Developing a Fuzzy Grey Decision System: An Application for the Safety of Hillside Residence Area in Taiwan

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Abstract: A fuzzy grey decision system framework is introduced as groups of expertise and disaster data collection of hillsides that can cooperate to prepare for and response to hillside safety situations. In this framework, the influential factors and weights play critical roles because they are the foundation for the evaluation model in hillside residence safety. Therefore, an integration system of Grey Statistics method and Fuzzy Analytic Hierarchy Process(FAHP) is proposed to search for the efficient model. Within this system, three pivotal issues need to be addressed: describing the information of uncertainty and imprecision, setting up a model of team decision, multi-standard and criticism, and providing an immediate evaluation system. In this paper, the system development processes and the implementation usage are discussed in detail. The results recognize relative weights between the influential factors and promote the real efficiency of Taiwan's hillsides disaster can be important references for establishing the evaluation model. In addition, this system significantly provides an immediate decision system to improve the application in hillside residence area, increases system accuracy and computational efficiency.

Key-Words: Hillside, Influential factors, Grey Statistics, FAHP, Immediate evaluation system, Computational efficiency.

1. Introduction

Limited resources of the plains highlighted the inevitability of hillside residence area development because of the physical environment of Taiwan is constituted major by mountainous lands. Taiwan is located on the border of Eurasia Plate and Philippine Plate where earthquakes are frequent and unavoidable, which adds to the instability of hillsides. Additionally, rainy weather and sudden rainstorms during typhoon season have a great influence on hillside constructions. Therefore, keeping hillside residences safe and sound is an imminent and significant issue.

Hillside residents and engineers always have to compromise between safety and comfort when designing a hillside residence area. The maintenance works must ensure that the building areas are used to satisfy safety compatibility. However, the hillside failure causes not only loss of resources but even loss of lives [1,2]. A decision framework is thus needed for to safety of various hillside residence area on satisfying the maintenance requirements, and to guide users to raise the capability of disaster prevention and ensure the inhabitancy quality. The safe qualification of the hillside house community still belongs to the policy subject in Taiwan. Decision details often have significant differences because of different groups and individual's subjective factor. Obvious reasons are that the uncertainty of information, quantization of influential factors and standardizing of system. Checklist is a field characterized by estimating structure, environment, slope, surrounding soil, etc. [3,4]. Experts' thinking process for analyzing community stability and determining possible causes always contains some testing and empirical rules. [5-7]. The monitoring system can measure the real conditions of the hillside fields in real time, understand the situation of the geology and provide an alternative method to judge the hillside safety [8-10]. A number of authors have discussed the concepts using the geographical information system. Star [11] showed that the analytical method not only determines the parameter weight and scores but also predicts the emergence of the calamity. Nowadays, it is widely recognized as an interface direction helping manage environmental emergence problems to use computer science and information technology to support decision-making skills and enhance problem-solving abilities [12,13].

In this paper, a fuzzy grey decision system framework is introduced as groups of expertise and disaster data collection of hillsides that can cooperate to achieve a common goal-preparedness for and responds to hillside safety situations. There are three primary subsystems in this framework: the database subsystem contains what is in charge of collecting the hillside disasters inspecting the expert explorations; the model-base subsystem mainly provides mathematical models to simulate and analyze the influential factors; the processes involved in the user interface subsystem are able to manipulate uncertain and imprecise information basing on artificial intelligence technology. The user interface provides an immediate evaluation system for taking action in hillside emergencies. In this framework, setting up criterions plays a critical role because it is the foundation of promoting the real efficiency and raising the capability of disaster prevention.

The objectives of evaluating hillside safety include the ability to provide a framework for describing performance criteria and expectations. The sub objectives required to achieve the primary goals are:

(1)Development of hillside safety evaluation model for reasoning stability and determining possible influential factors through hillside disasters and expert explorations.

(2)Establishment of a systematized analytical method, which is capable of dealing with uncertainty and can infer precision diagnosis.

(3)Provision of an immediate evaluation system for both hillside residents and engineers who can use visual situation observation of hillside fields to interpret the safety level of hillsides.

2. Methodology

2.1Research framework

There are numerous influencing factors in the evaluation of hillside safety, and the discrepancies in the verification of the extent of their influence usually result in distinctive differences during the assessment of the evaluation. The influencing factors selected in this research not only have multi-criteria objectives and unquantifiable evaluation items, they also have degrees of uncertainty. The significance of these factors will be determined through team decision and complemented with the analysis of existing disaster data. The information obtained and causes of disasters will be analyzed through the grey statistics method and the fuzzy analytic hierarchy process before it can be used as the basis for quantification analysis and the determination of the weight of individual factors. From the diagram of relationship in Fig.1, we can see the research method that is complementary to the quantification analysis of the influencing factors. For instance, the statistical data from case studies reinforces the different information generated from the experts' evaluation when causes of actual disasters have been reflected in the determination of weight. In addition, experts' opinions also make up for the shortage of case study information.

2.2Assessment of influencing factors

In order to prevent inconsistency in the experts' evaluation of hillside residential safety due to the differences in their areas of expertise, experience and knowledge, the grey statistics method [14] has been used to perform the data processing of expert opinion and information from the analyses of case studies through a whitening function. The steps in the procedure are as follows: (1) establish the whitening function for the 5 categories of significance on a scale between 0~10. (2) Compute the jth evaluation factor that belong to the sample coefficient $\eta_{jk} = \sum_{i=1}^{m} f_k(d_{ij}) p_i$ of the kth grey number (m is the sum of the number of expert decision and case studies), and $f_k(d_{ij})$ will be the whitening value of decision. (3)Calculate the decision vector of the whitening function about various evaluation factors.

2.3Weight quantification analysis

Different appraisals exist in the team decision, and the discrepancies came from their uncertainty regarding the evaluation system. The objectivity of the overall evaluation is more likely to be affected when members of the team have strong subjective opinions. The fuzzy analytic hierarchy process will then help us to determine the fuzzy weight of evaluation items [15, 16]. The steps are as follows: (1) establishing the determining matrix, use the matrix method to represent the significance ordering of evaluation items. (2) Normalization of the determining matrix: $\bar{u}_{ij} = u_{ij} / \sum_{k=1}^{n} u_{kj} (i, j = 1,2,\cdots n)$, the value of $\overline{w}_i$ turns out to be $\overline{w}_i = \sum_{j=1}^{n} \bar{u}_{ij}$, and n is the number of evaluation items. (3) Calculate the weight vector from $w_i = \overline{w}_i \Big/ \sum_{j=1}^{n} \overline{w}_j$. (4) Examine the consistency from $CR = CI/RI,\ CR < RI$, ($CI = 1/\ n(\lambda_{max} - n)$). The determination of the weight of influencing factors is done through the decision vectors from the grey statistics. The decision vectors will be used to establish the membership function $\underset{\sim}{A}$. $\underset{\sim}{A}=$ 0.9/high +0.7/medium high + 0.5 / medium+0.3/medium low+0.1/low. After computing the influencing significance of every factor in the function $\underset{\sim}{A}$, we can then use the values from the calculation to create a ranking of the influencing factors according to their significance to be used as a reference in determining the weight of each evaluation item. It can also be used to normalize the quantified value of influence within the evaluation items to obtain the relative weightings of each factor.

2.4Establishing evaluation model

In order to represent the actual decision making situation for the safety of hillside residences, we used the concept of α-cut [17] from fuzzy mathematics in this study. α-cut is used to represent the grading of decision in the evaluation of hillside residential safety, and the α-cut of A is defined as $A_\alpha=[x \mid \mu A(x) \geqq \alpha]$. α is a real number ($0 \leqq \alpha \leqq 1$), and when $x \in A_\alpha$, $\alpha \leqq \mu A(x) \leqq 1$, then α will be the decision judgment value. The greater α is, then the corresponding interval of A_α will be smaller, which means the decision makers had a better control of the system information. The trichotomy method has been used in this study to divide the overall assessment value into three grading terms, namely "safety", "caution" and "danger". The assessing decision makers were able to adjust the intervals of the grading based on the number of case studies available to them, making the results of the evaluation more optimistic.

3. Application and discussion

Hillside disaster reasons can be roughly divided into two categories: natural and man-made factors. Natural factors are those unplanned events that occur as a result of natural process such as earthquake, rainfall, groundwater, hydrogeology, geographical conditions and habituates characteristics. Man-made factor are caused by the interaction of people with the environment and human system. Some examples are a retaining wall design, building times, drainage system, engineering implications, maintenance and site choice. Some malevolent human activities such as wastes, dumped soil, inappropriate roadway planning and detention pond also belong to this category. Fig.3 demonstrates the level analysis of hillside residence safety. In this study, the evaluation items and factors have been categorized into three major evaluation items with 13 influential factors. These items and factors were then used to conduct a survey with 20 experts and gather the cases of hillside residential disasters in Taiwan (16 cases) in order to discuss the causes of these disasters. The results were then used to compile the numbers of decisions in the evaluation factors (as represented in Table 1).

3.1Weight analysis

The results of the weight analysis for evaluation items and influential factors were described in Table 2. From Table 2, we see that the addition of certain influencing factors to case study data did actually increase their weight, such as B1 and C1. It is not difficult to locate these influencing factors in the existing case studies of disasters and their influences. It is evident that there are differences in the weighting of "Natural environmental factors" and "Current factors of environments". After further discussion within these two items, we discovered that the differences are relatively small in the influential factors of item A. On the other hand, those in category B appeared to have greater differences, and they also had more impact overall on the evaluation. This is mainly attributed to more influencing factors such as B2 and B4. The reason why the relative weight of factors B1 and C3 appear to be lower was because some of the factors got eliminated during the developmental process, and the experts would see them as being less influential. In the overall analysis of influencing factors in the evaluation of hillside residence safety, the weightings of factors in overall data and experts' data were almost identical. This proved the complementary effect between the validity of experts' survey and the disaster data. However, in order to create an evaluation model that is suited for both the general public and professionals in the future, the secondary factors under the influencing factors still needs to be developed and analyzed in order to expand the scope of its applicability.

3.2Establishing fuzzy set

Based on the influencing factors on the safety of hillside residences (Table 2), the influencing factors $A(A_1 \sim A_4)$, $B(B_1 \sim B_5)$, $C(C_1 \sim C_4)$ have been classified into 5 categories through either semantic judgments or quantified values. The five categories were "very serious", "serious", "normal", "good" and "very good". The corresponding fuzzy values were (0.75,1,1), (0.5,0.75,1), (0.25,0.5,0.75), (0,0.25,0.5) and (0,0,0.25) respectively.

3.3Fuzzy comprehensive evaluation

Based on the weight of various evaluation items and the integration of the influential factors, we can calculate the overall fuzzy assessment value for the safety of the hillside residences. The formula would be: $\tilde{P}=\frac{1}{m}\sum_{i=1}^{m}(\tilde{X}\times W_i)\cong(P_1,P_2,P_3)$

where $\tilde{P}$ is the overall fuzzy assessment value. We can perform the defuzzification by using the gravity method. G= (P_1, P_2, P_3) /3, where G is the final overall assessment value for the safety of the hillside residences.

3.4Building the interface of system

The system will list the semantic terms on the display page so that the assessing decision makers will be able to follow the descriptions and input the relevant information into the system interface in a step-by-step manner (refer to Fig. 4). In order to make the computation of evaluation easier, the MS Excel 2003 system has been chosen in our model. The user interface will make the evaluation system easier to use, more practical and suitable to the users.

4. Conclusion

In this study, we have attempted to propose an evaluation model for the safety of hillside residence area. It features an integration of disaster case studies and expert opinion and makes use of the grey statistics method and the fuzzy analytic hierarchy process to look for an appropriate method and process to solve the problem. The system allows the evaluators to assess each influential item and factor more concretely and use this information to assess the current situation in their evaluation of the safety of hillside residence area. From the analyses of the evaluation system, we found that anyone, whether with or without the relevant professional background, could operate the system easily to obtain the evaluation results on the residential safety. This eliminates the elements of misjudgment made by non-experts due to the lack of professional knowledge and background. It has proven that the evaluation model is a viable alternative in the selection of a hillside residential evaluation model. From the results obtained from the study, we came to the following conclusions:

(1)The establishment of evaluation factor weighting from a combination approach with questionnaires and data investigation has the advantages of preventing biases and inconsistency in the experts' opinion and compensating for misjudgments made due to insufficient investigation materials.

(2)The "Natural environmental factors" and the "Current factors of environment" factors in the evaluation items have significant influence in the evaluation of hillside residential safety. This also reflects their influencing significance in the existing evaluation model.

(3)The grey statistics method can be used to take the ranking of the influencing factors' decision vector one step further to be used as the primary reference for the order of evaluation data acquisition.

(4)The significance of causes of disaster can be better reflected in the evaluation model if more case study investigation data are available. With more case studies available, the task of improving the authenticity of the evaluation model becomes easier.

(5)By using the grading levels established from α -cut in the evaluation model, any changes in the variable will affect the outcome of the hillside residence evaluation. In other words, when the degree of uncertainty and instability in the decision making environment is greater, the discrepancies in the results of the hillside residence evaluation will be greater due to the different considerations of the decision makers.

(6)The evaluation of hillside residential safety has its complexities and uncertainties. By using a computer processing system to assess the complicated data and information, the evaluation process can be tailored to carry out evaluations on specific residence to reduce the chances of a disaster occurring.

(7)The evaluation model and system offer an alternate choice for the evaluation of hillside residences. The system can be made more complete with the evaluation of disaster case studies and systematic corrections in the future.

References:

[1]C.H. Juang, D.H. Lee and C. Sheu , Mapping slope failure potential using fuzzy sets. *J. Geotech. Eng., ASCE* 118 3, 1992, pp. 475-493.

[2]D. Brown, J. Wolosick , Engineering a landslide: by fitting an earth-reinforcement system with state-of-the-art instrumentation, engineers hope to cull valuable data on slope stabilization. *Civ. Eng., ASCE* 65 7, 1995, pp. 72-73.

[3]G.R. Dodagoudar, G. Venkatachalam , Reliability analysis of slopes using fuzzy sets theory. *Comput. Geotech.* 27 2, 2000, pp. 101-115.

[4]J.Z. Cheng, T.T. Chang, Self safety inspect of hillside communities in Taiwan, Architecture and building research institute ministry of interior, 2002(in Chinese).

[5]J.B. Yang, N.J. Yau , Integrating case-based reasoning and expert system techniques for solving experience-oriented problems. *J. Chin. Inst. Eng.,* 23 1, 2000, pp. 83-95.

[6]P. J. H. Schoemaker, C.C. Waid, An experimental comparison of different approaches to determining weights in additive utility models, *Management Science,* 28, 1982, pp.182-196.

[7]M. Wang, J. Yang, A Multi-criterion Experimental Comparison of Three Multi-attribute Weight Measurement Methods, *Journal of Multi-criteria Decision Analysis Anal.*7, 1998, pp. 340-350.

[8]J. Dunnicliff, *Geotechnical Instrumentation for Monitoring Field Performance*, Wiley, New York, 1988.
[9]M.Y. Cheng and C.H. Ko , Computer-aided expert decision support system for disaster prevention of hillside residents. *J. Chin. Inst. Civ. Hydraul. Eng.,* 13 1, 2001, pp. 39-50 (in Chinese).
[10]M.Y. Cheng, C.H. Ko, Computer-aided decision support system for hillside safety monitoring, *Automation in Construction,* 11 4, 2002, pp. 453-466.
[11]J. Star, J. Estes, *Geographic Information System: An Introduction*, Prentice-Hall Inc., 1990.
[12]A. V. Gheorghe, D. V. Vamanu, Adapting to new challenges: IIDS for emergency preparedness and management, *International Journal of Risk Assessment and Management*, 2(3/4), 2001, pp. 211-223.
[13]N. Uddin, D. Engi, Disaster management system for southwestern, *Indiana. Natural azards Review*, 3(1), 2002, pp. 19-30.
[14]H.L. Cheng, J.G. Lin, *Grey Decision Making and Applications*, Jiangsu Technology press, 1989.
[15]C.S. Bell, L. Crumpton, Evaluation naval tactical missile systems by fuzzy AHP bases on the grade value of membership function, *European Journal of Operation Research,* 96, 1996, pp. 343~350.
[16]Amy H.I. Lee, W.C. Chen and C.J. Chang, A fuzzy AHP and BSC approach for evaluating performance of IT department in the manufacturing industry in Taiwan, *Expert Systems with Applications,* 27, 2006, pp. 1-12.
[17]T.L. Saaty, Vargas, Uncertainty and Rand Order in the Analytic Hierarchy Process, *European Journal of Operation Research,* 32, 1987, pp. 107-117.

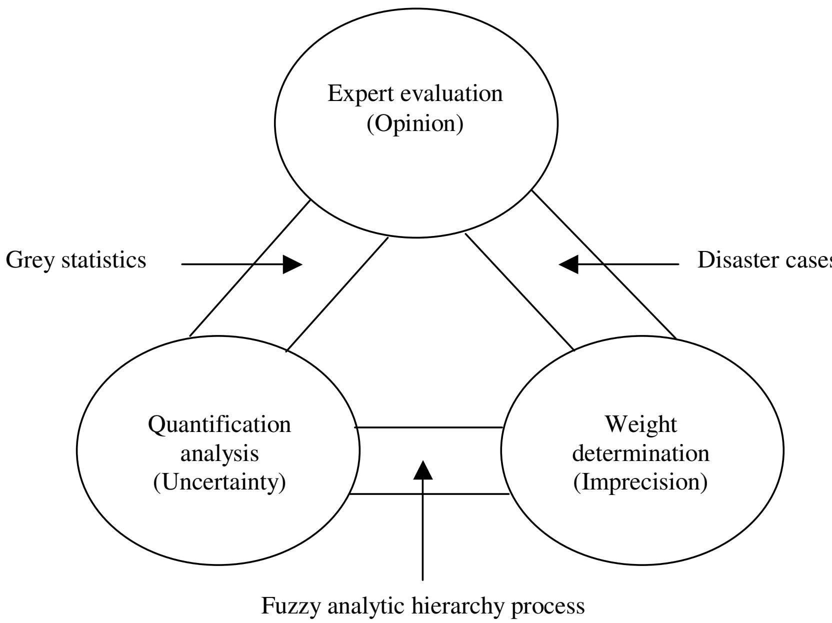

Fig. 1. The relationship of research framework.

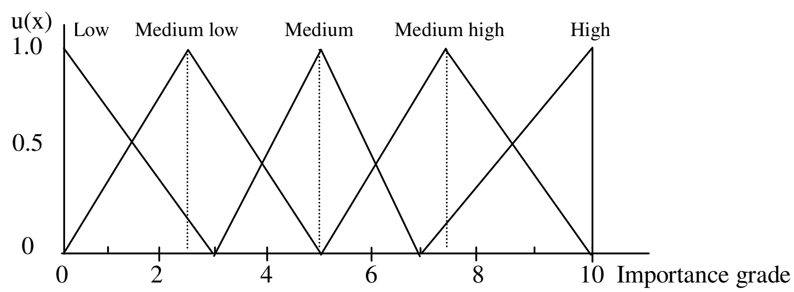

Fig. 2. The whitening function of five kinds for importance grade.

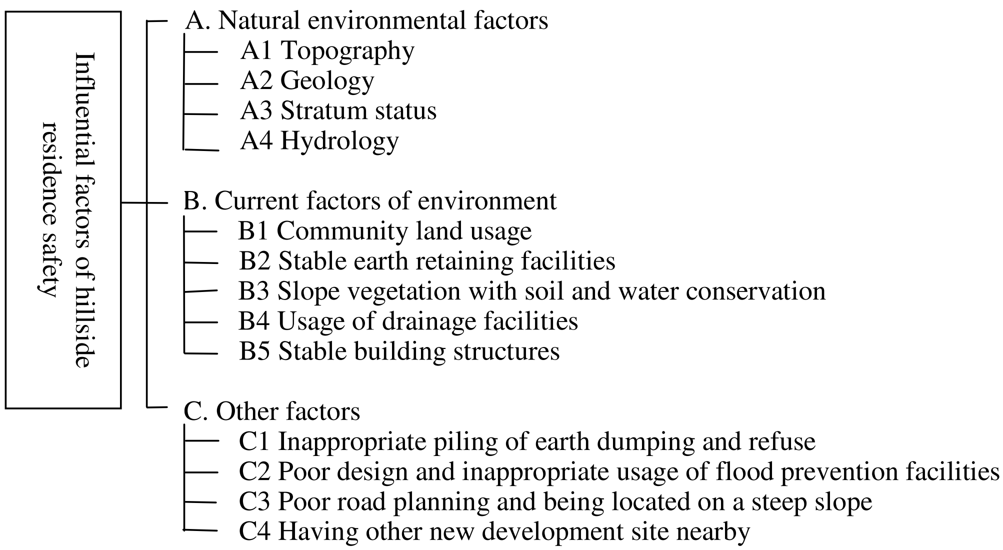

Fig. 3. The level analysis of hillside residence safety.

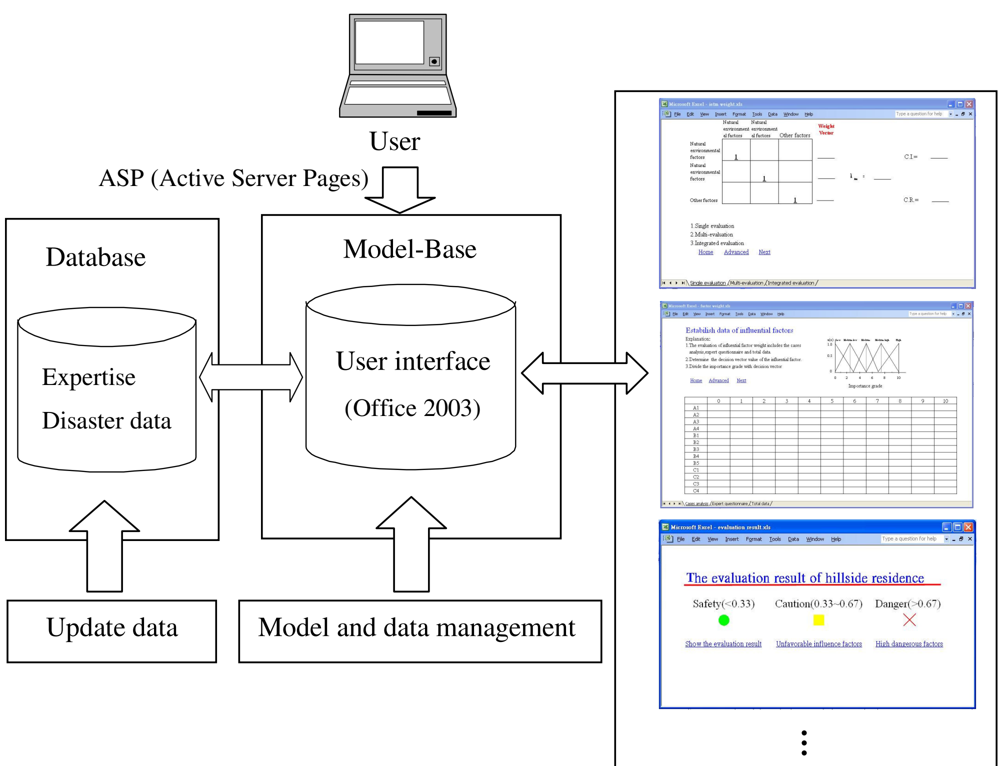

Fig. 4. System interface and structure.

Table 1. The statistical number of expert decision (disaster case) according to the importance grade

	0	1	2	3	4	5	6	7	8	9	10
A1	0	0	0	0	0(10)	2	5(6)	1	7	3	2
A2	0	0	0	0	0(7)	0	1(9)	4	4	4	7
A3	0	0	0	0	0(12)	1	2(4)	4	4	4	5
A4	0	0	0	0	1(12)	0	1(4)	3	7	5	3
B1	3	1	2	4	2(14)	3	3(2)	1	1	0	0
B2	0	0	0	0	1(4)	0	1(12)	3	4	5	6
B3	0	0	0	0	0(6)	2	3(10)	5	3	3	4
B4	0	0	0	0	0(4)	0	1(12)	2	5	6	6
B5	0	0	0	0	1(10)	1	4(6)	4	3	3	4
C1	0	0	0	2	1(11)	3	3(5)	2	1	4	4
C2	1	0	2	0	3(8)	2	4(8)	3	1	3	1
C3	2	0	3	3	4(14)	3	2(2)	2	0	1	0
C4	0	1	1	3	1(15)	5	2(1)	3	2	1	1

Table 2. The results of the weight analysis for evaluation items and influential factors

Item	Influential factor	Relative weight		
			Total data	Expert's data
A Natural environmental factors		0.391		
	A1		0.239	0.227
	A2		0.263	0.264
	A3		0.248	0.251
	A4		0.250	0.258
B Current factors of environment		0.440		
	B1		0.129	0.107
	B2		0.227	0.232
	B3		0.208	0.209
	B4		0.235	0.245
	B5		0.201	0.207
C Other factors		0.169		
	C1		0.313	0.292
	C2		0.277	0.265
	C3		0.160	0.192
	C4		0.250	0.251