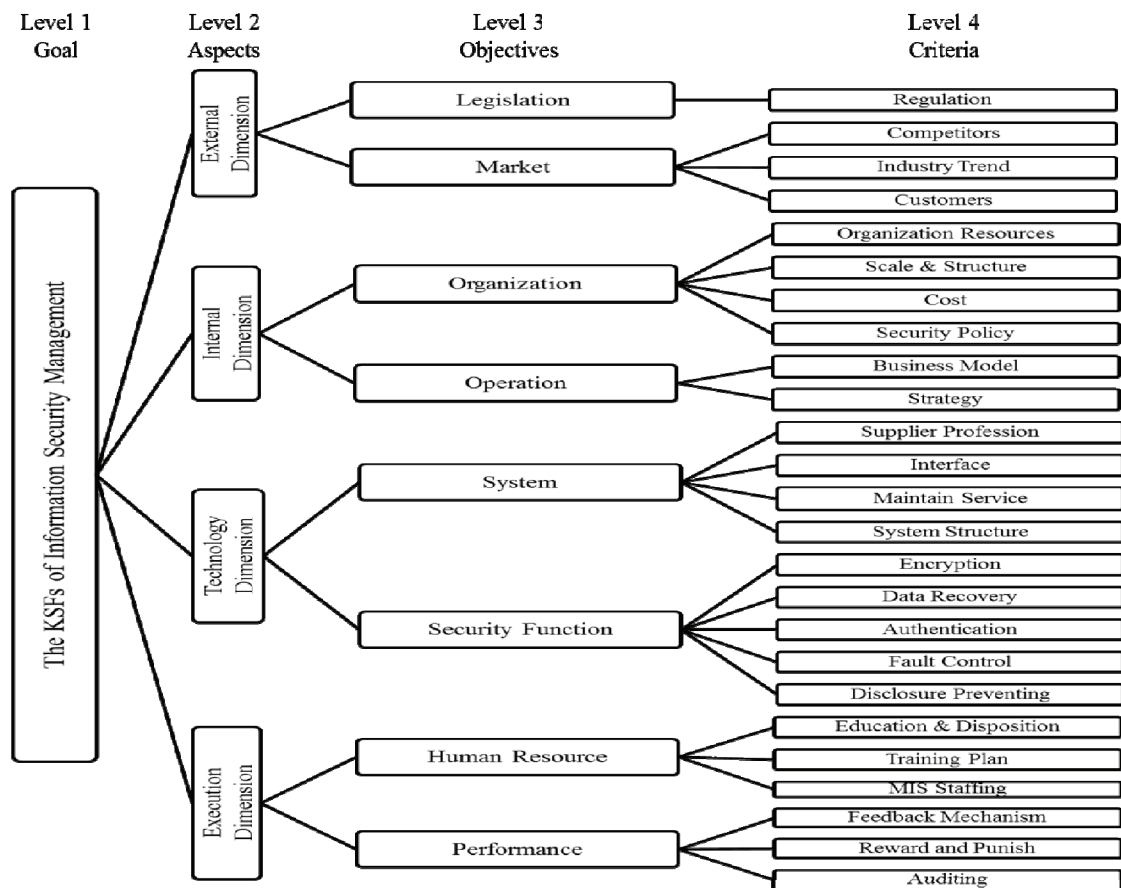


Figure 1. The hierarchy model of KSFs of information security management.

Table II. The criteria of KSFs and relative references

Aspects	Objectives	Criteria	Reference Index	References	
External Dimension	Legislation	Regulation	(17) (20) (22) (21) (23)	(1) Anderson & Choobineh (2008) [41]	
	Market	Competitors	(1) (4) (5) (6) (11) (14)	(2) Austin et al.(2003) [15]	
		Industry Trend	(1) (4) (5) (6) (11) (13) (14)	(3) Caminada (1998) [42]	
		Customers	(1) (4) (5) (14)	(4) Chang & Yeh (2006) [43]	
Internal Dimension	Organization	Organization Resources	(2) (15) (17) (22) (23)	(5) Chwelos et al. (2001) [44]	
		Scale & Structure	(2) (8) (15) (18) (23) (24)	(6) Cohen (1998) [45]	
		Cost	(4) (13) (16) (21) (23) (24)	(7) Dhillon & Backhouse (2001) [46]	
		Security Policy	(3) (4) (15) (16) (18) (20) (21) (24)	(8) Eloff & Solms (2000) [39]	
	Operation	Business Model	(1) (4) (12) (13) (15) (20) (24)	(9) Gollmann (1999) [12]	
		Strategies	(1) (4) (11) (12) (13) (18) (20) (24)	(10) Gordon & Loeb (2006) [47]	
	Technology Dimension	System	Supplier Profession	(8) (10) (17) (21) (22)	(11) Gordon & Maltin (2001) [7]
			Interface	(3) (9) (17) (22) (23)	(12) Hinde (2001) [11]
Maintain Service			(8) (10) (21) (22) (23)	(13) Kankanhalli et al.(2003) [8]	
System Structure			(2) (9) (17) (21) (22)	(14) Lillywhite (1999) [48]	
Security Function		Encryption	(3) (17) (21) (22) (23)	(15) Olnes (1994) [49]	
		Data Recovery	(9) (17) (20) (22) (23)	(16) Osborne (1998) [50]	
		Authentication	(2) (8) (19) (22) (23)	(17) Ozier (1997) [51]	
		Fault Control	(3) (15) (18) (19) (23)	(18) Pounder (2001) [14]	
		Disclosure Preventing	(3) (9) (19) (22) (23)	(19) Schultz et al. (2001) [52]	
		Education & Disposition	(3) (7) (12) (16) (17) (19)	(20) Solms (2001) [10]	
Execution Dimension	Human Resource	Training Plan	(7) (12) (16) (17) (18) (19) (23)	(21) Torres et al. (2006) [6]	
		MIS Staffing	(3) (7) (16) (19) (23)	(22) Tr��k (2003) [40]	
		Feedback Mechanism	(2) (8) (16) (18) (19)	(23) Tudor (2001) [53]	
	Performance	Rewards and Punish	(7) (8) (12) (17) (19)	(24) Ward & Smith (2002) [9]	
		Auditing	(16) (19) (20) (22) (23)		

Table V. The fuzzy weights of the criteria

Level 2 Aspects	Level 3 Objectives	Level 4			
		Criteria	Fuzzy weights	Ranking	Tests
External Dimension	Legislation	Regulation	1	1	CI=0.002 CR=0.002
	Market	Competitors	0.44	1	CI=0.068 CR=0.075
		Industry Trend	0.19	3	
		Customers	0.37	2	
Internal Dimension	Organization	Organization Resources	0.19	4	CI=0.084 CR=0.093
		Scale & Structure	0.24	2	
		Cost	0.35	1	
		Security Policy	0.22	3	
	Operation	Business Model	0.37	2	CI=0.043 CR=0.048
		Strategies	0.63	1	
Technology Dimension	System	Supplier Profession	0.19	4	CI=0.071 CR=0.079
		Interface	0.22	3	
		Maintain Service	0.27	2	
		System Structure	0.32	1	
	Security Function	Encryption	0.20	3	CI=0.078 CR=0.087
		Data Recovery	0.23	2	
		Authentication	0.25	1	
		Fault Control	0.18	4	
Execution Dimension	Human Resource	Disclosure Preventing	0.14	5	
		Education & Disposition	0.22	3	CI=0.057 CR=0.063
		Training Plan	0.43	1	
	Performance	MIS Staffing	0.35	2	
		Feedback Mechanism	0.33	2	CI=0.068 CR=0.075
		Reward and Punish	0.26	3	
		Auditing	0.41	1	

Table VI. The weights after series of hierarchical

Level 1 Goal	Level 2 Aspects		Level 3 Objectives		Level 4 Criteria		Final Weights	Ranking
KSF of Information Security Management	External	0.12	Legislation	0.46	Regulation	1	0.0552	4
			Market	0.54	Competitors	0.44	0.0285	19
					Industry Trend	0.19	0.0123	25
					Customers	0.37	0.0240	24
	Internal	0.21	Organization	0.61	Organization Resources	0.19	0.0243	23
					Scale & Structure	0.24	0.0307	17
					Cost	0.35	0.0448	8
					Security Policy	0.22	0.0282	20
			Operation	0.39	Business Model	0.37	0.0303	18
					Strategies	0.63	0.0516	6
	Technology	0.38	System	0.52	Supplier Profession	0.19	0.0375	13
					Interface	0.22	0.0435	9
					Maintain Service	0.27	0.0534	5
					System Structure	0.32	0.0632	3
			Security Function	0.48	Encryption	0.20	0.0365	14
					Data Recovery	0.23	0.0420	10
					Authentication	0.25	0.0456	7
					Fault Control	0.18	0.0328	16
	Execution	0.29	Human Resource	0.65	Disclosure Preventing	0.14	0.0255	22
					Education & Disposition	0.22	0.0415	12
					Training Plan	0.43	0.0811	1
			Performance	0.35	MIS Staffing	0.35	0.0660	2
					Feedback Mechanism	0.33	0.0335	15
					Reward and Punish	0.26	0.0264	21
					Auditing	0.41	0.0416	11