Paper

Structural modeling and systems analysis of uneasy factors for realizing safe, secure and reliable society

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Abstract— In this paper we try to extract various uneasy factors in our life. Then, we try to construct structural models among these factors using Decision Making Trial and Evaluation Laboratory (DEMATEL). For the purpose of analyzing priority among these factors we revised the DEMATEL and found effective factors to be resolved in order to realize future safe, secure and reliable (SSR) society.

Keywords— safe, secure and reliable society, DEMATEL, structural modeling, systems analysis.

1. Introduction

Any people are living with some anxiety in any society. For example, people have had traditional anxiety for fire, natural disaster, human relations, responsibility in their work, etc. So in a long history, people have advanced science and technology and developed modern social systems to decrease these anxiety. On the other hands, in addition to this kind of traditional anxiety, it is said that vague uneasiness on the socio-economic situation, educational systems, safety in our life, etc., is expanding in Japan, in the environment of economic stagnation after the collapse of the "bubble economy" [1]. Since new anxiety are generated in addition to traditional anxiety, anxiety become complex and with wide variety. Accordingly, it is difficult to find how to decrease these anxiety. Therefore, it is worthwhile to try to decrease anxiety of people by extracting and analyzing various uneasy factors in order to create future safe, secure and reliable (SSR) society.

In this paper after finding various uneasy factors in our life we try to construct a structural model among these factors. For the purpose of structural modeling and systems analysis we use a system methodology called Decision Making Trial and Evaluation Laboratory (DEMATEL) [2–5]. By using DEMATEL we could extract mutual relationships of interdependencies among various uneasy factors and the strength of interdependence as well. However, the original DEMATEL cannot reflect the importance or seriousness of each factor to the result. In this paper we propose a revised method of DEMATEL to overcome this difficulty in the original DEMATEL and try to extract effective factors to be resolved in order to realize future SSR society.

2. DEMATEL

2.1. Outline

DEMATEL was developed in Battelle Geneva Institute, to analyze complex "world problematique" dealing mainly with interactive man-model techniques and to evaluate qualitative and factor-linked aspects of societal problems. The applicability of the method is widespread ranging from industrial planning and decision making to city planning and design, regional environmental assessment, analyzing global world problematique, and so forth.

2.2. Methodology

DEMATEL will try to get a weighted hierarchical structural model by analyzing quantitative data on the strength of binary relations on every two factors.

First of all, we extract all the factors that belong to the problematique. Suppose the problematique is composed of n factors. Next, we pay attention to the strength of some relation between two factors, and we try to find the strength of relations for all the pairs (i, j) of all the n factors such that "How much would it help in order to resolve factor j by resolving factor i?"

Suppose x^*_{ij} which is (i, j) element of $n \times n$ matrix $\mathbf{X}^*$, denotes the strength of relation from factor i to factor j, and suppose

$x^*_{ij} = 0$: if by resolving factor i it would not help to resolve factor j at all;
$x^*_{ij} = 1$: if by resolving factor i it would help to resolve factor j a little bit;
$x^*_{ij} = 2$: if by resolving factor i it would help to resolve factor j very much.

Matrix $\mathbf{X}^*$ is called the direct matrix and the element $x^*_{i,j}$ denotes the strength of the direct influence from factor i to factor j.

Then suppose we obtain a direct matrix $\mathbf{X}^*_e$ concerning factor a, b and c as

$$\mathbf{X}^*_e = \begin{pmatrix} 0 & 2 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}. \tag{1}$$

Figure 1 shows this structure. Factor a and factor b are mutually influenced and factor a affects factor c. In addition factor c affects factor b. Therefore, factor a affects factor b

directly and indirectly. In this case the strength of influence is the largest from factor *a* to factor *b*.

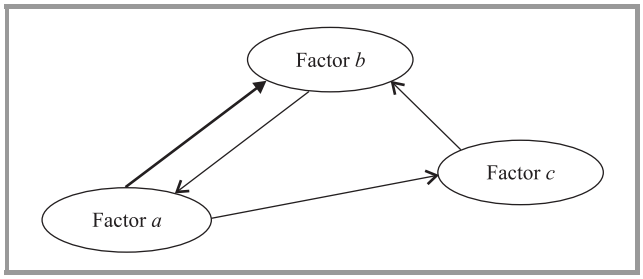

Fig. 1. Directed graph.

In DEMATEL we could further evaluate the other quantitative influence by simple matrix operations. Suppose we normalize the direct matrix $\mathbf{X}^*$ as

$$\mathbf{X} = \lambda \cdot \mathbf{X}^*, \tag{2}$$

where

$$\lambda = 1/(\text{the largest row sum of } \mathbf{X}^*).$$

In this case, $\mathbf{X}$ is called the normalized matrix. Since

$$\lim_{\theta \to \infty} \mathbf{X}^\theta = [0] \tag{3}$$

then we obtain

$$\mathbf{T} = \mathbf{X} + \mathbf{X}^2 + \cdots = \mathbf{X}(\mathbf{I} - \mathbf{X})^{-1}. \tag{4}$$

Matrix $\mathbf{T}$ is called the direct/indirect matrix. The (i, j) element t_{ij} of matrix $\mathbf{T}$ denotes the direct and indirect influence from factor i to factor j. For example, direct/indirect matrix $\mathbf{T}_e$ concerning direct matrix $\mathbf{X}_e^*$ is obtained as follows:

$$\mathbf{T}_e = \begin{pmatrix} 0.35 & 1.05 & 0.45 \\ 0.45 & 0.35 & 0.15 \\ 0.15 & 0.45 & 0.05 \end{pmatrix}. \tag{5}$$

Suppose D_i denotes the row sum of ith row of matrix $\mathbf{T}$. 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 ith column of matrix $\mathbf{T}$. 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 $(D_i - R_i)$ is negative, then the factor i is rather receiving the influence from the other factors. For example, calculating these values concerning direct/indirect matrix $\mathbf{T}_e$, then we obtain $D_a + R_a = 2.8$, $D_b + R_b = 2.8$, $D_c + R_c = 1.3$, $D_a - R_a = 0.9$, $D_b - R_b = -0.9$ and $D_c - R_c = 0$. These results suggest factor a plays a central role and is dispatching factor, factor b plays a central role and is receiving factor.

3. Composite importance of each factor

3.1. Definition

In the original DEMATEL method we could evaluate the quantitative strength of each relation between each pair of factors. Therefore, it is possible to find factors that are resolved slightly or enormously when some factor was resolved. In the case of a direct matrix $\mathbf{X}_e^*$, by resolving the factor a which plays a central role and is dispatching factor, many factors in problematique are encouraged to be resolved enormously. However, this analysis is based only on the relations among factors. That is, the original DEMATEL is not taking into account the importance of each factor itself. Hence, it is not possible to evaluate the priority among the factors. For example, if the importance of factor c is high, then it may be efficient to resolve factor c.

To overcome this difficulty we introduce a new measure called the composite importance $\boldsymbol{z}$ into the original DEMATEL. The composite importance $\mathbf{z}$ is evaluated as follows: suppose the problematique is composed of n factors. We ask the respondent on the importance of each element. Based on the answers of the respondent we obtain n dimensional column vector $\mathbf{y}^*$. When we ask the importance of each factor to the respondent with 5-grade evaluation, the ith element y_i^* of n dimensional vector $\mathbf{y}^*$ is determined based on the answer of the respondent as

$y_i^* = 0$: if factor i is not important at all;
$y_i^* = 1$: if factor i is not important so much;
$y_i^* = 2$: if factor i is important;
$y_i^* = 3$: if factor i is very important;
$y_i^* = 4$: if factor i is quite important.

Let normalize $\mathbf{y}^*$ as

$$\mathbf{y} = \mu \cdot \mathbf{y}^*, \tag{6}$$

where

$$\mu = 1/(\text{the largest element of } \mathbf{y}^*).$$

The ith element of the column vector obtained by multiplying the direct/indirect matrix $\mathbf{T}$ by $\mathbf{y}$, denotes the importance of factors resolved by resolving factor i. Then, taking into account the importance of factor i itself the composite importance of each element could be evaluated as

$$\mathbf{z} = \mathbf{y} + \mathbf{T}\mathbf{y} = (\mathbf{I} + \mathbf{T})\mathbf{y}. \tag{7}$$

3.2. Numeric examples

We show the numeric examples of the composite importance in the case of foregoing section. The composite importance is calculated from the strength of influence and the importance of factor. The strength of influence is given by direct/indirect matrix $\mathbf{T}_e$. As concerns the importance of factor, three cases are provided.

Suppose that the importance of each factor is same. This is equivalent to the case that the importance isn't taken into account. Let normalize importance be ${}^t\mathbf{y}_{e1} = (0.5 \;\; 0.5 \;\; 0.5)$, then the composite importance is

Table 1
The factors that prevent safety and security

Respondents	Private factors	Societal factors
University students	Career to pursue, scholastic performance, finance, health of one's own, health of family, marriage, looks, ability/character, human relations, part time/full time job	Traffic accident, fire disaster, natural disaster, recession, pension system, national debt, terrorism, war, public peace, child-abuse incident, BSE, decline in academic achievement, environmental destruction, radioactive leakage, depletion of natural resources
Unmarried adults	Finance, health of one's own, health of family, unemployment, marriage, looks, ability/character, human relations, part time/full time job	
Married adults	Finance, health of one's own, health of family, unemployment, children, looks, ability/character, human relations, part time/full time job	

calculated as ${}^t\mathbf{z}_{e1} = (1.425 \quad 0.975 \quad 0.825)$. This value suggests that resolving factor *a* is most effective and resolving factor *b* is more effective. As just described, in taking no thought of importance, the composite importance reflects only strength of influence.

In the next place, let normalize importance be ${}^t\mathbf{y}_{e2} = (0.3 \quad 0.1 \quad 0.8)$, then the composite importance is calculated as ${}^t\mathbf{z}_{e2} = (0.870 \quad 0.390 \quad 0.930)$. In this example, the priority corresponds to the importance of each factor. In addition, let normalize importance be ${}^t\mathbf{y}_{e3} = (0.1 \quad 0.4 \quad 0.8)$, then the composite importance is calculated as ${}^t\mathbf{z}_{e3} = (0.915 \quad 0.705 \quad 1.035)$. In this case, the priority doesn't correspond to both the strength of influence and the importance. That is the reason, why the priority of factor *c* is highest is that the importance of this factor is highest. Also factor *a*, which has lowest importance, has second priority, the reason is because the strength of influence of factor *a* is highest. As described above, the composite importance is the measure that reflects both the strength of influence and the importance of each factor. Therefore, this measure provides useful information in fixing an order of priority.

4. Data obtained from the respondents

We asked respondents to answer two kinds of questionnaire: questionnaire *A* and questionnaire *B*, for extracting and analyzing factors that prevent safety and security in our life. In questionnaire *A* we tried to extract the factors that prevent safety and security. In questionnaire *B* we asked the questions on binary relations on each pair of factors. Questionnaire *B* is designed based on the factors extracted in questionnaire *A*.

In questionnaire *A* we asked questions to 42 respondents on the factors that prevent safety and security where we let them answer without any restraint. As the result, we could extract two kinds of factors: one kind is private factors of respondents and the other kind is societal factors. We found that private factors depend upon the respondents' social standing: university students, unmarried adults and married adults. Table 1 shows the factors extracted.

In questionnaire *B* the importance of each factor is asked to the respondents by 5-grade evaluation as shown in Fig. 2, where we adopted 10 people each for university students, unmarried adults and married adults. In this questionnaire

Do you feel uneasy for your career to pursue?
1. I feel quite uneasy.
2. I feel very uneasy.
3. I feel uneasy.
4. I do not feel uneasy so much.
5. I do not feel uneasy at all.

Fig. 2. An example of questions on the importance of each factor.

How much would it help in order to resolve the anxiety for pension system by resolving the anxiety for your career to pursue?
1. I think it would help very much.
2. I think it would help fairly well.
3. I do not think it would help at all.
4. I do not know.

Fig. 3. An example of questions on the strength of relation between two factors.

the importance of each factor implies the degree of feeling uneasy for each factor. Then, the strength of relation is asked by 3-grade evaluation. In detail, we obtained information on the binary relations between two private factors, between two societal factors and a societal factor to a private factor. Figure 3 shows an example of questions on the strength of relation between two factors.

5. Results

5.1. Structural models among uneasy factors

5.1.1. Private factors

Structural models for private factors are shown in Figs. 4–6. In these figures thick arrow is drown from factor *i* to factor *j*

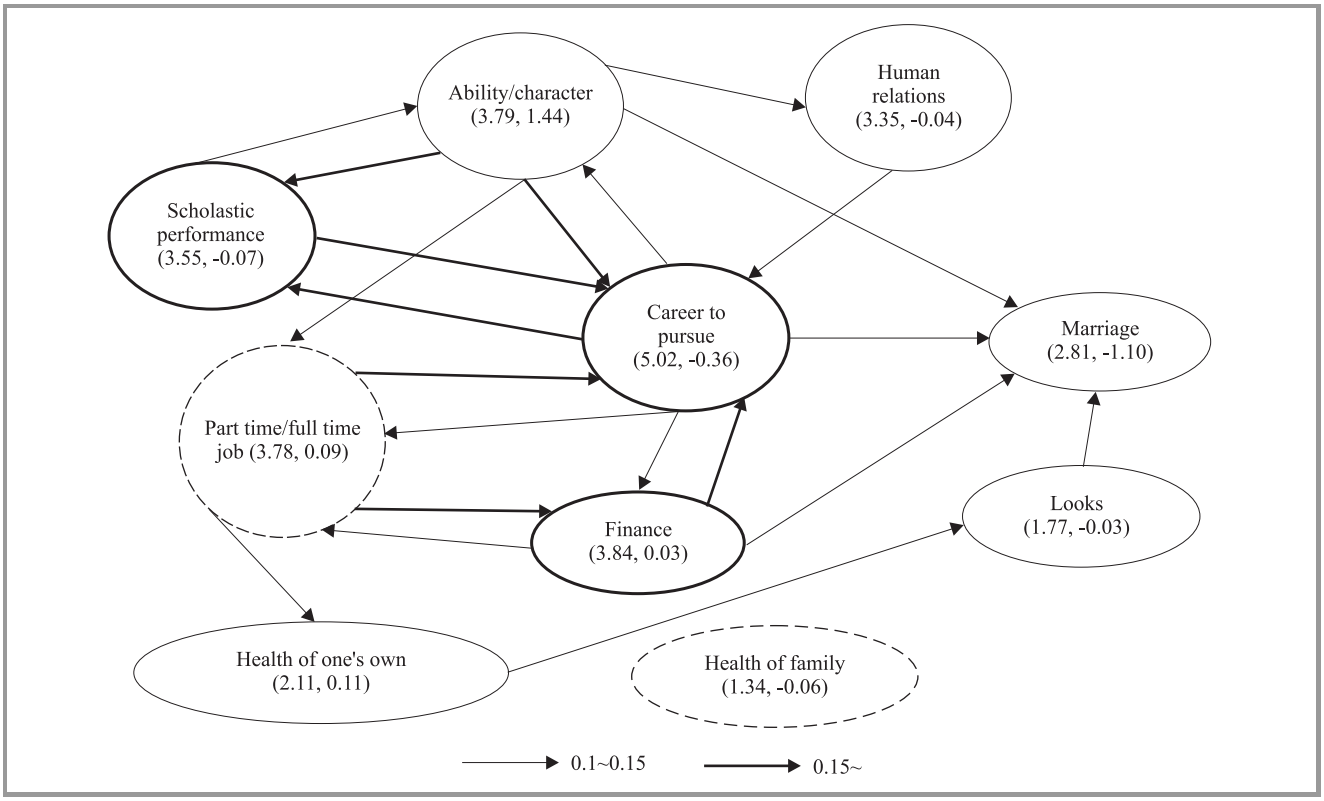

Fig. 4. Structural model for private factor of university students.

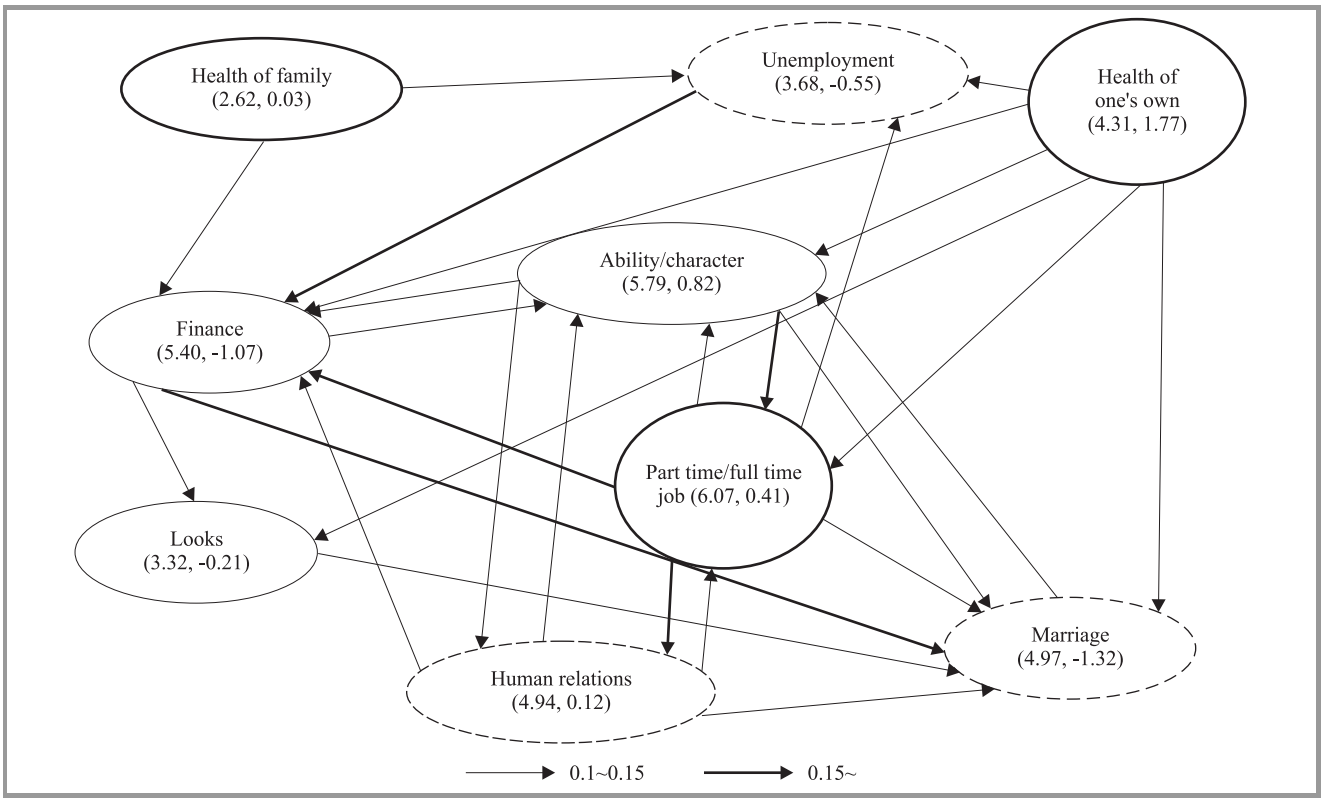

Fig. 5. Structural model for private factor of unmarried adults.

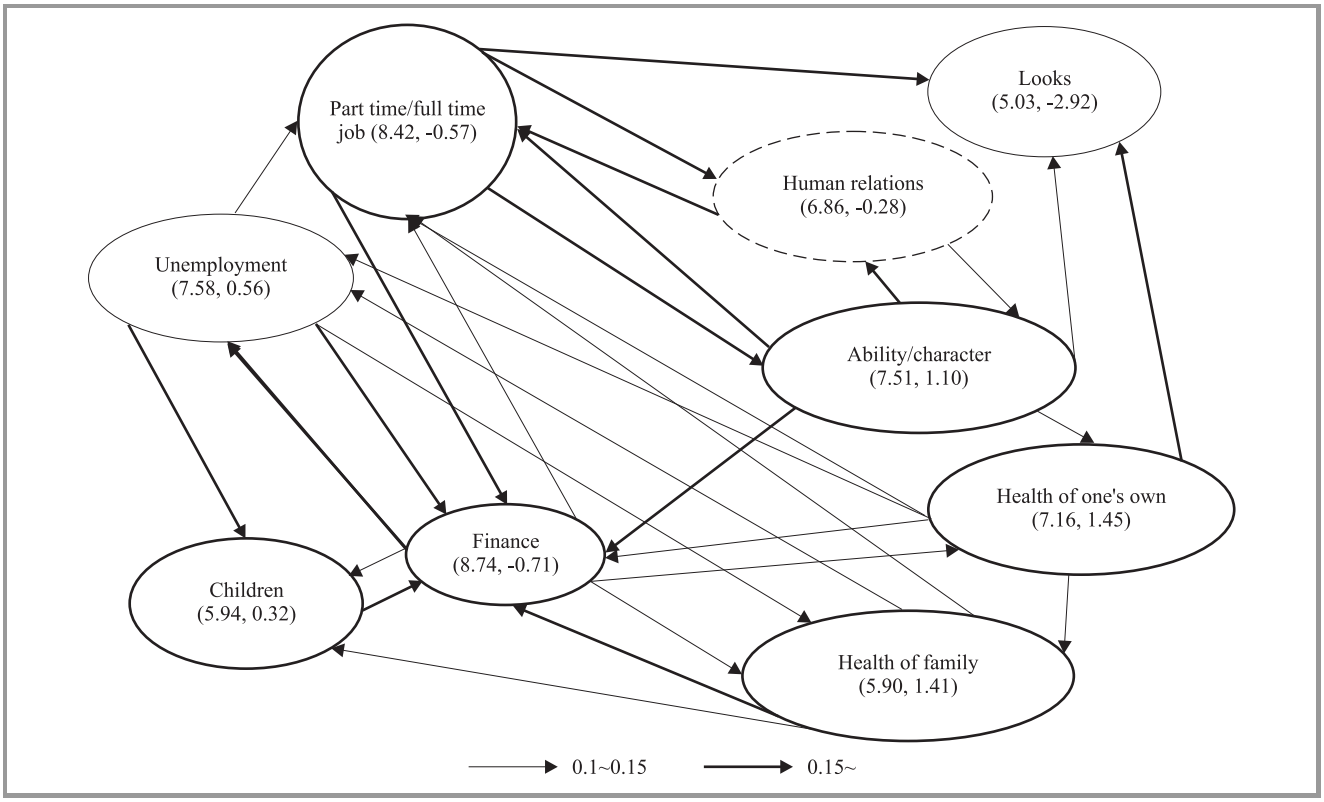

Fig. 6. Structural model for private factor of married adults.

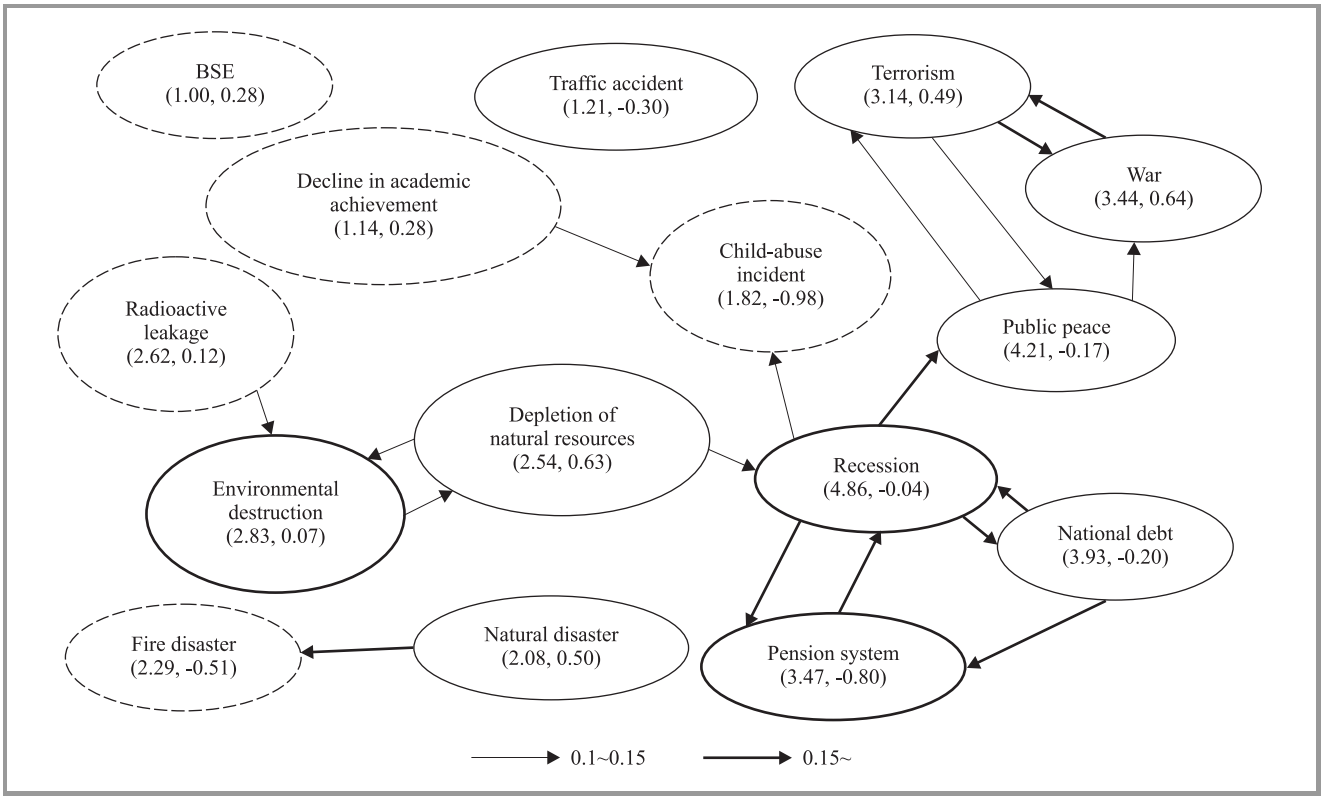

Fig. 7. Structural model for societal factors.

if x_{ij} is greater than or equal to 0.15, thin arrow if x_{ij} is between 0.1 and 0.15, and no arrow if x_{ij} is less than 0.1. Each factor is circled by a thick line if the importance y_i of factor i is greater than or equal to 0.55, by a thin line if y_i is between 0.45 and 0.55, and by a dotted line if y_i is less than 0.45. Under each factor the values of (D_i+R_i) and (D_i-R_i) are shown.
From Fig. 4 we found the following information for private factors of university students.

- "Ability/character" got the highest $(D-R)$ value, that is, this is the main influence dispatching factor that will affect other factors. This means that by resolving the anxiety on "ability/character" the anxiety on "scholastic performance", "career to pursue", "human relations", "marriage" and "part time/full time job" will be improved very much. That is, "ability/character" plays central role among many other factors.

- "Marriage" got the lowest $(D-R)$ value, that is, this is the main factor of receiving influence from other factors. This means that by resolving anxiety on "marriage" it will not affect other factors, but resolving the anxiety on "career to pursue", "ability/character", "looks" and "finance" will help to resolve the anxiety on "marriage".

- $(D+R)$ value of "career to pursue" is high. This means that "career to pursue" has strong connection with other factors and plays central role. Especially, it will receive big influence from "scholastic performance", "finance" and "part time/full time job", and it will affect "scholastic performance".

- $(D+R)$ value of "health of family" is low. This means that "health of family" is neither an influence dispatching factor nor an influence receiving factor.

From Fig. 5 we found the following information for private factors of unmarried adults.

- "Health of one's own" got the highest $(D-R)$ value, that is the most influence dispatching factor. This means that by resolving the anxiety on "health of one's own" the anxiety on "ability/character", "part time/full time job", "finance", "marriage" and "looks" will be improved very much.

- Just like university students "marriage" is a factor that will receive influence from the other factors for unmarried adults as well.

- $(D+R)$ value of "part time/full time job" is high. This means that "part time/full time job" has strong connection with the other factors and plays central role. Especially, it will receive big influence from "ability/character", and it will affect "finance" and "human relations".

- Just like university students "health of family" is neither an influence dispatching factor nor an influence receiving factor.

From Fig. 6 we found the following information for private factors of married adults.

- $(D-R)$ value of "ability/character" is high for married adults just like university students and unmarried adults. $(D-R)$ value of "health of one's own" is also high just like unmarried adults. Significant feature of married adults is that $(D-R)$ value of "health of family" is high. This means that by resolving the anxiety on "health of family" the anxiety on "finance" and "unemployment" will be improved very much. This structural model reflects the feeling of anxiety of married adults that the finance is supported by the family and "health of family" is one of the most important factor.

- $(D-R)$ value of "looks" is the lowest, that is, this is the main factor of receiving influence from the other factors.

- Compared with university students and unmarried adults $(D+R)$ value of almost all the factors is high and has strong relation with the other factors. Especially, $(D+R)$ value of "finance" is the highest, and "finance" has strong connection with the other factors. Especially, it will receive big influence from "ability/character", "children", "health of family", "unemployment" and "part time/full time job". $(D+R)$ value of "part time/full time job" is high just like unmarried adults.

5.1.2. Societal factors

From Fig. 7 we found the following information for societal factors.

- $(D+R)$ values of "recession", "public peace", "national debt" and "pension system" are high and these factors play central role. These four factors and "terrorism" and "war" are influencing each other.

- In general interrelations among various factors such as "bovie spongiform encephalopathy (BSE)", "traffic accident" and others are weak.

5.2. Composite importance of each factor

In Subsection 5.1 we obtained structural models of uneasy factors, and found factors with high $(D+R)$ value that play central role, factors with high $(D-R)$ value that mainly dispatch influence to the other factors, factors with low $(D-R)$ value that mainly receive influence from the other factors, and so forth. However, from these discussions we cannot find effective factors to be resolved in order to create future safe, secure and reliable society. For this purpose we

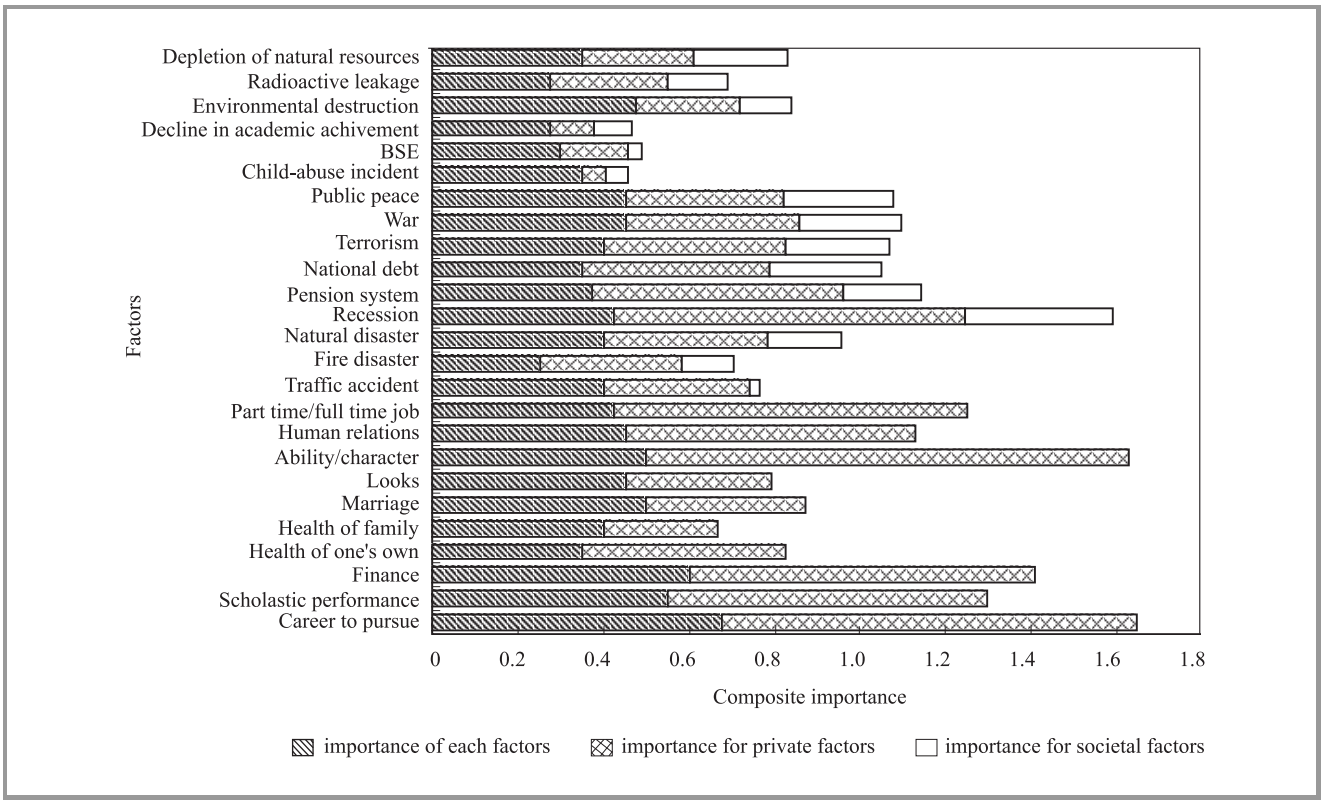

Fig. 8. Composite importance of university students.

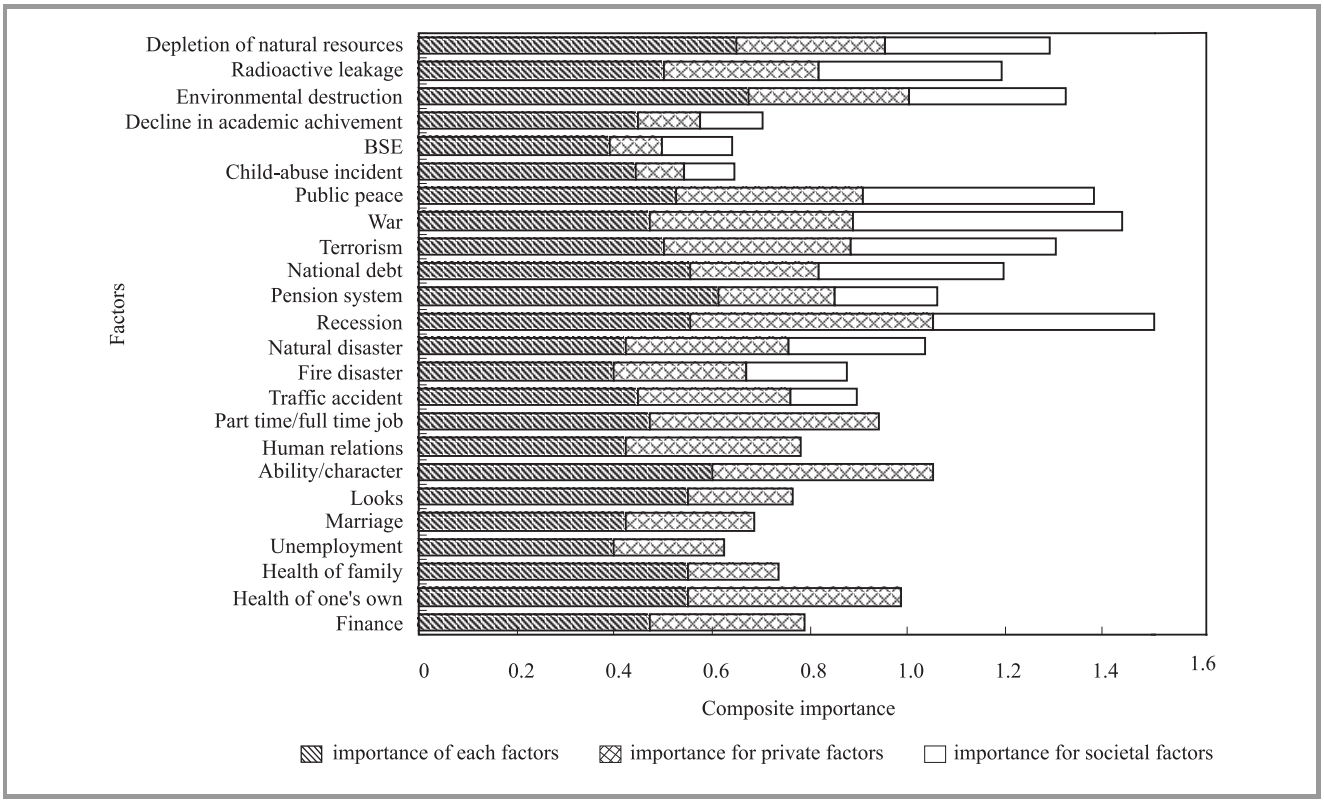

Fig. 9. Composite importance of unmarried adults.

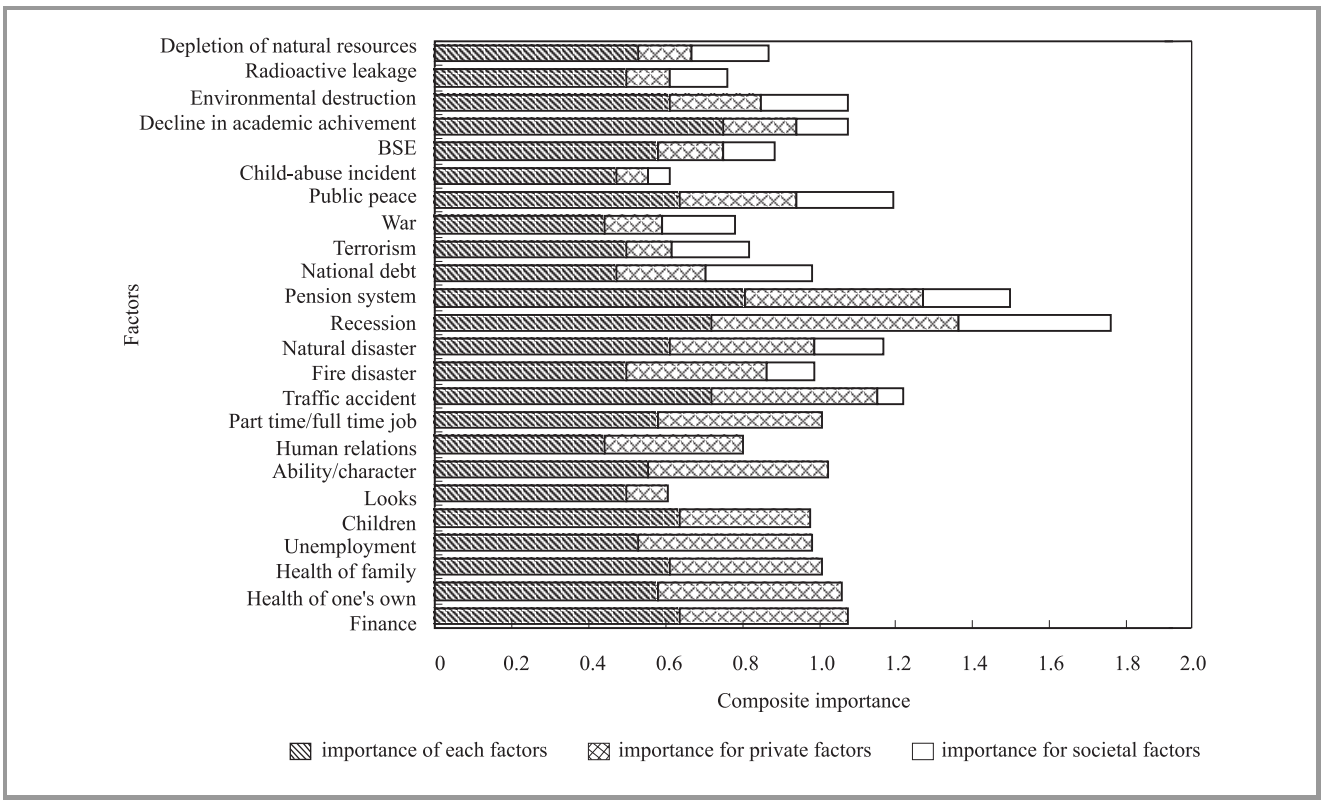

Fig. 10. Composite importance of married adults.

evaluated Eq. (7) the composite importance of each factor to be resolved in order to realize SSR society. Figures 8–10 show the results obtained for this purpose. In these figures the importance of each factor itself, composite importance of private factors, and composite importance of societal factors, are shown.

For university students, the composite importance of "career to pursue", "ability/character" and "recession" is high. Therefore, resolving anxiety for these factors is effective to resolve the anxiety for the other factors for them.

For unmarried adults, the composite importance of "recession", "war", "public peace", "environmental disruption", "terrorism" and "resource shortage" is high. Comparing with university students, unmarried adults feel more importance for societal factors. In addition, focusing attention to private factors, then factors that play central role and/or dispatch influences to the other factors doesn't necessary have high composite importance value. For example, though the factor that plays central role is "part time/full time job" and the most influence dispatching factor is "health of one's own", the composite importance of these factors is not so high. The composite importance of "ability/character" is high.

Finally, for married adults the composite importance of "recession" and "pension system" is high. As seen so far the composite importance of "recession" is high for all the people. That is, to resolve the anxiety for "recession" is the most effective means to improve the anxiety of other factors.

6. Concluding remarks

In this paper after finding various factors that prevent safety and security in our life we constructed structural models among these factors by using DEMATEL. From these models we found interdependencies among these factors and the strength of interdependencies. Furthermore, as a revised DEMATEL we proposed a new measure to show the composite importance of each factor and found the important factor to be resolved in order to resolve anxiety of the other factors effectively. This result may suggest to find effective policy to realize future SSR society.

For further research we may try to do more realistic questionnaire survey in order to propose effective policies to realize future SSR society. In this paper we studied abstract anxiety in general arising in Japanese society. For further research we may study in more specific field, e.g., the anxiety for buying food, anxiety to work in a specific environment, and so forth. If we could evaluate the cost, labor, etc., for resolving factors that prevent safety and security in our life we could get more useful results for realizing future SSR society.

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