8th Workshop on Non-Linear Dynamics and Earthquake Prediction

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Integrated Disaster Risk Management as an Innovation of Science and Technology: Issues, Methods and Challenges. Part I

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These are preliminary lecture notes, intended only for distribution to participants
Tonankai Erthquake Mitigation Initiative Project (Daidaitoku Okada Sub-project)
Entire Project Headed by Prof. Yoshiaki Kawata, DPRI, Kyoto University
Sub-project led by Norio Okada, DPRI, Kyoto University

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Project Period 2002-2006

- Purpose: Implementation-oriented Research Initiative in Disaster Risk Mitigation
- Expected Outcomes:
  - achievable, visible and transferable by 2006
  - customers, stakeholders-available outputs
  - unique and research value-added approach
  - academic initiative
 Chronology of Catastrophic Earthquakes Around Suruga-Nankai Trough
( http://www.greencompass.net/ )

■駿河・南海トラフの地震の震源域について
領域 X、Y、Zは、南東部、東南海、東北海の想定震源域。地質的には、領域 X が足摺岬（高知県）沖～潮岬（和歌山県）沖、領域 Y が潮岬沖～浜名湖（静岡県）沖、領域 Z が浜名湖沖～駿河湾沖域において想定する。なお領域 Y は想定東南海地震の震源域に該当する。震源域の深さ（断層面の分布する深さ）は、領域 Z については北西側で30kmより深い領域、東側で10kmより深い領域とされ、領域 X、Y については東西端での深さは同じで、とともに北端（沿岸寄り）が20km、南端（トラフ寄り）が10kmとされている。左図は、地震調査報告書「南海トラフの地震の長期評価」（2001）および中央防災会議「東海地震に関する専門調査会報告」（2001）をもとに作成。

■駿河・南海トラフの巨大地震
駿河・南海トラフ沿いに発生する地震は、ある一定の間隔で発生してきたことが知られている。しかも東海、東南海、南海という三つの巨大地震は同時もしくは近接して、東から順に発生しているのがわかる。
中央防災会議「東海東南海地震等に関する専門調査会」（2001）の報告によると、駿河・南海トラフに発生した巨大地震は西暦684年の白鳳地震から現在まで、9回の地震を挙げている。一方、同年9月に地震調査報告書「南海トラフの地震」（2001）の報告によると白鳳地震から1605年より前については検討の結果、南海トラフ沿いの地震として同定にいたらなかったとして、1605～1946年までの期間に、4回の一連の巨大地震を挙げている。左図はそれをもとに作成。なお地震の規模を示すM(マグニチュード)は理研年表（2001）によった。
また「東海地震」という呼称は、1944年の昭和東南海地震に対して使われてきたが、政府により先の想定震源域に基づいた検討が行われている現在は、この政府検討に基づいた呼称を用いることが多い。左図の地震もこの呼称によるものとする。
A Japan’s Challenge towards Anticipatory and Participatory Urban Disaster Risk Management: Case Study of Tonankai Earthquake Disaster Initiative

Norio Okada* and Hirokazu Tatano*

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IUEPA, Louisville, KY, 8 Sept.2004
Project Period 2002-2006

• Purpose: Implementation-oriented Research Initiative in Disaster Risk Mitigation

• Expected Outcomes:
- achievable, visible and transferable by 2006
- customers, stakeholders-available outputs
- unique and research value-added approach
- academic initiative
Major Challenges

- Anticipatory approach supported by the methodology of urban diagnosis and adaptive management
- Participatory process involving multiple stakeholders
- Integrated disaster risk management to be linked with urban and regional planning and management.
Lessons from the 1995 Hanshin-Awaji Earthquake Disaster

- Low-frequency, high-impact disaster (catastrophic disaster) requires a special approach different from the conventional one familiar to Japan.

- Coordinated approach to maximize the integrated capacity for the region to cope with holistic aspects of such a catastrophic disaster.

- Shift from failure-masked to fail-safe, risk management approach.

- From retroactive to proactive approach

- Link disasters to daily life concerns.
## Conventional and 21st century disaster plan

<table>
<thead>
<tr>
<th>Conventional disaster plan</th>
<th>21st century integrated disaster planning and management</th>
</tr>
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<tbody>
<tr>
<td>reactive</td>
<td>proactive</td>
</tr>
<tr>
<td>emergency and crisis management</td>
<td>risk mitigation + preparedness</td>
</tr>
<tr>
<td>countermeasure manual approach</td>
<td>anticipatory/precautionary approach</td>
</tr>
<tr>
<td>predetermined planning</td>
<td>adaptive management</td>
</tr>
<tr>
<td>sectoral countermeasure approach</td>
<td>comprehensive policy-bundle approach</td>
</tr>
</tbody>
</table>

- **Proactive**: Risk mitigation + preparedness
- **Adaptive management**: Comprehensive policy-bundle approach
- **Reactive**: Emergency and crisis management
City/Region/Community
Viewed as a Five-storied Pagoda
(Pagoda Model)
Multi-level Participatory Approach

• impact of the earthquake would be immense and distribute across regions and down to local communities

• coping capacity need to be fostered on community level in anticipation of the Tonankai Earthquake.

• administrators and experts engaged in inter-regional disaster management are expected to work together and develop effective mitigation countermeasures and implement them in advance.
Table 1 Occurrence Probabilities Predicted
<Source: 地震調査委員 Earthquake Investigation Committee (2001)>

<table>
<thead>
<tr>
<th></th>
<th>next 30 years</th>
<th>next 40 years</th>
<th>next 50 years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50%</td>
<td>70-80%</td>
<td>80-90%</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>60%</td>
<td>80%</td>
</tr>
</tbody>
</table>
Disaster Scenario

- **Tokai Earthquake**
  Transport infrastructure (highway, railway) is damaged, and for 3 months it is out of service due to restoration. Traffics have to go on detours.

- **Congestion of the main Detour (Chuo Route)**
  Assuming congestion of Chuo Route, congestion effect is inserted exogenously (Scenario 2, 3).
Assumption on Commodity Transport

- We assume that Commodity is transported by the Shortest Path (in terms of Transit Time) of all paths in the Network linking Origin and Destination.

- This makes us possible to consider the Choice of Detour. And we reflect the change of transit time on transport cost rate ($\Phi$) in our SCGE model.
Disaster - Damage to Transport Infrastructure

Region 1

Region 2

Utility of Consumer

damaged

damaged
Disaster
-Damage to Transport Infrastructure

Region 1

Region 2

Economic loss results in lower utility

Utility of Consumer

damaged

damaged

damaged
Disaster - Damage to Transport Infrastructure

Region 1

Damage to Transport Infrastructure:

Region 2

Economic loss results in lower utility

Utility of Consumer

damaged
Disaster
-Damage to Transport Infrastructure

Region 1

Utility of Consumer

Region 2
Economic loss results in lower utility

Damaged

Damaged
Disaster
-Damage to Transport Infrastructure

Region 1

Region 2
Utility of Consumer

damaged
Disaster - Damage to Transport Infrastructure

Region 1

Region 2

Utility of Consumer

damaged
Disaster
-Damage to Transport Infrastructure

Region 1

Region 2
Utility of Consumer
damaged

Utility of Consumer
damaged
Disaster - Damage to Transport Infrastructure

Region 1

Region 2

Utility of Consumer

damaged
Disaster
-Damage to Transport Infrastructure

Region 1

Region 2

Economic loss results in lower utility

Utility of Consumer

damaged

damaged

damaged

Economic loss results in lower utility
災害時

(2) 人的被害・ 生産資本被害

in Disaster -2

Damage to People or Production Capital
Disaster
- Production capital damage or Human damage in Region 1

Region 1

Region 2

Utility of Consumer
Disaster
- Production capital damage or Human damage in Region 1

Region 1

damaged

Region 2

Utility of Consumer
Disaster - Production capital damage or Human damage in Region 1

Region 1

Utility of Consumer

Region 2
Disaster
- Production capital damage or Human damage in Region 1

Region 1
- Damaged

Region 2
- Utility of Consumer
Disaster
- Production capital damage or Human damage in Region 1

Region 2
Utility of Consumer

Region 1
damaged
Disaster
- Production capital damage or Human damage in Region 1

Region 1
- Damaged

Region 2
- Economic loss results in lower utility

Utility of Consumer
Disaster
- Production capital damage
or Human damage in Region 1

Region 1
damaged

Region 2

Economic loss results in lower utility

Utility of Consumer
Disaster
- Production capital damage or Human damage in Region 1

Region 1
- Damaged

Region 2
- Economic loss results in lower utility

Utility of Consumer
Disaster
-Production capital damage or Human damage in Region 1

Region 2
Utility of Consumer

Region 1
damaged
Disaster
- Production capital damage
  or Human damage in Region 1

Region 1

Region 2

Utility of Consumer
Disaster
- Production capital damage
  or Human damage in Region 1

Region 1

Region 2

Utility of Consumer

damaged

Disaster
- Production capital damage or Human damage in Region 1

Utility of Consumer

Region 2

Region 1
Disaster
- Production capital damage or Human damage in Region 1

Region 1
- Damaged

Region 2
- Economic loss results in lower utility

Utility of Consumer
Disaster
- Production capital damage or Human damage in Region 1

Region 1

Region 2

Economic loss results in lower utility

Utility of Consumer

damaged
Production Structure of Firm - 1

Output

Leontief type

Intermediate Goods

Purchased from other/the same region

Compound Factor Forming Value-added

Cobb-Douglas type

Fundamental Compound Factor

Cobb-Douglas type

Labor

Capital

Knowledge

Business Trip

Cobb-Douglas type

Cobb-Douglas type

Cobb-Douglas type

Cobb-Douglas type
Main Result

Losses per employed person under scenario 1

Transport-related Losses (Trillion yen) (*10 Thousand yen)

Scenario 1
Scenario 2
Scenario 3

Hokkaido, Tohoku, Kanto, Yamanashi, Shizuoka, Toyama, Ishikawa, Aichi, Mie, Gifu, Kinki, Chugoku, Shikoku, Kyushu, Okinawa

Losses per employed person under scenario 1
Community-Based Approaches

Citizen-Involved Expert Initiatives

1. Noda, Osaka (Academics-led)
2. Noshibiwajima, Nagoya (NPO-led)
Collaborative Modeling (Regional-Professional)

- Participatory Approach-oriented
- Alternative Policy-making Process
- Policy Prioritizing Process from among a Policy Bundle
- Scenario-based, Contingency-context
- System Engineering-endorsed
- Economically-endorsed
- Socio-culturally Tailored
防災マップの作成
～NPOによる防災教育ワークショップにて

GISツールの説明
～団地内自主日本語教室にて
Managing policy

Setting up communication platform for policy development

Urban diagnosis

1. Action
   - Planning policy making/ revising
   - Observing current state

2. Plan
   - Setting up communication platform for policy development

3. Check
   - Planning policy making/ revising

4. Do
   - Observing current state

Management Cycle

Implementing policy
The multidisciplinary knowledge-creation model (Fong, 2005)
Participatory community diagnosis

System to facilitate knowledge sharing and generation

Two phases
- Community preparedness diagnostic survey
- Policy-setting workshops
Community diagnosis

Citizen (Local)

NPO (Practical)

Multilateral Knowledge Development

Their own community

Experience at cite

Self Diagnosis

Explicit Knowledge

Researcher (Analytical)

Their own community

Self Diagnosis

Community diagnosis
Community preparedness diagnostic sheet

43 questions are…

Selected from local people’s concern which NPO has got through their workshops ⇒ Practical knowledge

<table>
<thead>
<tr>
<th>Target Area</th>
<th>Survey Period</th>
<th>Valid Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higashiyama</td>
<td>Dec. 2004</td>
<td>3613</td>
</tr>
<tr>
<td>A Town</td>
<td>Nov. 2004</td>
<td>1155</td>
</tr>
<tr>
<td>K Town</td>
<td>Jan. 2005</td>
<td>184</td>
</tr>
</tbody>
</table>
地域防災力診断シート

近い将来、東海地震や南海地震が心配される。それらの地震が発生した場合、お住まいの自治体や地域自治体に対してどのように準備すべきかが問題である。

このシートは、あなたの回答を基にした地域の防災の備えを診断するものです。

1. 自宅の自宅に対する備えは10点満点で何点ですか？
   - 1.2.3.4.5.6.7.8.9.10点

2. 住む地域の地震に対する備えは10点満点で何点ですか？
   - 1.2.3.4.5.6.7.8.9.10点

3. 地震6強以上の地震で、自宅はどの程度の被害を受けますか？
   - 1.2.3.4.5.6.7.8.9.10点

4. 自宅からの震度のことを知っていますか？
   - 1.2.3.4.5.6.7.8.9.10点

5. 自宅の耐震診断を受けたことがありますか？
   - 1.2.3.4.5.6.7.8.9.10点

6. 自宅の耐震補強工事を受けたことがありますか？
   - 1.2.3.4.5.6.7.8.9.10点

7. 自宅の土台の安全なことをしましたか？
   - 1.2.3.4.5.6.7.8.9.10点

8. 周辺の住宅の耐震化は進んでいると思いますか？
   - 1.2.3.4.5.6.7.8.9.10点

Self-scored Preparedness

43 questions from NGO
## Regional Comparison (2 sample t-test)

<table>
<thead>
<tr>
<th>CPI</th>
<th>Housing</th>
<th>Storage</th>
<th>Shelter</th>
<th>Special Support</th>
<th>Community Linkage</th>
<th>Fire</th>
<th>Emergency Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higashiyama</td>
<td>3.45</td>
<td>4.74</td>
<td>5.94</td>
<td>5.14</td>
<td>4.55</td>
<td>5.20</td>
<td>4.95</td>
</tr>
<tr>
<td>A Town</td>
<td>3.35</td>
<td>4.31</td>
<td>5.95</td>
<td>5.16</td>
<td>5.03</td>
<td>6.21</td>
<td>4.57</td>
</tr>
<tr>
<td>K Town</td>
<td>3.46</td>
<td>4.86</td>
<td>6.35</td>
<td>5.33</td>
<td>5.38</td>
<td>6.63</td>
<td>5.03</td>
</tr>
</tbody>
</table>

\[ H_0: (\text{Avr. Higashiyama}) = (\text{Avr. Other Town}) \]

Highlighted elements are rejected in significant level 5%.

Higashiyama is significantly low score in 【Community Linkage】 and 【Fire】
Individual distribution of CPI

- Optimistic residents
- Pessimistic residents
- Neutral residents

Graph showing the distribution of CPI averaged over elements with self-evaluated scores for mutual preparedness.
Prescriptive workshop (Apr. 2005)

Understanding the diagnostic survey results

List up local ideas to decrease weak points
Some of the local ideas

- **<Storage>** Let us know **repeatedly** to encourage personal storage.
- **<Shelter>** It is not possible for all of us to get sheltered in the school (Officially designated shelter). It’s better to have an **unofficial place for evacuation** in our neighbourhood.
- **<Shelter>** We asked a neighbor church to let it open in emergency to over-80, injured handicapped as a shelter.
- **<Others>** We have a vague consciousness on a disaster. But it is necessary for our sense to be stimulated by posters and other printed materials to be **always aware of it**.
- **<Others>** First comes **myself and my family’s** safety ensuring. Second comes safety for my neighbours. Community’s linkage is an important factor to keep up for the purpose.
Discussions

• Citizens has been already aware of “sustainability” of disaster preparedness

• Spatial unit of disaster preparedness is 5-10 neighbouring households, not community board or other existed organization.
Conclusions

• Disaster preparedness in the context of
  – Sustainable community management
  – Multidisciplinary knowledge management

• Community diagnosis is introduced as its facilitating system

• Further examination is needed for
  – Plan and Action
  – Collective project learning
  – Treatment

\{ to increase disaster preparedness
Collaborative Modeling (Community-Laymen)

- Starting with Shared Views of Status-quo
- Community Diagnosis
- Building up Evidences, Experiences and Confidences
- Fostering Coping Capacity (Plan-Do-Check-Act Cycle Repeated)
- Before-During-After Disaster (Case station)
Fix Your Furniture to Wall or Floor

• At least in Bedroom
• Let us start Check (Status-quo) and Act!
• Plan is not enough, Do, Check and Act!
• Let experts assist, involved and mutually learn (Co-learn)
• Let other residents involved and disseminate the small and smart technology
• Let an NPO involved as catalyst
We are architecting and implementing adaptive management in Research Development

More to Come in Future

Thank you!
Fig. 1: Brief Picture of Regional Economy

Fig. 2: Production Technology of Firms

Fig. 3: Long-run/Short-run Equilibrium

Fig. 4: 14 Zones for Loss Estimation

Fig. 5: Regional Highway Network

Fig. 6: Regional Railroad Network
Fig. 7: The Transport-related Losses due to Transport Infrastructure Damage from the Tokai Earthquake (Accumulating Total of 3 months)

Fig. 8: The Transport-related Losses due to Traffic Restriction in the Warning of the Tokai Earthquake (per day)
A SCGE Framework of Economic Loss Assessment Caused by Transport Infrastructure Damage from Catastrophic Earthquakes

by

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Abstract

This paper intends to show a process of assessing economic impacts of transport infrastructure damage from catastrophic earthquakes. A spatial computable general equilibrium (SCGE) model is employed which considers two types of inter-regional flow and transportation modes (i.e. business trip by train and commodity flow by autotruck). Next, scenario analyses for a large earthquake are conducted on condition that adjustment of labor and capital inputs is restricted in the equilibrium of the recovery period. It could then be seen how much transport-related economic losses arrive at each region through inter-industrial and inter-regional relationships of economy.
1 Introduction

Most part of Japan is exposed to the threats of natural disasters such as earthquakes and floods. The losses could be serious if catastrophic disasters hit metropolitan areas in which large population and assets are concentrated. Also, in such cases, losses would spill over into surrounding regions or whole nation.

Our daily activities are formed on transport infrastructure in terms of inter-regional trade and exchanging visits. They have increased in the last half of 20th century and, according to the white paper of transport\(^1\), national freight transport in 1997 became about 1.6 times as much as that of 1975 by ton kilometer, and national passenger transport became almost twice as many in the same period by man kilometer. This implies that socio-economic losses might become huge, too, if transportation service becomes unavailable in some zones. Indeed, the Great Hanshin-Awaji Earthquake (1995) and the Torrential Rain Disaster in the Tokai region (2000) showed severe impacts on transport infrastructure for both freight transport and passenger trips, as well as regional/national economy.

Traditionally damage is classified into direct and indirect effects. When a large earthquake occurs, it first hits some regions locally and causes direct losses such as human damage, production capital damage and infrastructure damage. Secondly such direct losses trigger socio-economic losses through inter-industrial and inter-regional relationships of economy. Recent findings show that such indirect effects are too big to brush off\(^2\). This implies it is necessary to make countermeasures to minimizing indirect effects in addition to mitigating direct loss.

Thinking of the above background, this paper focuses on primal transportation network and aim firstly at showing a process of assessing the economic impact of transport infrastructure damage from catastrophic earthquakes. Damage to transportation network is regarded as change of inter-regional transport costs, and the effect of regional welfare level is quantified as transport-related loss, at which finally arrived at region through interdependency of economy.

Methodology of the Quantification of Economic Losses

In order to measure such losses, the following three methods might be primarily available: user disbenefit (consumer surplus), input-output (I-O) analysis and computable general equilibrium (CGE) approach. User disbenefit approach quantifies the loss at its birthplace, while the other two methods measure it at its endpoints.

There are a number of existing studies in every approach. For example, Muraki et al\(^3\) modeled a stochastic mechanism to determine an earthquake centrum and its magnitude, simulating damage pattern on transport facilities, and evaluated passengers’ disruption impacts of primal railroad network of Japan. It is based on user benefit.

Meanwhile it is significant to evaluate losses at endpoints as well, since it could be measured know how much losses finally arrive back households. We would then use I-O or CGE method. Moreover, if transportation network is explicitly considered in I-O or CGE model, it almost inevitably leads to multi-regional (zonal) framework. A number of studies\(^4,5\) has been dealing with such regional economic models and transportation in an integrated way, and applied for measuring losses due to earthquake impacts on transportation.
Unless transportation network is explicitly considered, non-spatial CGE is also promising approach to disaster impact analysis. Rose et al (6) some CGE applications for evaluating losses due to lifeline disruptions. In their approach, it must be emphasized that they distinguish several stages of earthquake responses along the timeframe, and that they mention the appropriate modeling approach whether, for instance, it is reasonable to think the economy could be in equilibrium in a timeframe concerned. This frame of analysis is very important in our model, too, and will be described in more details later.

Spatial Computable General Equilibrium Model

The effect of catastrophe could spill over regions and arrive at non-suffered areas, although very limited area is directly suffered. Consequently we employ CGE approach extended to multiple areas, namely a spatial computable general equilibrium (SCGE) model. SCGE requires inter-regional transport condition to link one region to another. So it is a nice tool for us to analyze how economic losses due to damaged transport infrastructure go back to both the suffered and non-suffered regions.

There are several SCGE models already developed for economic appraisal of transportation policy analysis (7), and some were applied for damage assessment of catastrophe (8). As to transport infrastructure issues it is desirable to build a model dealing with both people and goods, since the transport-related losses from catastrophe, which are of our interest, yield due to changes of traffic condition, or transportation costs of both freight and passenger trips.

Many of SCGE studies have discussed the relationship between inter-regional commodity transport costs and regional economy, meanwhile few has considered passenger flows. Ueda et al (9) built a SCGE model considering inter-regional passenger trips of firms and households instead of freight transport between regions, and applied it for assessing the economic impact of catastrophe in high-speed rail network of Japan. In the meantime Bröcker (10) shows an idea to include business and private passenger travel in SCGE model in which there has been already inter-regional trade mechanism modelled.

Based on these existing study results, we build a SCGE model including both commodity flow, as transport for firm’s intermediate inputs, and business trip from passenger flow, as an input factor which develops some technical knowledge through face-to-face communication.

2 The Model

2.1 Production Sector

It is assumed that a nation consists of $N$ regions connected by transportation networks: railroads for passenger trips and highways for commodity transport, and that there are $M$ kinds of industrial agencies in each region (Fig.1).

Each agency, or firm, aims at maximizing its profit. Firm $i$ in region $k$ produces commodity $i$ by inputting the following factors: the intermediate goods $j$ transported from region $l$, labor and capital inputs provided by the household in region $k$, and business trip input for face-to-face communication. It is assumed that the production technology has the property of constant return to scale. Fig.2 shows production technology of industrial agencies.
Maximizing the firm’s profit is equivalent to the following 3-staged optimization problems.

**Stage 1**

\[
\pi_i^k = \max_{\pi_i^k, X_{ji}^k} \left[ p_i^k Q_i^k - \sum_{j=1}^M q_j^k X_{ji}^k - c_{V_i^k}(w^k, r, \tau^k) V_i^k \right]
\]

\[
\text{s.t. } Q_i^k = \min \left\{ \frac{X_{i1}^k}{a_{i1}}, \ldots, \frac{X_{Mi}^k}{a_{Mi}}, \frac{V_i^k}{a_{V_i}} \right\}
\]

**Stage 2**

\[
c_{V_i^k}(w^k, r, \tau^k) V_i^k = \min_{L_i^k, K_i^k, \kappa_i^k} \left[ w^k L_i^k + r K_i^k + c_{Ti}^k(\tau^k) \kappa_i^k \right]
\]

\[
\text{s.t. } V_i^k = \alpha_{2i} \left\{ (L_i^k)_{Li}^k (K_i^k)_{Ki}^k \right\}^{1-\beta_i} \left( \kappa_i^k \right)^{\beta_i}
\]

**Stage 3**

\[
c_{Ti}^k(\tau^k) \kappa_i^k = \min_{n_{kl}^i} \sum_{l=1}^N \tau_{kl} n_{kl}^i
\]

\[
\text{s.t. } \kappa_i^k = \alpha_{3i} \prod_{l=1}^N (n_{kl}^i)_{kl}^i
\]

where

\( \pi_i^k \): profit of firm \( i \),

\( p_i^k \): producer price of commodity \( i \),

\( Q_i^k \): output of commodity \( i \),

\( q_i^k \): consumer price of commodity \( i \),

\( X_{ji}^k \): amount of intermediate inputs \( j \) for commodity \( i \),

\( V_i^k \): compound goods of input factors (labor, capital and business trip) forming value added,

\( c_{V_i^k} \): unit cost function for \( V_i^k \),

\( a_{ji}^k \): input coefficient,

\( a_{V_i^k} \): production capacity rate,

\( \kappa_i^k \): knowledge obtained by business trips and face-to-face communication,

\( c_{Ti}^k \): unit cost function for \( \kappa_i^k \),

\( \tau_{kl} \): passenger transport cost for business trip from region \( k \) to \( l \),

\( \tau^k \): passenger transport cost for business trip from region \( k \),

\( L_i^k, K_i^k \): the amount of labor and capital respectively, supplied from household to firm \( i \),

\( \delta_{Li}, \delta_{Ki} \): share parameters of labor and capital inputs respectively, in firm \( i \),

\( \beta_i \): parameter of substitution in firm \( i \) between fundamental compound factors and knowledge,

\( n_{kl}^i \): business trips of firm \( i \) in region \( k \), to region \( l \),

\( \delta_{n}^i \): parameter of business trip on destination choice,

\( \alpha_{2i}, \alpha_{3i} \): adjustment factors.

Suffix \( k \) means the variables or parameters belong to region \( k \).

Solving (1) - (6), the following demand functions are obtained for firm \( i \) in region \( k \).

- Demand function for business trip input

\[
n_{kl}^i = \frac{\delta_{n}^i \beta_i c_{V_i^k}(w^k, r, \tau^k)}{\sum_{l=1}^N \delta_{n}^i \beta_i c_{V_i^k}(w^k, r, \tau^k)} = \delta_{n}^i \frac{\beta_i c_{V_i^k}}{\tau_{kl}}
\]
N.B. $\sum_{i=1}^{N} \delta_{ni}^{kl} = 1$

- Demand function for labor input and capital input

\[
L_i^k = \frac{\delta_{Li}^k}{\delta_{Li}^k + \delta_{Ki}^k} \left(1 - \beta_i^k\right) \frac{c_{Vi}^k(\omega, r, \tau^k)}{\omega} = \delta_{Li}^k \left(1 - \frac{\beta_i^k}{\delta_{Li}^k}\right) c_{Vi}^k
\]

(8)

\[
K_i^k = \frac{\delta_{Ki}^k}{\delta_{Li}^k + \delta_{Ki}^k} \left(1 - \beta_i^k\right) \frac{c_{Vi}^k(\omega, r, \tau^k)}{r} = \delta_{Ki}^k \left(1 - \frac{\beta_i^k}{\delta_{Ki}^k}\right) c_{Vi}^k
\]

(9)

N.B. $\delta_{Li}^k + \delta_{Ki}^k = 1$

- Demand function for intermediate inputs

\[X_{ji}^k = a_{ji}^k Q_i^k\]

(10)

- Demand function for compound factor input (which composes value-added)

\[V_i^k = a_{Vi}^k Q_i^k\]

(11)

Production function can be described as a function of wage rate (labor price), interest and passenger transport cost:

\[
c_{V_i}^k(\omega, r, \tau^k) = \begin{cases} 
(\alpha_i^k)^{-1} \left\{ \prod_{i=1}^{N} (\omega_i^k)^{\beta_i^k} \right\}^{1-\beta_i^k} & \text{if } \beta_i^k \neq 0 \\
(\alpha_i^k)^{-1} (\omega_i^k)^{\beta_i^k} \delta_{Li}^k (r) & \text{if } \beta_i^k = 0
\end{cases}
\]

(12)

where $\alpha_i^k = \alpha_{2i}^k \cdot \alpha_{3i}^k$.

### 2.2 Household Sector

The household earns an income by supplying firms with labor and capital, and consumes commodities/services to maximize her utility. She decides how much she consumes commodities/services which are provided by firms in the region $k$ she lives, and maximize her utility $U^k$ under income constraint.

\[
U^k(q^k, y^k) = \max_{d^k} \left\{ \sum_{i=1}^{M} (\gamma_i^k)^{\frac{1}{\sigma}} (d_i^k)^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}}
\]

(13)

s.t. \[\sum_{i=1}^{M} q_i^k d_i^k = y^k = \omega^k L^k + r K^k\]

(14)

where

- $y^k$ : income of household,
- $\gamma_i^k$ : parameter,
- $\sigma$ : parameter of substitution,
- $d_i^k$ : the amount of consumption of commodity $i$,
- $q_i^k$ : consumer price of commodity $i$,
- $\omega$ : wage rate,
- $r$ : interest,
$L^k$, $K^k$: the amount of labor and capital that household possesses, respectively.

Suffix $k$ means the variables or parameters belong to region $k$.

Solving (13) and (14), we obtain the following demand function of household consumption.

$$d^k_i(q^k, y^k) = \frac{\gamma^k_i(q^k_i)^{1-\sigma} y^k}{\sum_{j=1}^{M} \gamma^k_j(q^k_j)^{1-\sigma} q^k_j}$$  \hspace{1cm} (15)

Substituting (15) into (13),

$$U^k(q^k, y^k) = \left\{ \sum_{i=1}^{M} \gamma^k_i(q^k_i)^{1-\sigma} \right\}^{\frac{1}{1-\sigma}} y^k .$$  \hspace{1cm} (16)

### 2.3 Inter-regional Trade

Deterministic trade theory says that inter-regional trade is specialized to either emigration or ingression, and that direction of commodity flow is one-way. In reality, however, bi-directional trade is observed. This is because commodities are actually differentiated by region or by firm, which makes difficult to deal with inter-regional trade in a deterministic way.

This paper introduces spatial price equilibrium (SPE) theory and treats inter-regional trade in a probabilistic way. Let $s^{kl}_i$ denote a probability that industry $i$ in region $l$ buy goods $i$ from region $k$. And we might define $s^{kl}_i$ as

$$s^{kl}_i = \frac{Q^k_i \exp\{-\lambda_i p^k_i (1 + \phi^{kl}_i)\}}{\sum_{m=1}^{N} Q^m_i \exp\{-\lambda_i p^m_i (1 + \phi^{ml}_i)\}}$$  \hspace{1cm} (17)

where

- $\lambda_i$: parameter,
- $\phi^{kl}_i$: transport cost from region $k$ to $l$, per unit commodity $i$.
- $\phi^{kl}_i$ is assumed to be proportional to transit time unless transit route is changed.

The amount of commodity $i$ carried from region $k$ to $l$ is $s^{kl}_i$ times as much as total demand of region $l$. Therefore, using (17), we have the following equation:

$$z^{kl}_i = s^{kl}_i \left( \sum_{j=1}^{M} X^l_{ij} + d^l_i - I M^l_i \right)$$  \hspace{1cm} (18)

where $z^{kl}_i$ is the amount of commodity $i$ transported from region $k$ to $l$, and $I M^l_i$ is the amount of commodity $i$ imported in region $l$.

From a viewpoint of inter-regional commodity flow, if prices are positive, total payment of region $l$ for a commodity $i$ equals to the sum of sales of all possible regions, some of which will be subtracted for transport cost.

$$q^l_i \sum_k z^{kl}_i = \sum_{k=1}^{N} \mu^k_i (1 + \phi^{kl}_i) z^{kl}_i$$  \hspace{1cm} (19)

Dividing (19) by $\sum_k z^{kl}_i$, we could derive

$$q^l_i = \frac{\sum_{k=1}^{N} \mu^k_i (1 + \phi^{kl}_i) z^{kl}_i}{\sum_k z^{kl}_i} = \sum_{k=1}^{N} \left( \frac{z^{kl}_i}{\sum_k z^{kl}_i} \right) \mu^k_i (1 + \phi^{kl}_i)$$

$$= \sum_{k=1}^{N} s^{kl}_i \mu^k_i (1 + \phi^{kl}_i) .$$  \hspace{1cm} (20)
The relationship of producer’s and consumer’s prices are also lead by (1) and (2). If a firm $i$ in region $k$ is competitive,

$$p^k_i Q^k_i = \sum_{j=1}^{M} q^k_{ji} X^k_{ji} + c^k_{jVi} (w^k, r, \tau^k) V^k_{Vi}$$  \hspace{1cm} (21)

since $n^k_i = 0$. Substituting (10) and (11) into (21),

$$p^k_i = \sum_{j=1}^{M} q^k_{ji} \frac{X^k_{ji}}{Q^k_{ij}} + c^k_{jVi} (w^k, r, \tau^k) \frac{V^k_{Vi}}{Q^k_{ij}} = \sum_{j=1}^{M} q^k_{ji} a^k_{ji} + c^k_{jVi} (w^k, r, \tau^k) a^k_{Vi} \cdot$$  \hspace{1cm} (22)

2.4 Equilibrium Condition in Normal Time

It is assumed that the commodity market achieves equilibrium between regions with SPE, and that the labor and capital markets achieve equilibrium in each region. This is the equilibrium in normal time. And those markets are described as follows.

**Labor Market and Capital Market**

The balance equations of labor and capital input factors are written as follows.

$$\sum_{i=1}^{M} L^k_i = L^k$$ \hspace{1cm} (23)

$$\sum_{i=1}^{M} K^k_i = K^k$$ \hspace{1cm} (24)

**Commodity Market**

As to commodity market, the balance equations are given as follows.

$$Q^k_i - EX^k_i = \sum_{l=1}^{N} z^k_{il} (1 + \phi^k_{il})$$ \hspace{1cm} (25)

$$\sum_{k=1}^{N} z^k_{il} = \sum_{j=1}^{M} X^l_{ij} + d^l_i - IM^l_i \hspace{1cm} (26)$$

where $EX^k_i$ is the amount of commodity $i$ exported.

(25) balances firm’s supply in region $k$ and inter-regional commodity flow from $k$. (26) balances inter-regional commodity flow to region $l$ and commodity demand of $l$.

Markets are assumed to be perfectly competitive and in long-run equilibrium in normal time. Finally the equilibrium condition is given by a set of equations (2), (4), (6)-(12), (15), (17), (20) and (22)-(26).

2.5 Equilibrium Condition in Recovery Period

Most SCGE approach assumes long-run equilibrium scheme, or freedom of mobility for all endogenous variables. However, this assumption might not be necessarily suitable for measuring economic losses in static models. Especially, care should be attentioned to capital stock. This
paper prohibits capital stock level to move between regions, even between industries located in
the same region. The reason is as follows. Capital stock mobility between industries or regions
implies that the economic system allows debit and credit. If so, the economic impacts would
arrive back investors who might live in any regions, or even out of the nation. This would be
true, to a certain extent. However, without any constraint, it might be possible to ascribe all
losses to out of the suffered region ultimately. Then, lost in a maze, we would be no longer sure
what we were measuring. Most of economic losses must arrive at local people. In the static
framework, the amount of capital stock could drop away only when it is damaged by disaster.

This idea might be considered as a short-run equilibrium in microeconomics\(^1\).\(^2\)

Again, in our framework, equilibrium condition in recovery period is a short-run equilibrium
with transport costs changed from normal time. For convenience, add suffixes \((0)\) and \((1)\) to
variables below in order to distinguish recovery period from normal time.

With this short-run equilibrium approach, a new equilibrium could be found by solving simul-
taneously the set of equations where the exogenous variables \(\tau_{kl}(0)\) and \(\phi_{kl}(0)\) are replaced by
\(\tau_{kl}(1)\) and \(\phi_{kl}(1)\), respectively (Fig.3).

Consequently the transport-related losses could be measured by equivalent variation (\(EV\)).

3 Numerical Study

3.1 Setup

This chapter carries out simulating the transport-related losses, by the SCGE model built in
the previous chapter.

Model Size

As to industry, three sectors are assumed \((M = 3)\): Agriculture, Forestry and Fishery; Mining
and Manufacturing; Construction and Services.

The nation is divided into 14 zones \((N = 14)\): Hokkaido, Tohoku, Kanto, Yamanashi(pref.),
Shizuoka(pref.), Toyama(pref.), Ishikawa(pref.), Gifu(pref.), Aichi(pref.), Mie(pref.), Kinki, Chugoku,
Shikoku and Kyushu-Okinawa (Fig.4).

Transportation Network and Transport Costs

As to transportation, we assume networks for highway (Fig.5) and railroad (Fig.6). Assuming a
traffic assignment rule of the shortest path, change of transit time/travel time might be reflected
on the new transport cost rate \(\phi_{kl}^{(1)}\) or new \(\tau_{kl}\). This is a basic idea to connect physical damage
on infrastructure with change of transport costs in our SCGE model.

Data

The benchmark data, which is regarded as the solution to the set of equations of the model
in normal time, is available from inter-regional input-output table\(^1\). Business trip input is one

\(^1\) Miyagi et al\(^1\) showed a framework to develop the inter-regional input-output table of Japanese 47 prefectures
from the 47 intra-regional prefetural I-Os and the commodity flow survey. Or, 9 inter-regional I-O table would
Two exogenous elements – freight transport cost rate $\phi_{kl}$ and passenger transport cost $\tau_{kl}$ – are prepared by using road timetable and railroad timetable, respectively.

**Parameter Calibration**

There are several parameters appearing in the model. Most of them can be calibrated by using benchmark data from the input-output table. A parameter of substitution $\sigma$, however, is hard to calibrate by one-shot dataset. We referred to Ichioka\textsuperscript{13)}.

### 3.2 Regional Economy due to Transport Infrastructure Damage from Catastrophic Earthquake

This section analyzes the economic impact of the Tokai Earthquake. According to damage anticipation to this earthquake, almost all plain area of Shizuoka prefecture is believed to have strong shakes of intensity 6+ on the richter scale\textsuperscript{2}. Referring to this and anticipated damage to the transport infrastructure\textsuperscript{14)}, we assume transport condition scenarios in the following, in which there are several facilities damaged of To-Mei Expressway, Route 1 and some bridges of Tokaido Shinkansen (high speed railroad).

### Based on the setting in the last section, the shortest path traffic assignment rule consideres detour traffic. However, it is hard to take congestion into account endogenously. Consequently we might assess the impact of transport infrastructure damage from the Tokai Earthquake with some "given" stories on traffic jam, and three scenarios are assumed as follows.

1. **Scenario A-1**: new transport cost condition that can be achieved on transport infrastructure damage in Shizuoka region.
2. **Scenario A-2**: a condition that, adding to scenario A-1, 10 percent congestion of Tokyo-Nagoya transport by Chuo route is taken into account. The transit time becomes longer by 10 percent than the one calculated by the shortest path traffic assignment rule. Chuo route would be the main alternative route if the east-west transportation was blocked in Shizuoka area.
3. **Scenario A-3**: a condition that, adding to scenario A-2, 15 percent of intra-regional transport is considered in Aichi and Mie prefectures.

Referring to the Hanshin-Awaji Earthquake statistics, the recovery period is thought as 3 months. Fig.7 is the output of the above 3 scenarios. It shows:

- **(a)** the impact of transport infrastructure damage spread all over the nation.
- **(b)** the sum of regional economic losses is 2.8 (trillion JPY) on scenario A-1. Almost half of it arrives at Kanto region because of its geographical and economic scales. Also the impact for west Japan (Kinki, Chugoku, Shikoku and Kyushu·Okinawa) is not small. This implies interdependence of economy between such regions and east (Kanto region).
- **(c)** the losses with respect to "per employed person" come back to Shizuoka area most.

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\textsuperscript{2}Japanese standard.
(d) When 10 percent congestion is added to transit time by Chuo route, the losses enlarge by almost 600 (billion JPY in 3 months).

3.3 Economic Impact of the Warning on the Tokai Earthquake

This section deals with the warning announcement of the Tokai Earthquake. Japan has investigated for the past quarter century to plate-border-type earthquakes in Tokai area. And, based on the premise of earthquake prediction, the warning is announced if the committee of experts judges that crustal movement is extraordinary enough. Under the warning, there are many actions for safety taken in the regions concerned\(^3\), most of which are restriction of daily activities. It suspends public transportation services at the closest safe places/terminals. As to private automobile, traffic is regulated on going into the concerned regions from outside, or its running speed. Consequently people living in or passing through Tokai area have to accept much inconvenience for physical security.

However, it is hard to say today that earthquake prediction has become practical art. There still remains uncertainty on occurrence of an earthquake after the warning announcement, and if it lasted for a long time, the economic losses would become serious. Who could take economic risk for the warning announcement? Unfortunately very little argument has been done so far.

Therefore, it might be worth measuring the economic impact of the warning by our SCGE framework.

The process of analysis is same as the previous one, except for one point: "recovery period" would be replaced by "the warning" or "the warning period of duration". And the transportation scenario under the warning announcement is also different. Three scenarios are assumed as follows.

1. Scenario B-1: because of traffic (car, train) restriction in the area concerned, Hokuriku route becomes the cheapest way to move from/to Tokyo to/from Nagoya or Osaka.
2. Scenario B-2: in addition to B-1, Hokuriku Shinkansen (high speed railroad) is supposed to be in service. Therefore passenger transport costs is less than that of B-1.
3. Scenario B-3: in addition to B-2, Chubu Expressway is assumed to be in service, which makes freight transport costs less expensive.

The result can be seen in Fig.8. It shows the effects of transport costs change spread over regions, especially metropolitan area. The transport-related losses are calculated as about 110 (billion JPY/day), 100, 62 for scenario B-1, B-2, B-3, respectively. This implies that development of transportation network contributes a lot to mitigation in the warning announcement, or that, inversely, the impact of both To-Mei and Chuo routes shutting down seems too serious.

\(^3\)Almost 260 municipalities are designated in the real world, but this model assumes 4 prefectures -Yamanashi, Shizuoka, Aichi and Mie- as the concerned area. Because of scale problem, the model assumption does not correspond perfectly to the reality.
3.4 Summary of This Study

The results of the above two analyses are compared in this section to infer from the viewpoint of risk management.

First, the results of scenario A-1 and B-1 are compared. The former scenario assumes the occurrence of the Tokai Earthquake, and that To-Mei route is damaged. The latter, on the other hand, assumes transportation scenario under the warning announcement, and that both To-Mei and Chuo routes are shutting down. Therefore, roughly speaking, the difference between two cases is whether or not Chuo route is travelable. And the effect of Chuo route in service when To-Mei is damaged turns out about 80 (billion JPY/day), which means the significance of Chuo route, even if we take errors from several assumptions into consideration.

Our SCGE model does not treat traffic jam endogenously. Thus, secondly, in order to see how much the losses might enlarge due to congestion, we made a scenario that Chuo route as major detour is jammed. This is the comparison of scenario A-2 to A-1. The result implies that almost 6.7 (billion JPY/day) may come out because of congestion. It amounts approximately to 20 percent or more of the transport-related losses on scenario A-1. Therefore it might be said that we need policies to cut down congestion as the next step to keeping alternative routes.

Thirdly, comparison of scenario B-2 or B-3 to B-1 could be understood as the effect of transportation network development. The results imply that a project would be meaningful if it contributed to network redundancy.

4 Concluding Remarks

In this paper, we first showed a process to assess the economic impact due to traffic infrastructure damage from catastrophic earthquakes. The spatial computable general equilibrium model employed in this paper has the following properties:

- Two types of transportation network is treated in the model: highways for freight transports and railroads for passenger trips.

- A short-run equilibrium is assumed that labor and capital inputs are fixed in the recovery period.

Simulation was next conducted. As a result, we found that the transport-related losses are spread over regions for both the earthquake scenario and the earthquake warning scenario, and that the total amount of losses could be seriously large. In addition, it would be said that, from 3.2, the losses due to congestion could be too much to ignore, and that, from 3.3, some high-speed transport projects could contribute a lot to mitigation.

Also, economic loss assessments are compared between two primary scenarios related to the Tokai Earthquake: the economic impact of transport infrastructure damage and the one in the warning announcement. From the result, we infer that it would be important to keep a primal east-west transport available in emergency.
References