Modeling the Cooperation Network Formation Process for Evacuation Systems Design in Disaster areas with a Focus on Japanese Mega-disasters

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Outline

■ Introduction

■ Evacuation Behaviors during the 2011 Great East Japan Earthquake in the Rikuzentakata city
  - basically analysis about evacuation from the tsunami
  - a role of cooperative behavior

■ Network Formation Model for Evacuation Behaviors
  - A Framework of the Network Formation Model
  - A Case Study of the 2004 Mudslide Disasters in Niihama-city

■ Summary
Introduction: a evacuation system design

the 2011 Great East Japan Earthquake

- Residents evacuate from areas threatened by the tsunami & by radiation
- People made their decisions during disasters on
  - information available about the potential danger
  - assessment of their ability to evacuate
  - relying on cooperation behaviors among residents

Disaster preventions

Local evacuation plans
- transmitting emergency information
- evacuation routes and centers
- transporting residents

Difference in the type of residents’ reaction and preparation

Coperations Advantaging in emergency
Introduction: Cooperative behaviors

Cooperative Behaviors

Impact of One to One

Consideration other’s behavior (altuistic)

- A limitation of behaviors under a disaster
- Residents’ behavior choices are influenced by the perceived utility of a given action for themselves and for their group
- Cooperative network formation is a complex mechanism

Analyze the network formation processes and structures
Damage in Rikuzentakata

Feature:
- has ria coast and 2km square plain area
- Tsunami reached the coast about 40 minutes after the earthquake

<table>
<thead>
<tr>
<th>Number of death</th>
<th>Flooded area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ishinomaki</td>
<td>Rikuzentakata</td>
</tr>
<tr>
<td>Natori</td>
<td>Sendai</td>
</tr>
<tr>
<td>Otsuchi</td>
<td>Kamaishi</td>
</tr>
<tr>
<td>Sanriku</td>
<td>Sennan</td>
</tr>
<tr>
<td>Kesennuma</td>
<td>Watari</td>
</tr>
</tbody>
</table>

Composition ratio:
- victim
- population

Number of death and Flooded area (km²) for different locations in and around the Sanriku region.
Surveys and Datasets

Questionnaire by MLIT
Days: September – December 2011
Respondent: 10,603 people
   (227 people in Rikuzenntakata)
Questions: Preparation of Tsunami
          Evacuation behavior of the day

Interview by Iwate Nippo (newspaper)
Days: November 2011- March 2012
Respondent: 1,590 people
   (in Iwate prefecture)
Questions: Evacuation behavior of
          the day and others’ behavior

Questionnaire by University of Tokyo
Days: September 2012
Respondent: 163 family
   in Rikuzenntakata
Questions: Evacuation behavior of
          the day
          Travel behavior of the everyday in after-quake
          Friendship network in after-quake

Interview by University of Tokyo
Days: September 2012
Respondent: 25 family
   in Rikuzenntakata
Questions: Same of the left
Actions at the arrival of tsunami

Proportion of action taken by the survivors and deaths/missing.(estimated)

Proportion of Survivor(%)  Proportion of Death/missing(%)

- 2,5,6 proportion is about the same.

Even if they have the same risk perception and behavior, damage varies depending on location and time.
Start time evacuation behavior

Why did you start evacuation? (survivor)

There is need to evacuate quickly. But How?

Changes in activity

Composition ratio (survivor)

0 0.2 0.4 0.6 0.8
14:50 14:55 15:00 15:05 15:10 15:15 15:20 15:25
time

Evacuate / On the way of evacuation
Join together
Other activity

Could join together
Helped by others
Tsunami was approaching
Aware of danger by earthquake and surroundings
Told to evacuate early
The Others

① evacuated quickly
Joined together
② evacuated after activities
How did they Aware of danger?

Quake occurence

Feel the strong quake

Listening to others
Talking with others

See tsunami coming

Have you seen tsunami hazard maps?

Q Did you see the Tsunami?

Actually carried away by
Almost carried away by
Saw Tsunami coming from the distance.
Did not see the Tsunami coming
Listening to other’s caution

People’s behavior were depended on whether or not they think Tsunami is coming, and not by other’s caution.
### Talking with others

#### 15 Cases of talking about the tsunami

<table>
<thead>
<tr>
<th>Talk with ...</th>
<th>Influence about aware of danger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rescue crew</td>
<td>No Influence 2/2 case</td>
</tr>
<tr>
<td>City staff</td>
<td></td>
</tr>
<tr>
<td>Unknown people</td>
<td>No Influence 3/3 case</td>
</tr>
<tr>
<td>Neighborhood</td>
<td>No Influence 2/4 case</td>
</tr>
<tr>
<td>Friend</td>
<td>Influence 2/4 case</td>
</tr>
<tr>
<td>Family</td>
<td>Influence 6/6 case</td>
</tr>
</tbody>
</table>

People’s act were also depended on with whom they talk to.
A model of Awareness influence

A Binary logit model about aware of tsunami’s danger

Aware:Determined by comparison of the behavior before and after

\[ V_{\text{aware}} = \beta_{\text{sea}} \text{Distance} + \beta_{\text{accom}} x_{\text{accom}} + \beta_{\text{male}} x_{\text{male}} + \beta_{\text{eld}} x_{\text{eld}} + \beta_{\text{talk}} x_{\text{talk}} + \beta_{\text{listen}} x_{\text{listen}} + \beta_{\text{see}} x_{\text{see}} \]

\[ V_{\text{not-aware}} = \text{Const} \]

\[ P_{\text{aware}} = \frac{\exp(V_{\text{aware}})}{\exp(V_{\text{aware}}) + \exp(V_{\text{not-aware}})} \]

• “Listening” & “Seeing” are significant and promote risk awareness
• “Talking” influence is not clearly

<table>
<thead>
<tr>
<th>( \beta )</th>
<th>parameter</th>
<th>ttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to the sea</td>
<td>-0.336</td>
<td>-0.64</td>
</tr>
<tr>
<td>Accompany</td>
<td>0.841</td>
<td>0.74</td>
</tr>
<tr>
<td>Male</td>
<td>1.803</td>
<td>1.61</td>
</tr>
<tr>
<td>Elderly</td>
<td>0.768</td>
<td>0.76</td>
</tr>
<tr>
<td>Talking</td>
<td>0.729</td>
<td>0.70</td>
</tr>
<tr>
<td>Listening</td>
<td>2.601</td>
<td>2.13*</td>
</tr>
<tr>
<td>Seeing</td>
<td>3.294</td>
<td>2.95*</td>
</tr>
<tr>
<td>Const(not aware)</td>
<td>2.601</td>
<td>3.69*</td>
</tr>
</tbody>
</table>

Observations | 70
Initial Likelihood | -47.8
Final Likelihood | -28.5
\( \hat{\rho}^2 \) | 0.24

Note. * = significant at .05
Approach for early evacuation

Proportion of having not been evacuated

Quake occurrence → Tsunami arrival

- Feel the strong quake
- Listening to others
- Talking with others
- See tsunami coming

10min

- Disaster Education
- Awareness training
- Listening the alarm (but depend on education)
- Talking with family, friends, neighborhoods

<not aware people>
cooperative behavior having a role for evacuating early

<aware people>
Take a time for cooperative behaviors
Networks of cooperative behaviors

In space of residents, cooperative behaviors gather and cooperative networks is made.

cooperative network in disasters

- **Scale-free characters**
  1. **Low Clusterability**
     means minimal communication in emergency
  2. **Hub nodes**
     mean a main person that play central role in the district
  3. **Short distance**
     means that information can be transmitting in the district immediately

Scale-free networks have advantages and are closer to reality.
Introducing: Framework of the
Network Formation Model

Four Characteristics of the model

Residents’ cooperation networks in disasters are formed by the accumulation of personal cooperation behaviors.

1. Complexity
   • Residents chose their individual cooperation and select other people to cooperate with.
   • These choices are influenced by utility to the individual and group and by others’ behaviors. → Network formation is a complex mechanism.

2. Growth
   • The number of nodes (residents) in the network increases.

3. Rule of preferential attachment
   • Residents intend to cooperate select others who are vulnerable, who possess key information, or who are important in that district.

4. Personal parameters
   • It is possible to describe a personal character using node parameters.

Introduced a model to reproduce the 1~4
**Introduction of The Fitness model**

We used the fitness model (Bianconi and Barabasi 2001)

The probability that a new node will connect to a node \( v_i \) shows a rule of preferential attachment

\[
\frac{\partial k_i}{\partial t} = m \prod (k_i) = \frac{m \eta_i k_i}{\sum_{j=1}^{n} \eta_j k_j} \quad (1)
\]

We show how this model produces a scale free network. The time evolution of \( k_i \) follows a power law.

\[
k_{\eta_i}(t, t_0) = m \left( \frac{t}{t_0} \right)^{\beta(\eta_i)} \quad (2)
\]

The sum over \( j \) can be written as an integral over \( t_i \) in the approximate approach

\[
\sum_{j} \eta_j k_j \cong \int d\eta \eta \rho(\eta) \int_{t_0}^{t} k_{\eta_i}(t, t_0) \cong c m t \quad (3)
\]

\[
\left( c = \int \frac{\eta}{1 - \beta(\eta)} \rho(\eta) d\eta \right) \quad (4)
\]

Eq.(3) and (4) into Eq.(1)

\[
\frac{\partial k_{\eta_i}}{\partial t} = \frac{\eta k_{\eta_i}}{c t} \quad (5)
\]

Eq.(5) has a solution in the form of Eq.(2)

\[
\beta(\eta) = \frac{\eta}{c} \quad (6)
\]

The cumulative probability \( P[k_\eta(t) > k] \) that for a certain node \( k_\eta(t) > k \)

\[
P[k_\eta(t) > k] = P \left[ t_0 < t \left( \frac{m}{k} \right)^{c/\eta} \right] \approx t \left( \frac{m}{k} \right)^{c/\eta} \quad (7)
\]

The probability \( p(k) \) that a node has \( k \) links

\[
p(k) = -\int \frac{\partial P(k_\eta(t) > k)}{\partial k} \rho(\eta) d\eta \approx \int \left( \frac{m}{k} \right)^{c/\eta} \frac{c t}{\eta k} \rho(\eta) d\eta \quad (8)
\]

Depending on the distribution of fitness \( \eta \), \( p(k) \) follows a power law.

\[
\begin{align*}
t_i & : \text{the time at which node } v_i \text{ was born} \\
\eta_i & : \text{A fitness parameter} \\
\rho(\eta) & : \eta \text{is chosen from the distribution} \\
m & : \text{number of links that new node are connected} \\
k_i & : \text{the degree of the node } i
\end{align*}
\]
The distributions of fitness and the network formation processes

**first-mover-advantage phase**
- All fitness values are the same → The network structure is scale free
- The probability of getting new links (from Eq.(1)) only depends on only a node’s degree \( k_i \).
  → A node joining the network early establishes more links more easily.

\[ p(k) \propto k^{-3} \]

**fit-get-rich phase**
- The fitness distribution is uniform → the network structure is nearly scale free
  \[ \rho(k) \propto k^{-2.255} \]
- The probability of getting new links (from Eq.(1)) depends on fitness and degree.
  → A large fitness node establishes make more links.

**winner-takes-all phase**
- The fitness distribution is large
  → a node that has an especially large fitness value makes the most links
Case Study of the 2004 mudslide disasters in Niihama

1. The 2004 mudslide disaster in Niihama

Two disasters were caused by typhoons on August 18 and September 29, 2004.

The August typhoon

- Maximum rainfall of 55mm per hour
- Mudslides left 3 people dead

The September typhoon

- 281mm of rainfall
- Mudslides left 5 people dead

2. Survey

Hato & Nakagawa (2005)

- Resident’s behaviors during these disasters by interview
- Interviewing them about their awareness of the danger, risk management behaviors, and cooperation behaviors
- Cooperation behaviors include rescuing others, evacuating with others, accommodating evacuees, meeting and exchanging information.
### Basic Analysis of the networks

#### Table. Results of Network Analysis

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cooperation network</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nishikusuzaki mudslide</td>
<td>Nishikusuzaki near-pond</td>
<td>Ohjyoin</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>23</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Number of links</td>
<td>27</td>
<td>11</td>
<td>23</td>
</tr>
<tr>
<td>Average distance</td>
<td>3.22</td>
<td>3.27</td>
<td>2.19</td>
</tr>
<tr>
<td>Clustering coefficient</td>
<td>0.11</td>
<td>0.00</td>
<td>0.54</td>
</tr>
<tr>
<td>Degree centrality</td>
<td>0.32</td>
<td>0.36</td>
<td>0.79</td>
</tr>
</tbody>
</table>

**Short average distance**

**Hub nodes**

![Nishikusuzaki mudslide network](image1)

![Nishikusuzaki near-pond network](image2)

![Ohjyoin network](image3)
Formation processes of the networks

1. Nishikusuzaki near-pond network

- 8 am
- 8-9 am
- 10 am
- 11 am

• No. 4 formed links at each point in time
• No. 4 transmitted information regarding the pond water

→ First-mover-advantage phase
Formation processes of the networks

2. Ohjyoin mudslide network

- No. 13 and No. 25 were destroyed by the mudslide

→ winner-takes-all phase
Formation processes of the networks

3. Nishikusuzaki mudslide network

- No. 49 subscribed to the network from the beginning and formed links smoothly.
- No. 65 and No. 78, which is subscribed later, have multiple links.

→ Fit-get-rich phase
Estimation Results

We applied the fitness mode to the Nishikusuzaki mudslide network.

- The probability that a new node will connect to a node

\[ P_i = \prod (v_i) = \frac{\eta_i k_i}{\sum_{j=1}^{n} \eta_j k_j} \quad (9) \]

\[ \eta_i = \exp(x_i) \quad \eta_i > 0 \]

- Estimated the fitness parameter by means of maximum likelihood estimation

✓ All fitness parameters are significant at the .01 level.

<table>
<thead>
<tr>
<th>Household number</th>
<th>Fitness parameter</th>
<th>( t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>4.30E-03</td>
<td>–27.74*</td>
</tr>
<tr>
<td>13</td>
<td>1.60E-03</td>
<td>–23.15*</td>
</tr>
<tr>
<td>14</td>
<td>8.09E-03</td>
<td>–22.22*</td>
</tr>
<tr>
<td>35</td>
<td>4.28E-03</td>
<td>–19.78*</td>
</tr>
<tr>
<td>41</td>
<td>2.40E-03</td>
<td>–24.75*</td>
</tr>
<tr>
<td>49</td>
<td>2.35E-03</td>
<td>–24.47*</td>
</tr>
<tr>
<td>59</td>
<td>2.60E-02</td>
<td>–9.89*</td>
</tr>
<tr>
<td>65</td>
<td>2.93E-02</td>
<td>–9.33*</td>
</tr>
<tr>
<td>67</td>
<td>5.37E-03</td>
<td>–18.86*</td>
</tr>
<tr>
<td>69</td>
<td>1.12E-02</td>
<td>–16.12*</td>
</tr>
<tr>
<td>70</td>
<td>1.45E-03</td>
<td>–18.00*</td>
</tr>
<tr>
<td>78</td>
<td>2.31E-02</td>
<td>–13.18*</td>
</tr>
<tr>
<td>87</td>
<td>9.48E-03</td>
<td>–12.88*</td>
</tr>
<tr>
<td>90</td>
<td>7.76E-03</td>
<td>–21.41*</td>
</tr>
<tr>
<td>Degree 1</td>
<td>9.12E-04</td>
<td>—</td>
</tr>
</tbody>
</table>

| Observations     | 410               |
| Likelihood at 0  | –1570             |
| Final likelihood | –1156              |
| \( \rho^2 \)     | 0.26              |
| \( \rho^2 \)     | 0.25              |

Note. * = significant at .01; — = not applicable.
Formation processes of the networks from the estimation results

Figure Network structure and fitness parameters

![Diagram showing network structure and fitness parameters](image)

- **fit-get-rich phase**
- **winner-takes-all phase**

Figure Evolution of the variance of fitness parameters

- Red circles: \( \eta > 0.012 \)
- Green circles: \( 0.012 > \eta > 0.006 \)
- Blue circles: \( 0.006 > \eta \)
- Gray circles: Degree 1

- **9-11 am**: Concentration
- **12 am-5 pm**: Multi Core

![Evolution graph](image)
Summary

■ Evacuation Behaviors during the 2011 Great East Japan Earthquake in the Rikuzentakata city
  ➢ People who was educated about disaster evacuated immediately.
  ➢ For not aware of people, cooperative behavior was useful.

■ Network Formation Model for Evacuation Behaviors
  ➢ A Framework of the Network Formation Model
    ➢ Capturing features of residents’ cooperation behavior
    ➢ Personal characteristics becoming explanatory variables
    ➢ Specifying the structure of residents’ cooperation networks

Thank you for your attention.