

# Dynamic Structural Modeling and Its Applications: An Analysis of Anxiety Structure

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## Abstract

This study aims at investigating and analyzing the changes of consciousness structure. The method is already known and is referred to as —structural modeling; to investigate and analyze the change of consciousness structure. However, there have been only a few studies conducted to analyze the change of consciousness structure. We have therefore proposed the dynamic structural modeling as an outline to investigate and analyze the change of consciousness structure. As an example, we have applied the principle to the data about the structural change of human anxiety at the 2011 off the Pacific coast of Tohoku Earthquake and the result gives us useful information.

**Keywords:** Dynamic Structural Modeling, DEMATEL, anxiety, the 2011 off the Pacific coast of Tohoku Earthquake.

## 1. Introduction

The 2011 off the Pacific coast of Tohoku Earthquake that occurred on March 11, 2011 affected many different areas. It has been noted that the circumstance, has resulted in a significant change of human consciousness structure. For example, the anxiety about earthquakes, which previously was not included as a factor significant to alter human consciousness. Also, a large part of the human mind is thought to be formed like a nuclear power plant. The change in consciousness structure consequently affects the aspect of behaviors. It makes a person a lot more anxious or even more cautious in certain aspects.

This study aims to analyze these changes of human consciousness structure. A model named “structural modeling” exist that analyzes the causal structure recognized by human [1]. There is also a method used to investigate the structure based on the covariance between each variable, such as structural equation model. However, a method to dynamically investigate and analyze structural change has not yet been established.

This study therefore proposes a method for especially investigating and analyzing the consciousness structure that is changes as time passes. Here in this study, the modeling method for analyzing the consciousness structure that is changing as time passes, is called dynamic structural modeling. The “consciousness structure” descri-

bed in this study indicates that according to a particular subject there can be found a relationship between multiple matters (factors), that can be considered especially as causal relationships.

In the following sections, section 2 describes the outline of the proposed method, section 3 investigates and analyzes its concreteness, section 4 examines the method and compares it with existing researches, and section 5 offers a description with a conclusion.

## 2. Method

### 2.1 Investigation Method

The proposed dynamic structural modeling consists of two parts; the investigation and the analysis. Section 2.1 describes the investigation method and section 2.2 describes the analysis method. To start, quantitative research, a type of structural modeling used for Decision MAKing Trial and Evaluation Laboratory (DEMATEL) method developed at the Battelle Geneva Research Laboratory[2,3], is applied on multiple persons along with a time axis. The investigation by the DEMATEL method starts by listing multiple factors in advance. Next, two factors are extracted among them and “whether factor A influences another factor B or not (or its degree)” is investigated for each targeted person. It is executed for all combinations. In other words, a paired comparison method is applied and data is generated. Show section 3.1 for a concrete case. This study expands the method to investigate each person repeatedly in a certain term and grasp them in time series. However, it may be performed after any event, so if it is difficult to grasp them in time series, aided recall would be used (it is primarily desirable that the same target person is investigated at each time point).

Here the data handled in this study is formalized. At the given time  $t$  ( $1 \leq t \leq T$ ), the  $N \times N$  matrix  $X_{i,t}$  (its diagonal matrix is 0) it consists of degrees of influences  $x_{n,n'}$ , investigating the influences of  $N$  factors ( $1 \leq n \leq N$ ).

$N$ ) for the target person  $i$  ( $1 \leq i \leq I$ ) is created. When the  $X_{i,t}$  is considered as a graph, it can be recognized the weighed adjacency matrix when concepts are nodes. The matrix for each person is defined as  $X_i = \{X_{i,1}, \dots, X_{i,t}, \dots, X_{i,T}\}$ . Figure 1 illustrates the above.

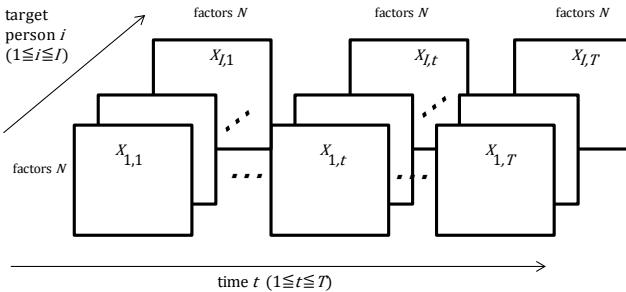


Fig.1 Proposed beam former.

## 2.2 Analysis Method

To analyze a changing structure, there is an approach which requires paying attention to the factors first. Which factors are important is investigated and how the ranks (characteristics) are changing. Based on the above, the following analysis method is proposed.

In this study, a simple method has been proposed to investigate the rank of each factor against the entire structure. The characteristics used by the DEMATEL method at each time point (such as the degree of influences, the degree of central role, and the degree of cause), are derived in all[2,3], and the differences are compared.

Concretely, a direct-influence matrix is calculated. The direct-influence matrix in this study indicates the created sum  $D_t = \sum_{i=1}^I x_{i,t}$  at each time  $t$  for each target person. It represents the strength of the direct affection from each factor based on all target persons. For example, it represents how a factor A directly influences a factor B. Then, the factor of  $D_t$  is defined as  $d_{t,n,n'}$  (The former index  $n$  is a row and the latter a column). The normalized direct-influence matrix is obtained based on it. The normalization means that the sum of the row of each matrix,  $ad_{t,n} = \sum_{n'=1}^N d_{t,n,n'}$  is calculated and  $D_t$  is divided by the maximum value, i.e.  $A_t = D_t / \max\{ad_{t,n}\}$ .

Next, it is called an indirect influence in the case that a factor A influences a factor B, and furthermore indirectly influences a factor C via the factor B. It is calculated as the  $k$ -th power of  $A_t$ . Normalization results in  $\lim_{k \rightarrow \infty} A_t^k = [0]$ .

The sum of the direct influence and the infinite number of the indirect influences, which represents total influences, is called a total-influence matrix. It is calculated as  $TA_t = A_t(I - A_t)^{-1}$ . The influence between each factor is defined as  $ta_{t,n,n'}$ .

Using the total-influence matrix calculated in this way; the temporal difference of the four characteristic values, “the degree of influences”, “the degree of receiving influences”, “the degree of central role”, and “the degree of cause”, is calculated.

The degree of influences represents how one factor has the influence strength against all factors. It is calculated as the sum of the row  $ad_{t,n} = \sum_{n'=1}^N ta_{t,n,n'}$  and the difference of the influence degree is calculated as  $ad_{t,n} - ad_{t-1,n}$ .

The degree of receiving influences represents how one factor receives the influence from all other factors. It is calculated as the sum of the column  $ad_{t,n'} = \sum_{n=1}^N ta_{t,n,n'}$  and the difference of the influence degree is calculated as  $ad_{t,n} - ad_{t-1,n'}$ .

In addition, the degree of central role is calculated from an integral view points between the influences and the receiving influences how one factor relates to other influences. It is calculated as the sum of both,  $C_{t,n} = ad_{t,n} + ad_{t,n'}$  and the difference of the degree of central role is calculated as  $C_{t,n} - C_{t-1,n}$ .

The degree of cause is the degree of the independent influence other than the influences of other factors, which is calculated as  $O_{t,n} = ad_{t,n} - ad_{t,n'}$ , and its negative value mainly means receiving influences. The difference of the degree of cause is calculated as  $O_{t,n} - O_{t-1,n}$ .

All are vectors. An analysis is also considered to calculate them for each target person  $i$ , but in this study average characteristics are analyzed after adding for all target persons.

## 3. Case Analysis

### 3.1 Investigation Design

The change of consciousness structure is then concretely analyzed by using the method proposed in this study. The theme of this investigation is that through the disaster, the 2011 off the Pacific coast of Tohoku Earthquake, how consciousness against earthquakes and accidents, especially the structure among multiple anxieties, is changing. This is considered in order to enable and grasp

the relationship between anxieties and help in the reduction.

The investigation design is described. The investigation term was from November 4, 2011 to November 7, 2011. The investigation method adopted questionnaire survey via internet and the number of the investigated persons were 480. The investigation was made all over the country (Japan) and had as subject 20 to 69 year-old male and female, along with the population composition for male-female and regions every 10 years old based on the national census.

As the time series, the structure at 3 points, the pre-earthquake, just the post-earthquake, and the present (November) is grasped. However, multiple investigations for an individual person for each time point is required, but at this moment the data before the earthquake cannot be obtained so that the difference between the structure at 3 points, the pre-earthquake, just the post-earthquake, and the present (November) is handled using aided recall. It must be noted that aided recall is used.

Next, the details about the questionnaire, (a) the preparation of anxiety items and (b) the measurement method of the influence strength of the relationship between anxieties are described. Other items asked on the questionnaire include: the degree of each anxiety, the property of each person, and the behaviors just after the disaster. These items are also investigated but they are not described because they are not related to this paper. Next is a description of the details.

#### (a) Preparation of anxiety items

Concerning anxiety; there are many types of anxiety in the world but, a limitation is necessary because there is a limit in investigating everything (the investigation methods with the use of free answer and so on are also considered). It also aims to reduce the load for answer. Therefore at the beginning, “anxiety” is divided into 6 categories; “individual anxiety”, “anxiety between individuals”, “anxiety against corporations (and organizations)”, “governmental anxiety”, “anxiety of the entire society”, and “external anxiety such as natural disasters and accidents” according to the quality and scale difference of the subject having the anxiety.

In addition, individual anxiety is again subdivided into income anxiety such as economy, health anxiety, and so on. The anxiety between individuals means in other words the anxiety of human relationship. Since human relationship in connection to location shall be separated especially because of the post-earthquake, it is roughly divided into the relationship with systems such as family, friends and

neighboring human relationship in connection to location. The economic anxiety items for corporations and organizations are especially handled which directly influence individuals. For anxiety of the entire society; the population ageing with decreasing birthrate and the failure of the social security system including pension are adopted that are often discussed today. Moreover, it is subdivided into the anxiety against natural disasters and accidents of nuclear power plants which consists of the significant anxiety component factors after the earthquake (Table 1).

#### (b) Measurement method with regards to the influence strength and the relationship between anxieties

With regards to influences, the extraction of 2 anxieties among anxiety sub items listed in table 1, it is investigated whether a target person think “anxiety A influences anxiety” and moreover let a target person answer the influence degree with 5 rank scales, 1-5. They are applied for all anxiety combinations. There exist impossible combinations because of causal reason, but all combinations are investigated. In addition, let a target person recall the pre-earthquake, just the post-earthquake, and the present, respectively, and answer the thought at each point in time as described above.

Table 1: Anxiety Items

| Concept  | Categories                                       | Factors   |
|--|--|---|
| Anxiety  | Individual anxiety                               | Deterioration of personal and familial employment situation and income                        |
|  |  | Deterioration of personal and familial health   |
|  | Anxiety between individuals                      | Deterioration of human relationship with family or friends                                    |
|  |  | Deterioration of human relationship nearby including neighbors and a neighborhood association |
|  | Anxiety against corporations (and organizations) | Deterioration of private corporation profit   |
|  | Governmental anxiety                             | Deterioration of the government finance   |
|  | Anxiety of the entire society                    | Failure of the social security system   |
|  |  | Progress of society of aging population with decreasing birthrate                             |
| External anxiety such as natural disasters and accidents |  | Natural disasters such as earthquakes, tsunamis, and landslides                               |
|  |  | Influence of the nuclear power plant accident   |

Table 2: Characteristic value and difference of each anxiety at 3 time points (gray is top 3)

| Anxiety   | Pre-earthquake          |                                    |                            |                     | Post-earthquake         |                                    |                            |                     | Present                 |                                    |                            |                     | [post]-[pre]            |                                    |                            |                     | [present]-[post]        |                                    |                            |                     |
|---|-------------------------|------------------------------------|----------------------------|---------------------|-------------------------|------------------------------------|----------------------------|---------------------|-------------------------|------------------------------------|----------------------------|---------------------|-------------------------|------------------------------------|----------------------------|---------------------|-------------------------|------------------------------------|----------------------------|---------------------|
|   | the degree of influence | the degree of receiving influences | the degree of central role | the degree of cause | the degree of influence | the degree of receiving influences | the degree of central role | the degree of cause | the degree of influence | the degree of receiving influences | the degree of central role | the degree of cause | the degree of influence | the degree of receiving influences | the degree of central role | the degree of cause | the degree of influence | the degree of receiving influences | the degree of central role | the degree of cause |
| Deterioration of personal and familial employment situation and income            | 1.05                    | 1.64                               | 2.69                       | -0.59               | 1.15                    | 1.83                               | 2.98                       | -0.68               | 0.95                    | 1.75                               | 2.70                       | -0.80               | 0.09                    | 0.19                               | 0.28                       | -0.09               | -0.19                   | -0.08                              | -0.27                      | -0.11               |
| Deterioration of personal and familial health                                     | 0.70                    | 1.03                               | 1.73                       | -0.34               | 0.84                    | 1.22                               | 2.06                       | -0.38               | 0.78                    | 1.17                               | 1.95                       | -0.39               | 0.14                    | 0.18                               | 0.32                       | -0.04               | -0.06                   | -0.05                              | -0.11                      | -0.01               |
| Deterioration of human relationship with family or friends                        | 0.52                    | 0.75                               | 1.28                       | -0.23               | 0.58                    | 0.85                               | 1.43                       | -0.27               | 0.58                    | 0.83                               | 1.40                       | -0.25               | 0.06                    | 0.10                               | 0.16                       | -0.04               | 0.00                    | -0.03                              | -0.03                      | 0.02                |
| Deterioration of human relationship nearby including neighbors and a neighborhood | 0.41                    | 0.63                               | 1.04                       | -0.21               | 0.49                    | 0.68                               | 1.17                       | -0.19               | 0.46                    | 0.65                               | 1.11                       | -0.18               | 0.08                    | 0.06                               | 0.13                       | 0.02                | -0.03                   | -0.03                              | -0.06                      | 0.00                |
| Deterioration of private corporation profit                                       | 1.72                    | 1.75                               | 3.47                       | -0.03               | 2.03                    | 2.03                               | 4.05                       | 0.00                | 1.95                    | 1.93                               | 3.88                       | 0.02                | 0.31                    | 0.28                               | 0.58                       | 0.03                | -0.08                   | -0.10                              | -0.17                      | 0.02                |
| Deterioration of the government finance   | 2.10                    | 1.97                               | 4.07                       | 0.13                | 2.29                    | 2.24                               | 4.52                       | 0.05                | 2.22                    | 2.14                               | 4.36                       | 0.08                | 0.19                    | 0.27                               | 0.45                       | -0.08               | -0.07                   | -0.10                              | -0.17                      | 0.03                |
| Failure of the social security system   | 1.82                    | 1.94                               | 3.75                       | -0.12               | 1.98                    | 2.17                               | 4.15                       | -0.19               | 1.90                    | 2.09                               | 3.99                       | -0.19               | 0.16                    | 0.24                               | 0.40                       | -0.07               | -0.08                   | -0.08                              | -0.16                      | 0.01                |
| Progress of society of aging population with decreasing birthrate                 | 1.59                    | 1.59                               | 3.18                       | -0.01               | 1.72                    | 1.85                               | 3.57                       | -0.13               | 1.68                    | 1.82                               | 3.50                       | -0.13               | 0.14                    | 0.25                               | 0.39                       | -0.12               | -0.04                   | -0.03                              | -0.06                      | -0.01               |
| Natural disasters such as earthquakes, tsunamis, and landslides                   | 1.87                    | 1.10                               | 2.96                       | 0.77                | 2.26                    | 1.32                               | 3.58                       | 0.95                | 2.17                    | 1.20                               | 3.37                       | 0.98                | 0.40                    | 0.22                               | 0.61                       | 0.18                | -0.09                   | -0.12                              | -0.21                      | 0.03                |
| Influence of the nuclear power plant accident                                     | 1.84                    | 1.21                               | 3.06                       | 0.63                | 2.27                    | 1.43                               | 3.69                       | 0.84                | 2.16                    | 1.30                               | 3.46                       | 0.86                | 0.43                    | 0.21                               | 0.64                       | 0.21                | -0.11                   | -0.12                              | -0.24                      | 0.01                |

## 4. Results

The analysis results represented in 2.2 (1) are described (Table 2). After calculating the direct-influence matrix; the characteristic values and the differences are compared using the matrix. The normalized direct-influence matrix is visually mentioned in the appendix (Appendix). In addition, the value is 0 in case that the answer is “no relationship”. The value uses the score evaluated with 1-5 in other cases. Impossible combinations because of causal reason are also used instead of removed.

The degree of influences and the difference are observed. The top and bottom of the degree of influences include “deterioration of the government finance”, “natural disasters such as earthquakes, tsunamis, and landslides”, and “influence of the nuclear power plant accident” at the pre-earthquake, just the post-earthquake, and the present, similarly. These values are increasing from the pre-earthquake to just the post-earthquake at the top of the difference. In addition, from just the post-earthquake to the present, the deterioration of personal and familial employment situation and income, etc are decreasing and furthermore the influences of natural disasters and nuclear power plant accidents are also decreasing.

The degree of receiving influences and the difference are observed. The top of the degree of receiving influences include “deterioration of private corporation profit”,

“deterioration of the government finance”, and “progress of society of aging population with decreasing birthrate” at the pre-earthquake, just the post-earthquake, and the present, similarly. The differences between the pre-earthquake and just the post-earthquake show the increase of “deterioration of private corporation profit”, “deterioration of the government finance”, and “progress of society of aging population with decreasing birthrate”. On the other hand, the differences between just the post-earthquake and the present show the decrease of the degree of receiving influences of natural disasters and nuclear power plant accidents.

The degree of central role and the degree of cause are described. Among them, the structure of the former is similar to the degree of receiving influences and the latter the degree of influences. However observing the differences of the degree of central role and the degree of cause from just the post-earthquake and the present, “deterioration of personal and familial employment situation and income” is decreasing.

## 5. Discussions

Results of the dynamic structural modeling of this study shows the anxiety structure as having the influences of natural disasters and nuclear power plant accidents. It also shows deterioration of private corporation profit caused by the government finance, and failure of the social security system. Just after the earthquake such tendency had

increased but these influences have slightly decreased from just the post-earthquake to the present.

However as the problem of the analysis, the above mentioned structure does not inspect how much concretely it influences the degree of anxiety. Therefore, if the elimination of anxiety is aimed politically, a measure of correlation with “the degree of anxiety” must be obtained. To obtain such a realization, network autocorrelation [4] and so on must be calculated using the degree of anxiety and the integral priority must be considered including the consideration of the factor priority. Moreover, a study must be conducted on how the results obtained by the analysis (1) and (2) are related.

From a methodological view point, the dynamic structural modeling as an expansion of the structural modeling which handles the temporal difference is performed and can be used to grasp a concrete task structure. For an exact investigation, temporal investigation for concrete panel data is required as described before. Here, it shall be noted that in this study the difference is detected without assuming temporal correlation structure like statistical temporal model but the difference itself is detected.

Next, the difference between the existing studies and dynamic structural modeling is described. From an investigation, analysis, and application view point, the following characteristics are determined compared with the existing studies.

It should be note at first that the study is original as an investigation method because the structural modeling is expanded in time series [5,6]. In the existing studies, the structural difference of various groups has been studied [7]. In addition, the method called ISM tried to expand to time series [8]. But the structural modeling has not been well expanded to the time series. However, the consciousness structure how to observe and grasp a problem is not constant but temporally changing and human behaviors changes according to the structural change, so that their analysis, reason specification of the changes, and so on are mandatory problems to be solved.

Next, the DEMATEL method as an analysis method usually calculates characteristic values and performs statistic processing on them [2,3,5,6]. However, in this study, it is characterized that temporal difference of characteristics using the DEMATEL method is observed. There is also other difference of analysis method. Different from structural equation model and so on which inspects the assumption beforehand based on covariance between variables, the relationship between variables is directly investigated to a target person. The difference is that the method of human recognition is focused other than causal

structure behind. Therefore, it shall be noted that the correlation of variable degrees may not always be approved.

It is important to analyze the anxiety structure. Anxiety is often shown in our life and it performs an important role in psychology because it is related to various mental disorder and behavior [9]. In addition, the measure of risk aversion of Japanese people can be noticed and is often related to anxiety [10]. From the point of view of anxiety analytic, there are some studies in the areas such as social psychology and clinical psychology. For example, classification and analysis methods from another view point such as “state-trait anxiety theory” are proposed. There are some similar studies about anxiety structure such as studies using correlation and using the DEMATEL method [7]. However, the difference in this study is the analysis of how each individual recognizes the relationship between anxiety factors and how it “changes”.

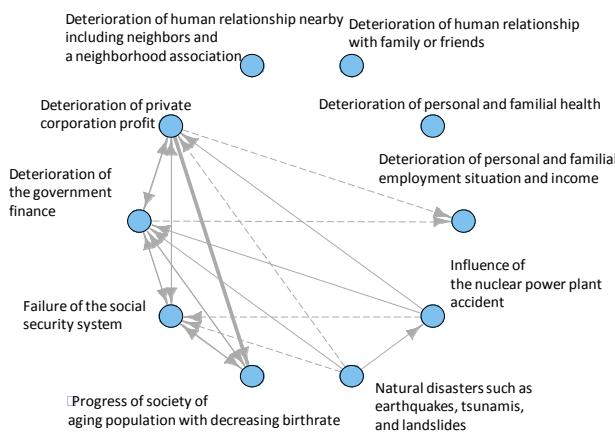
## 6. Conclusions

In this study, the investigation called dynamic structural modeling and its analysis method has been proposed to analyze the consciousness structure which temporally changes. Applied to the data about anxiety structure change, useful knowledge has been obtained. Concretely, the anxiety structure shows influences of natural disasters and nuclear power plant accidents. It is also influenced by deterioration of private corporation profit caused by the government finance, and failure of the social security system. Just after the earthquake such tendency had increased but it seems like such influences have been determined as being slightly lower or have decreased from the just the post-earthquake period to the present.

The method of this study focused on “how human grasp problem structure” and how it changes. On the other hand, the analysis could be difficult because of the complexity of the data structure. Hereafter as more advanced analysis, the difference according to the properties would be detected and the degrees of anxiety influences analyzed using network autoregressive model described in the conclusions. The usage of tensor analysis, graph mining, and so on could also be considered.

## Appendix

The difference between the structures at 3 time points (2 or more average score. The solid line: existing before the earthquake, the dotted line: added just after the earthquake, the bold line: added at the present)



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