

Decision support for extracting and dissolving consumers' uneasiness over foods using stochastic DEMATEL

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Abstract— In this paper we try to extract consumers' uneasy factors on foods such as carcinogenic substance, bovine spongiform encephalopathy (BSE) problem, genetic recombination, etc., and try to construct structural models among these uneasy factors using stochastic DEMATEL. Stochastic DEMATEL is developed as a revised DEMATEL (Decision Making Trial and Evaluation Laboratory) to extract structural models of a complex problematique composed of many factors under uncertainty. For structural modeling of uneasy factors on foods we look at the binary relation such that "How much would it help to dissolve uneasy factor j by dissolving uneasy factor i ?" Finally, we try to find the priority of dissolving each factor among all the uneasy factors based on the information of stochastic composite importance. This would contribute for decision support to dissolve uneasy feeling and to get sense of security on foods.

Keywords— safe, secure and reliable society, structural modeling, decision support, stochastic DEMATEL, stochastic composite importance.

1. Introduction

Food safety has been the focus of concern of the general consumers, policymakers and risk assessors. Fisher *et al.* [1] presented the potential of a transdisciplinary approach to food risk analysis in terms of delivering additional improvements to public health. As one of such approaches we will try to extract a structural model among consumers' uneasy factors on foods such as carcinogenic substance, bovine spongiform encephalopathy (BSE) problem, genetic recombination, etc., and try to construct structural models among these uneasy factors using stochastic DEMATEL.

DEMATEL (Decision Making Trial and Evaluation Laboratory) [2–4] has been widely used to extract a problem structure of a complex problematique. By using DEMATEL we could quantitatively extract interrelationship among multiple factors contained in the problematique.

It is important and useful to get the structural model of a problematique from which we could find the priority among multiple strategies to improve the structure. This is the main aim of DEMATEL. However, the conventional DEMATEL is insufficient to obtain significant implication of the priority of the strategies for decision making as follows:

1. Shortage of information on the importance of each factor

In the conventional DEMATEL it is hard to find the superiority of factors, since we could get only interrelationship of factors contained in the problematique. To overcome this difficulty we developed a new criterion "composite importance (CI)" [5] combining the interrelationship of factors and the importance of each factor.

2. Shortage of flexibility to describe structural uncertainty

Conventional DEMATEL describes the deterministic interrelationship among factors contained in the problematique. However, the strength of the interrelation among factors may be dependent on the various situations, and the fluctuation may depend on the factors taken into account. To overcome this difficulty we developed a stochastic DEMATEL [6] to deal with flexible interrelationship among factors in the problematique.

In this paper in the context of finding priority among multiple strategies to improve the structure of the problematique, we aim at three objectives as follows:

- We describe the method of stochastic DEMATEL briefly.
- We show usefulness and future problem of stochastic DEMATEL through an empirical analysis of ordinary consumers' and food specialists' uneasiness over foods where we deal with structural modeling of uneasy factors on foods.
- Using the information of stochastic composite importance (SCI) we try to find the priority of dissolving uneasy factors on foods.

2. Outline of stochastic DEMATEL

2.1. DEMATEL

Suppose, in a complex problematique composed of n factors, binary relations and the strength of each relation are investigated. An example of binary relation is such that "How much would it contribute to resolve uneasy factor j

by resolving uneasy factor i ?" We would get $n \times n$ adjacent matrix X that is called the direct matrix. The (i, j) element x_{ij} of this matrix denotes the amount of direct influence from factor i to factor j . If the direct matrix X is normalized as $X_r = \lambda_1 X$, by using $\lambda_1 = 1/(\text{the largest row sum of } X)$, we would obtain

$$X^f = X_r + X_r^2 + \Lambda = X_r(I - X_r)^{-1}. \quad (1)$$

Matrix X^f is called the direct/indirect matrix. The (i, j) element x_{ij}^f of the direct/indirect matrix denotes the amount of direct and indirect influence from factor i to factor j .

Suppose D_i denotes the row sum of i th row of matrix X^f . Then, D_i shows the sum of influence dispatching from factor i to the other factors both directly and indirectly. Suppose R_i denotes the column sum of i th column of matrix X^f . Then, R_i shows the sum of influence that factor i is receiving from the other factors. Furthermore, the sum of row sum and column sum ($D_i + R_i$) shows the index representing the strength of influence both dispatching and receiving, that is, ($D_i + R_i$) shows the degree of central role that the factor i plays in the problematique. If ($D_i - R_i$) is positive, then the factor i is rather dispatching the influence to the other factors, and if negative, then the factor i is rather receiving the influence from the other factors. We call D_i the degree of dispatching influences, R_i the degree of receiving influences, ($D_i + R_i$) the degree of central role and ($D_i - R_i$) the degree of cause.

2.2. Composite importance

Suppose based on the degree of dispatching influences we found a factor that may contribute to improve the overall structure. In this case to resolve this factor is not necessarily the best choice, since the factor that could contribute to resolve some important factors may be more efficient to resolve even if it may not contribute to improve overall structure. Since the original DEMATEL is not taking into account the importance of each factor itself, it is not possible to evaluate the priority among the factors. Similarly, it is not possible to evaluate the priority of each factor by just looking at the importance of each factor. We need to take into account both the strength of relationships among factors and the importance of each factor. To reflect both viewpoint we proposed the composite importance z as [4]

$$z = y_r + X^f y_r = (I + X^f) y_r, \quad (2)$$

where y_r denotes the normalized n -dimensional vector of y that denotes n -dimensional vector composed of the importance of each factor, where normalized means to divide each element of y by the largest element in y .

2.3. Stochastic direct matrix

In the ordinary DEMATEL the direct influence from factor i to factor j is written in the (i, j) element x_{ij} of

the direct matrix X . Suppose the structure of the problematique is uncertain and x_{ij} is a random variable. Furthermore, suppose the stochastic parameter values of x_{ij} are different for different pair of i and j . When each element of the direct matrix is a random variable, each element of the direct/indirect matrix X^f is also a random variable. Furthermore, the composite importance z is also a random variable. Therefore, it is necessary to extend the ordinary DEMATEL to deal with uncertainty in the problem structure. We developed a stochastic DEMATEL [6] in which we could take care of various uncertainties in the problem structure.

In the stochastic DEMATEL it is postulated that we describe the amount of direct influence by expectation and the amount of uncertainty by variance and the shape of distribution. Suppose we got $n \times n$ direct matrix X and the matrix E of probability density function as

$$E = \begin{bmatrix} g_{11}(x|\theta_{11})\Lambda & g_{1n}(x|\theta_{1n}) \\ \mathbf{M} & \mathbf{O} & \mathbf{M} \\ g_{n1}(x|\theta_{n1})\Lambda & g_{nn}(x|\theta_{nn}) \end{bmatrix}, \quad (3)$$

where $g_{ij}(x|\theta_{ij})$ denotes the probability density function of direct influence from factor i to factor j , and θ_{ij} denotes the parameters of this probability distribution including expectation and variance of the random variable x_{ij} .

Let G_X be a set of stochastic direct matrices X^s generated by a Monte Carlo method from the direct matrix X with probabilistic information. Then, we obtain

$$G_X = \{X_1^s, X_2^s, \Lambda, X_t^s\}. \quad (4)$$

In the stochastic DEMATEL we need to collect the information on the variance as well as on the expectation of influence.

2.4. Manipulation in stochastic DEMATEL and stochastic composite importance

We normalize the stochastic direct matrix as

$$X_r^s = \lambda_2 X^s, \quad (5)$$

where $\lambda_2 = 1/(\text{the largest row sum of } X^s)$. Then we obtain

$$X^{sf} = X_r^s + (X_r^s)^2 + \Lambda = X_r^s(I - X_r^s)^{-1}, \quad (6)$$

where X^{sf} denotes a stochastic direct/indirect matrix that has the same property as the ordinary direct/indirect matrix. If we obtain X^{sf} for all X^s contained in G_X , we obtain a set G_{XF} of stochastic direct/indirect matrix as

$$G_{XF} = \{X_1^{sf}, X_2^{sf}, \Lambda, X_t^{sf}\}. \quad (7)$$

Stochastic composite importance is obtained as

$$z^s = y_r + X^{sf} y_r = (I + X^{sf}) y_r. \quad (8)$$

The set G_Z of SCI is obtained as

$$G_z = \{z_1^s, z_2^s, \Lambda, z_t^s\}. \quad (9)$$

Furthermore, we could obtain the set of the degree of dispatching, the set of the degree of receiving, the set of the degree of central role and the set of the degree of cause, respectively.

In the ordinary DEMATEL we could decide the priority of each factor based on the value of composite importance itself. In the stochastic DEMATEL we use three stochastic decision principles as follows:

- **Expectation principle.** We decide the priority based on the expected value or median of SCI.
- **Max-min principle.** We decide the priority of each factor by maximizing the worst value (either 2.5% or 25%) of SCI. This principle reflects a pessimistic decision.
- **Max-max principle.** We decide the priority of each factor by maximizing the best value (either 75% or 97.5%) of SCI. This principle reflects an optimistic decision.

The stochastic DEMATEL could describe the uncertainty of the structure of complex problematic, could describe the uncertainty of priority by SCI and could decide the priority of each factor reflecting the decision makers attitude whether he/she is pessimistic, neutral or optimistic.

3. Structural modeling of uneasy factors over foods by stochastic DEMATEL

We use the data obtained from ordinary consumers and food specialists. For both groups 10 uneasy factors are chosen as follows:

- 1) food additive (FAD),
- 2) genetic recombined food (GRF),
- 3) food forged display (FFD),
- 4) agricultural chemical problem (AGC),
- 5) imported food (IPF),
- 6) BSE problem (BSE),
- 7) environmental hormones (EVH),
- 8) carcinogenic (CAR),
- 9) allergic (ALL),
- 10) food poisoning (FPO).

Respondents to the questionnaire are 10 ordinary consumers and 10 food specialists. The importance of each factor is asked to the respondents by 5-grade evaluation where the importance of each factor means the degree of feeling uneasy for each factor. Then, the strength of binary relation for each pair of factors is asked by 3-grade evaluation. We look at the binary relation such that “How much

would it contribute to resolve uneasy factor j by resolving uneasy factor i ?”

The direct matrix is obtained by averaging the data of 10 people on the strength of binary relations. The data for the importance of each factor are first normalized between 0 and 1 and then averaged for 10 people.

The dispersion of the data of the strength of binary relations obtained from the respondents are used as the variance of the strength of binary relations. This implies that the variations among people would induce structural uncertainty. The shape of the stochastic distribution is assumed to be cutting normal distribution defined on [0–1,000,000], since the data obtained from respondents are all positive numbers. The number of stochastic direct matrices generated by random numbers are 1,000.

Structural model for uneasy factors of ordinary consumers is described as follows: the degree of central role for FFD (1.45) is high and FFD has the property of both cause factor and effect factor, but since the degree of cause for FFD (0.55) is positive, FFD is rather a cause factor. Actually, FAD, GRF, IPF, BSE and ALL are greatly affected by FFD.

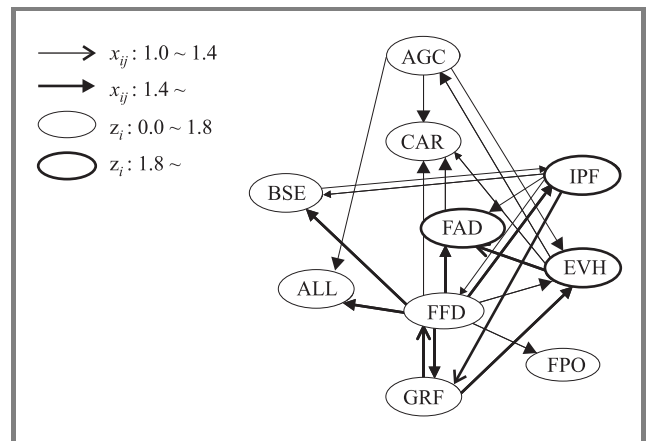


Fig. 1. Structural model of uneasy factors for ordinary consumers.

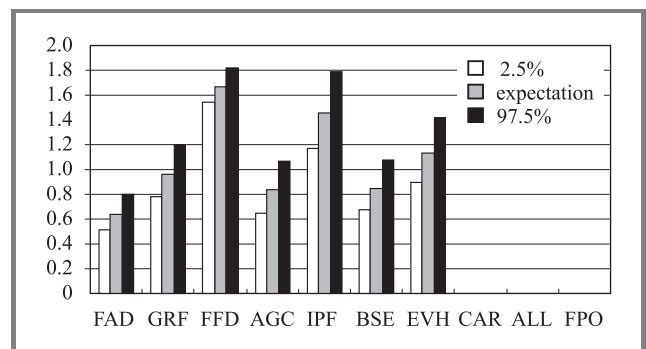


Fig. 2. Degree of dispatching influences for ordinary consumers.

The degree of central role for FFD (1.45) is the highest, and then IPF (1.33), EVH (1.24), GRF (0.941) and AGC (0.850). These factors are all cause factors. On the other hand CAR, ALL and FPO are completely effect fac-

tors. Figure 1 shows a structural model of uneasy factors for ordinary consumers.

Figure 2 presents the degree of dispatching influence, and Fig. 3 shows the stochastic composite importance, for ordinary consumer. In these figures, besides expected values, 2.5% and 97.5% data are also shown.

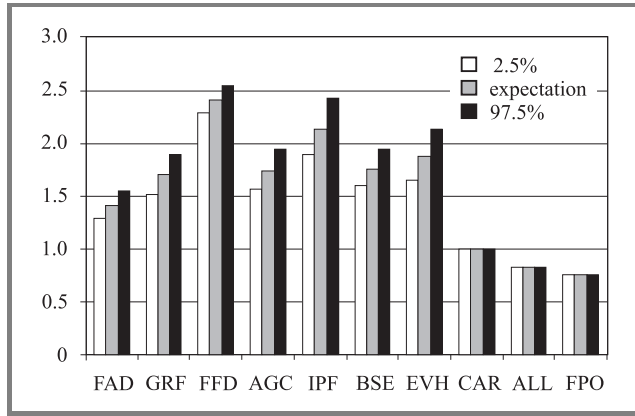


Fig. 3. Stochastic composite importance for ordinary consumers.

Figure 4 shows a structural model of uneasy factors, Fig. 5 presents the degree of dispatching influences, and Fig. 6 shows the stochastic composite importance, for food specialists.

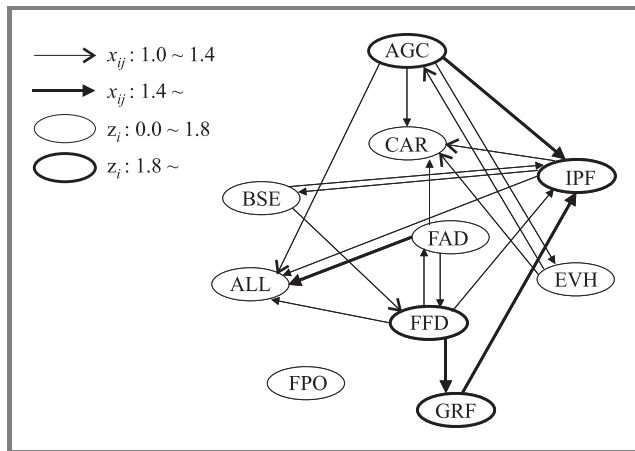


Fig. 4. Structural model of uneasy factors for food specialists.

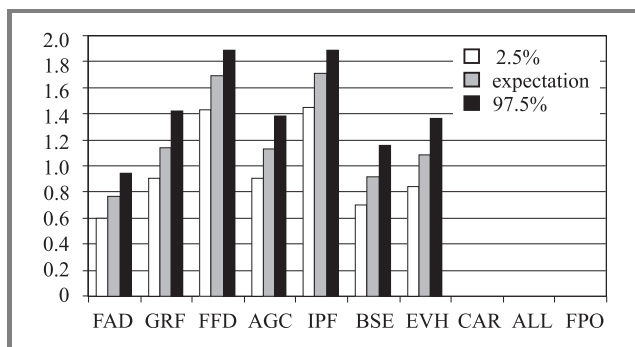


Fig. 5. Degree of dispatching influences for food specialists.

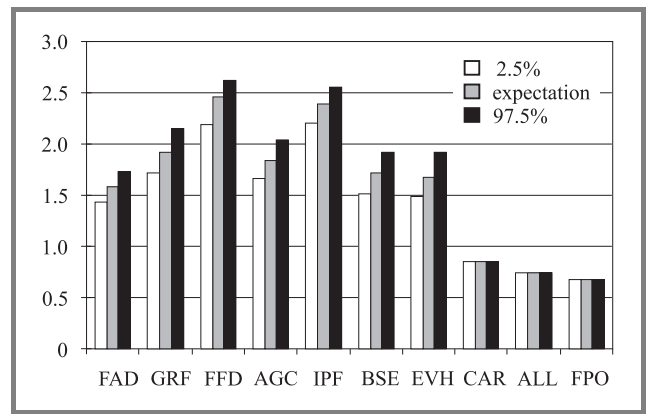


Fig. 6. Stochastic composite importance for food specialists.

For ordinary consumers is as follows: FFD, IPF, EVH, BSE, AGC, GRF, FAD, CAR, ALL, FPO. On the other hand, the priority for food specialists is as follows: FFD, IPF, GRF, AGC, BSE, EVH, FAD, CAR, ALL, FPO. These results are obtained from SCI.

4. Concluding remarks

In this paper a stochastic DEMATEL is applied to structural modeling of ordinary consumers' uneasy factors on foods taking into account the uncertainty of structure. It is demonstrated that the stochastic DEMATEL and the information obtained by the SCI are quite useful for structural modeling of complex problematic under uncertainty. A new knowledge obtained in this study is that in order to resolve uneasy factors over foods it is effective to solve the problems of food forged display (FFD) and imported food (IPF).

For further study we need to develop a method of identifying appropriate probability distribution function or we need to develop a non-parametric approach. We also need to develop a method of collecting information on variance. For these purposes we need to experience more empirical analysis of various case studies.

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References

- [1] A. R. H. Fischer, A. E. I. de Jong, R. de Jonge, L. J. Frewer, and M. J. Nauta, "Improving food safety in the domestic environment: the need for a transdisciplinary approach", *Risk Anal.* vol. 25, no. 3, pp. 503-517, 2005.
- [2] E. Fontela and A. Gabus, "DEMATEL, innovative methods", Rep. no. 2, "Structural analysis of the world problematic (methods)", Battelle Institute, Geneva Research Center, 1974.

- [3] E. Fontela and A. Gabus, "The DEMATEL, observers", DEMATEL 1976 Rep. Battelle Institute, Geneva Research Center, 1976.
- [4] J. N. Warfield, *A Science of Generic Design: Managing Complexity through Systems Design*. Ames: Iowa State Univ. Press, 1994.
- [5] H. Tamura and K. Akazawa, "Structural modeling and systems analysis of uneasy factors for realizing safe, secure and reliable society", *J. Telecommun. Inform. Technol.*, no. 3, pp. 64–72, 2005.
- [6] H. Tamura and K. Akazawa, "Stochastic DEMATEL for structural modeling of a complex problematique for realizing safe, secure and reliable society", *J. Telecommun. Inform. Technol.*, no. 4, pp. 139–146, 2005.



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