Integration of Multiple Spatiotemporal Demographic Data and Its Applications for Disaster Mitigation Planning

Toshihiro OSARAGI
Tokyo Institute of Technology
Outline

✔ Background & Motivation

✔ Spatiotemporal Demographic Data
  (its potential and limitation)

✔ Integration Method (1) for Demographic data
  (building use / purpose / attribute)

✔ Integration Method (2) for Demographic data
  (inflow / outflow / static)

✔ Applications for Disaster Mitigation Planning

✔ Summary and Conclusions
Shibuya City in Tokyo

A picture taken from a model produced by Google Earth
Shibuya City in Tokyo
Ordinal modeling techniques of environment and urban systems based only on static physical objects do not always describe a certain aspects of their realities.

The next step in modeling of the urban environment is to take people into account.

In order to consider people in spatial models, it would be a possible means to use spatially referenced demographic data (Census Data).
Background

Most estimates of human activities have been estimated based on static population distributions (Census Data).

However

The actual spatial distribution of people changes by the hour, or even by the minute, since they are travelling for a variety of purposes over long distances.

Person-Trip Survey Data (PT Data) can provide us the information about the dynamically varying spatiotemporal distribution of people.
Person Trip Survey Data (PT Data)

Purpose of trip:
- commuting to work
- working
- working
- private
- returning home

Destination of trip:
- home
- office
- branch
- office
- shop
- home

Means of transport:
- on foot
- by bus
- by foot
- by taxi
- by taxi
- on foot
- on foot
- by bus
- on foot

Time of departure and arrival:
- 08:00
- 08:10
- 08:40
- 08:50
- 14:00
- 14:20
- 16:40
- 17:00
- 18:00
- 18:10
- 18:30
- 18:40
- 19:10
- 19:20
Overview of PT Data

Questionnaire-based survey

- **Regions:**
  Greater Tokyo Metropolitan Area

- **Sampling:**
  Random sampling based on census data
  (1,235,883 persons from 32,896,705 persons)

- **Valid data:**
  883,044 samples
  sampling ratio = 2.68 %
  (= 883,044 / 32,896,705)

- **Contents:**
  Personal attributes, Departure/ Arrival Location and Time, Purpose of trip, Means of trip, ... etc.
Survey Area of PT Data

Tokyo Bay The Pacific Ocean Sagami Bay
Numbered Subdivision of Area for Address

Boundary of Chome

Tokyo

Shinjuku

Ikebukuro

Akihabara

Shibuya

Shinagawa

Tokyo Bay

0 5 10 km
Zone of PT Data
Spatiotemporal Distribution of People inside Buildings

6:00 AM

[Map showing distribution of people inside buildings at 6:00 AM]
Spatiotemporal Distribution of People inside Buildings

12:00 AM
Spatiotemporal Distribution of People inside Buildings

5:00 PM
Background / Motivation

Person-Trip Survey Data (PT Data) provide us the information about the dynamically varying spatiotemporal distribution of people.

However

The problem with “zone” is that they are not regular in size making inter-comparisons very difficult.
Limitation of PT-data (1)

Zone Boundary of PT-data

Regular Grid Cell
Limitation of PT-data (2)

Zone Boundary of PT-data

Specific Zone
Person Trip Survey Data (PT Data)

**Questionnaire survey**

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Detailed behavior</strong></td>
<td><strong>Low frequency of survey</strong> (once every 10 years)</td>
</tr>
<tr>
<td>(purpose of trip, location/time information of trip, means of transportation etc.)</td>
<td><strong>Low sample rate</strong> (2~3%)</td>
</tr>
<tr>
<td><strong>Many kinds of attributes</strong></td>
<td></td>
</tr>
<tr>
<td>(age, gender, occupation, residence etc.)</td>
<td><strong>Not regular in size</strong></td>
</tr>
</tbody>
</table>
Mobile Spatial Statistics (MSS) data

**Strengths**
- Able to grasp distribution of people with **small spatial unit** (250m or 500m grids)
- Able to grasp population **every hour**
- **High sample rate** (penetration) (around 40 %)

**Limitations**
- Unable to distinguish people **staying inside buildings or moving outside**
- **Few kinds of attributes** (age, gender, residence)
Mobile Spatial Statistics (MSS) data


Mobile phone: DoCoMo (Nippon Telegraph and Telephone Corporation)
Grid size: 500 m (250 m in highly populated area)
Mobile Spatial Statistics (MSS) data


Mobile phone: DoCoMo (Nippon Telegraph and Telephone Corporation)
Grid size: 500 m (250 m in highly populated area)
Mobile Spatial Statistics (MSS) data


Mobile phone: DoCoMo (Nippon Telegraph and Telephone Corporation)
Grid size: 500 m (250 m in highly populated area)
Mobile Spatial Statistics (MSS) data

Tuesday (Oct. 20, 2015)

Sunday (Oct. 18, 2015)

Mobile phone: DoCoMo (Nippon Telegraph and Telephone Corporation)
Grid size: 500 m (250 m in highly populated area)
Mobile Spatial Statistics (MSS) data

Mobile phone: DoCoMo (Nippon Telegraph and Telephone Corporation)
Grid size: 500 m (250 m in highly populated area)
Tuesday (Oct. 20, 2015)

Sunday (Oct. 18, 2015)

Mobile phone: DoCoMo (Nippon Telegraph and Telephone Corporation)
Grid size: 500 m (250 m in highly populated area)
Summary of Strengths / Limitations

**MSS data**
- **Strengths**
  - Detailed behavior/attributes
  - Disaggregate data (Individual data)
- **Limitations**
  - Only the number of people
  - Aggregate data
  - Time cross section (every hour)

**PT data**
- **Strengths**
  - Age, gender, residence
  - Movement of people
- **Limitations**
  - Questionnaire
  - Low frequency of survey (once every 10 years)
  - Low sample rate (2~3%)
  - Irregular shape
  - Large spatial unit

Enhance these urban demographic big-data by complementing the disadvantages and utilizing the advantages.
Outline

- Background & Motivation
- Spatiotemporal Demographic Data (its potential and limitation)
- Integration Method (1) for Demographic data (building use / purpose / attribute)
- Integration Method (2) for Demographic data (inflow / outflow / static)
- Applications for Disaster Mitigation Planning
- Summary and Conclusions
Attribute/ Purpose of Stay/ Building use

MSS data

Precise Spatiotemporal distribution of population

Decomposed into each building use

Building use
- Day of week
- Time of the day
- Location

School
Office
Restaurant
Shop
Hospital
Amusement
Bar
Estimating Number of People by Each Building Use

The number of people in building use $j$

$$y_i^t = \sum_j y_{ij}$$

$$= \sum_j D_{ij}^t x_{ij}$$

= $\sum_j \alpha_j^t \beta_i x_{ij}$

Time fluctuation factor (Temporal Change) Location factor (Average Density)

i : cell
j : building use
t : time

MSS data

Density of people

GIS data

Floor-area of buildings

GIS data

Floor-area of buildings

MSS data

Density of people
Location Characteristic Factor

High density housing estate  Low density detached house

\[ \beta_i > \beta_i \]
Location Characteristic Factor

High density housing estate  Flats in business district

\[ \beta_i > \beta_i \]
Generalization of Model

Descriptive model

Average density = unique parameter for each zone \( i \)

\[ y_i^t = \beta_i \sum_j \alpha_j^t x_{ij} \]

Temporal changes

Predictive model

\[ y_i^t = \left( \sum_k \gamma_k z_{ik} \right) \left( \sum_j \alpha_j^t x_{ij} \right) \]

The number of people

\( i \) : cell
\( j \) : building use
\( t \) : time

\( \frac{1}{N} \sum_{t=1}^N \beta_i = 1 \)
Calibration Method of Model

\[ y_i^t = \left( \sum_k \gamma_k z_{ik} \right) \left( \sum_j \alpha_j^t x_{ij} \right) \]

\[ \frac{1}{N} \sum_{t=1}^{N} \left( \sum_k \gamma_k z_{ik} \right) = 1 \]

\[ \gamma_k = 1 \text{ for all } k \]

\[ \left| \frac{n \alpha_j^t - n-1 \alpha_j^t}{n-1 \alpha_j^t} \right| \leq 0.01\% \]

\[ \left| \frac{n \gamma_k - n-1 \gamma_k}{n-1 \gamma_k} \right| \leq 0.01\% \]

GIS data

MSS data

GIS data

GIS data
### Explanatory Variables

<table>
<thead>
<tr>
<th>No.</th>
<th>Building use</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Public / Religious facility</td>
<td>Government office, Museum, Temple and shrine</td>
</tr>
<tr>
<td>2</td>
<td>Educational facility</td>
<td>Elementary/junior high/high school, University, Vocational school, Study cram school</td>
</tr>
<tr>
<td>3</td>
<td>Medical / welfare facility</td>
<td>Hospital, Nursing care welfare facility, etc.</td>
</tr>
<tr>
<td>4</td>
<td>Office</td>
<td>Logistics, Post office, Finance, Insurance, Real estate, Industry</td>
</tr>
<tr>
<td>5</td>
<td>Restaurant / Bar</td>
<td>Home delivery, Restaurant</td>
</tr>
<tr>
<td>6</td>
<td>Commercial facility</td>
<td>Service, Sales business, Automobile industry (including automobile repair business)</td>
</tr>
<tr>
<td>7</td>
<td>Mass retailer</td>
<td>Supermarket, Department store, Large store, etc.</td>
</tr>
<tr>
<td>8</td>
<td>Hotel</td>
<td>Hotel, Inn</td>
</tr>
<tr>
<td>9</td>
<td>Sports / Entertainment facilities</td>
<td>Sports facility, Entertainment</td>
</tr>
<tr>
<td>10</td>
<td>Apartment house</td>
<td>Flat, Apartment house, Dormitory, Company house</td>
</tr>
<tr>
<td>11</td>
<td>Detached house</td>
<td>Detached house</td>
</tr>
<tr>
<td>12</td>
<td>Railway station</td>
<td>The number of railways (FY2005 National Land Numerical Data)</td>
</tr>
<tr>
<td>13</td>
<td>Park (outside buildings)</td>
<td>Area of park (Land Use Current State Survey Data, 2011)</td>
</tr>
</tbody>
</table>
### Explanatory Variables (Predictive model)

<table>
<thead>
<tr>
<th>No.</th>
<th>Building use</th>
<th>Size of building</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Small</td>
</tr>
<tr>
<td>1</td>
<td>Public / Religious facility</td>
<td>~150 m²</td>
</tr>
<tr>
<td>2</td>
<td>Educational facility</td>
<td>~700 m²</td>
</tr>
<tr>
<td>3</td>
<td>Medical / welfare facility</td>
<td>~175 m²</td>
</tr>
<tr>
<td>4</td>
<td>Office</td>
<td>~80 m²</td>
</tr>
<tr>
<td>5</td>
<td>Restaurant / Bar</td>
<td>~75 m²</td>
</tr>
<tr>
<td>6</td>
<td>Commercial facility</td>
<td>~105 m²</td>
</tr>
<tr>
<td>7</td>
<td>Mass retailer</td>
<td>~190 m²</td>
</tr>
<tr>
<td>8</td>
<td>Hotel</td>
<td>~550 m²</td>
</tr>
<tr>
<td>9</td>
<td>Sports / Entertainment facilities</td>
<td>~260 m²</td>
</tr>
<tr>
<td>10</td>
<td>Apartment house</td>
<td>~200 m²</td>
</tr>
<tr>
<td>11</td>
<td>Detached house</td>
<td>~80 m²</td>
</tr>
<tr>
<td>12</td>
<td>Railway station</td>
<td>The number of railways (FY2005 National Land Numerical Data)</td>
</tr>
<tr>
<td>13</td>
<td>Park (outside buildings)</td>
<td>~330 m²</td>
</tr>
<tr>
<td>14</td>
<td>Commercial based complex (1)</td>
<td>~260 m²</td>
</tr>
<tr>
<td>15</td>
<td>Commercial based complex (2)</td>
<td>~210 m²</td>
</tr>
<tr>
<td>16</td>
<td>Office based complex (1)</td>
<td>~240 m²</td>
</tr>
<tr>
<td>17</td>
<td>Office based complex (2)</td>
<td>~330 m²</td>
</tr>
</tbody>
</table>
Study Area

(500 m by 500 m grid cell, the total number of cells is 806)
Validation of Descriptive Model

Weekday 6:00
$R^2 = 0.878$

Weekday 18:00
$R^2 = 0.990$
Validation of Descriptive Model

![Graphs showing validation of Descriptive Model for Bank holidays at 6:00 and 18:00, with R² values of 0.928 and 0.985 respectively.](image)
Validation of Predictive Model

Weekday 6:00

\[ R^2 = 0.659 \]

Weekday 18:00

\[ R^2 = 0.841 \]
Validation of Predictive Model

More adequate explanatory variables to describe the location characteristics are needed.
Spatial distribution of the estimated values of location characteristic factor $\beta_i$
Temporal Change of Density $\alpha_i$ by Building Use

Density of number of people by building use per 100 m$^2$, for the descriptive model

Weekday

Bank holiday

[Graph showing density of people by building use per 100 m$^2$ for different building uses on weekday and bank holiday, with a legend indicating different line types for various building uses.]
Temporal Change of Density $\alpha_i$ by Building Use

Density of number of people by building use per 100 m², for the descriptive model

Weekday

Bank holiday
Temporal Change of Density $\alpha_i$ by Building Use

Density of number of people by building use per 100 m$^2$, for the descriptive model

- Public / religious
- Restaurant / Bar
- Sports / entertainment
- Educational
- Commercial
- Medical / welfare
- Mass retailer
- Hotel
- Office
- Apartment house
- Detached house
- Park

Weekday

Bank holiday

[1,000 persons /station]
Number of People by Building Use

At 12:00 on Weekday

Weekday MSS data

(1) MSS data
- ~6000
- ~12000
- ~18000
- ~24000
- 24000~

(2) Office
- ~3000
- ~6000
- ~9000
- ~12000
- 12000~

(3) Detached house
- ~400
- ~800
- ~1200
- ~1600
- 1600~

(4) Commercial
- ~600
- ~1200
- ~1800
- ~2400
- 2400~
Number of People by Building Use

At 12:00 on Bank Holiday

MSS data

Office
Detached house
Commercial
Key Concept for Linking Population Statistics

PT data

- Purposes of stays
- Attributes of stayers

Composition ratios

Building use
- Day of week
- Time of day
- Location

School
Office
Restaurant

Shop
Hospital
Amusement
Bar
Estimating the Number of People by Purpose

\[ Y_{ijl}^t = m_{ijl}^t y_{ij}^t \]

where

\[ m_{ijl}^t = \frac{n_{ijl}^t}{\sum_l n_{ijl}^t} \]

- \( Y_{ijl}^t \): Estimated number of people for each building use \( j \) at time \( t \)
- \( y_{ij}^t \): \( \alpha_j^t \beta_i x_{ij} \)

- \( i \) : cell (location)
- \( j \) : building use
- \( l \) : purpose
- \( t \) : time

PT data
Number of People by Building Use in Specific Cell

Ueno Railway station

Weekday

Bank holiday
Number of People by Purpose in Specific Cell

Ueno Railway station

Weekday

Bank holiday
Number of People in Commercial Facilities

Spatial distribution of the number of people in commercial facilities at 18:00 by attributes

Male

Female

20s  30s  40s  50s

Shibuya  Asakusa  Shibuya  Asakusa

20s  30s  40s  50s

Shibuya  Asakusa  Shibuya  Asakusa

~10  ~20  ~40  ~80  80~
Personal Attributes in Shibuya

Cell including Shibuya 109

Number of people $Y_{t,h}$

- female 20s
- male 20s
- male 30s

Time [Oclock]

- 12
- 13
- 14
- 15
- 16
- 17
- 18
- 19
- 20
- 21
- 22

[*x1,000*]
Personal Attributes in Ginza

Cell including Ginza Station

Number of people $Y_{gtu}$

Time [O'clock]

Male 20s 30s 40s 50s 60s 70s

Female 20s 30s 40s 50s 60s 70s

female 20s
female 30s
female 40s
Personal Attributes in Osaki-hirokoji

Cell including Osaki-hirokoji Station

Number of people $Y_{jt}$

<table>
<thead>
<tr>
<th>Time [O'clock]</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
</tr>
</tbody>
</table>

- Male 30s
- Male 40s
- Female 30s

Male 20s 30s 40s 50s 60s 70s
Female 20s 30s 40s 50s 60s 70s
Outline

✔ Background & Motivation

✔ Spatiotemporal Demographic Data (its potential and limitation)

✔ Integration Method (1) for Demographic data (building use / purpose / attribute)

✔ Integration Method (2) for Demographic data (inflow / outflow / static)

✔ Applications for Disaster Mitigation Planning

✔ Summary and Conclusions
Konzatsu Tokei® (KT) data

Mobile phone location data acquired from GPS

Data on the flow of people, showing where they came from and where they went

Strengths
- Able to grasp movement of people
- Able to get data in quasi real time data

Limitations
- Low sample rate (0.2〜0.3%)
- Few kinds of attributes (age, gender)
Advantages/ Disadvantages

**PT data**
- Disaggregate data (Individual data)
- Detailed behavior/ attributes
- High sample rate (40%)
- Movement of people
- Age, gender, residence
- Quasi real time
- 250m / 500m grid
- Short-time interval (every 5 min)
- Any specific date

**MSS data**
- Irregular shape
- Large spatial unit
- Aggregate data
- Low sample rate (0.2%)
- Any specific date
- 250m / 500m grid
- Short-time interval (every 5 min)

**KT data**
- Questionnaire
- Low frequency of survey (once every 10 years)
- Low sample rate (2~3%)
- Only the number of people
- Aggregate data
- Time cross section (every hour)
- Aggregate data

**Limitations**
Integration of Demographic Data

Integrate three datasets by enhancing strengths and by reducing limitations.

- MSS data
- KT data
- PT data

Distribution at 7:00

Commuting:
- 7:00
- 8:00
- 17:00
- 23:00

Returning home:
- House
- Building
- Car
- House

GPS

Questionnaire survey

Movement
Data Used for Integration

\[ M^t_i \]

\[ a P^t_i \]

\[ \text{Outflow} \]

\[ \text{Inflow} \]

\[ a P^{t+\Delta t}_i \]

\[ \text{Total number of people} \]

\[ M^{t+\Delta t}_i \]

\[ \text{Ratio of static people} \]
Data Used for Integration

Matrix of Spatial Movement

<table>
<thead>
<tr>
<th>KT data</th>
<th>from</th>
<th>$i(t)$</th>
<th>$\cdots$</th>
<th>$d_{ij}^{t}$</th>
<th>$\cdots$</th>
<th>$j(t+\Delta t)$</th>
<th>$\cdots$</th>
<th>$i(t+\Delta t)$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>($t \rightarrow t+\Delta t$)</td>
<td></td>
<td>($t \rightarrow t+\Delta t$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>($t \rightarrow t+\Delta t$)</td>
<td></td>
<td>($t \rightarrow t+\Delta t$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>($t \rightarrow t+\Delta t$)</td>
<td></td>
<td>($t \rightarrow t+\Delta t$)</td>
</tr>
</tbody>
</table>

Probability Matrix of Spatial Movement

<table>
<thead>
<tr>
<th>from</th>
<th>$i(t)$</th>
<th>$\cdots$</th>
<th>$p_{ij}^{t}$</th>
<th>$\cdots$</th>
<th>$j(t+\Delta t)$</th>
<th>$\cdots$</th>
<th>$i(t+\Delta t)$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$i(t)$</td>
<td>$\cdots$</td>
<td>$p_{ij}^{t}$</td>
<td>$\cdots$</td>
<td>$j(t+\Delta t)$</td>
<td>$\cdots$</td>
<td>$i(t+\Delta t)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>($t \rightarrow t+\Delta t$)</td>
<td></td>
<td>($t \rightarrow t+\Delta t$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>($t \rightarrow t+\Delta t$)</td>
<td></td>
<td>($t \rightarrow t+\Delta t$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>($t \rightarrow t+\Delta t$)</td>
<td></td>
<td>($t \rightarrow t+\Delta t$)</td>
</tr>
</tbody>
</table>

average value for one year

Weekday
Weekend
Special day
**Outline of Integration Method**

Matrix of Spatial Movement

<table>
<thead>
<tr>
<th>from</th>
<th>to</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i(t)$</td>
<td>$j$ $(t+\Delta t)$</td>
<td>$T_{ij}^{t}$ $(t \rightarrow t+\Delta t)$</td>
</tr>
<tr>
<td>total</td>
<td>$M_{j}^{t+\Delta t}$</td>
<td>$\sum_{j} T_{ij}^{t}$</td>
</tr>
</tbody>
</table>

- **MSS data (constrain)**
  - Number of people for each grid
  - Probability of movement among grids
    - $d_{ij}^{t} \rightarrow p_{ij}^{t}$

- **KT data (probability of movement)**
  - Ratio of Static people
    - $aP_{i}^{t} \rightarrow T_{ii}^{t} / \sum_{j} T_{ij}^{t}$

- **PT data (ratio of static people)**

**Maximum likelihood estimation**
Study Area and Demographic Data

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Date (weekday)</th>
<th>Date (weekend)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSS (Distribution)</td>
<td>Tuesday, Oct. 20, 2015</td>
<td>Sunday, Oct. 18, 2015</td>
</tr>
<tr>
<td>PT data</td>
<td>A weekday in Oct. of 2008 (Excluding Mon. and Fri.)</td>
<td>A weekend in Oct. of 2008 (Estimated by Osaragi, 2016)</td>
</tr>
<tr>
<td>MSS (Flow) (for validation)</td>
<td>Tuesday, Oct 20, 2015</td>
<td></td>
</tr>
</tbody>
</table>

Area: 2500 grids (about 500 m by 500 m) in Tokyo ward
Time: 3:00~26:00

[Map of study area with key stations and areas]

- Ikebukuro Sta.
- Shinjuku Sta.
- Shibuya Sta.
- Tokyo Sta.
- Ojima
- Shinagawa Sta.
Static/Outflow/Inflow population

MSS data

KT data

Static/Outflow/Inflow

Movement

(c) Number of Stay/Outflow/Inflow in each grid estimated by using MSS data and PT data

(d) Number of Outflow/Inflow estimated by maximum likelihood method
Outflow/Inflow Population at Specific Cell

Outflow (8:00 – 9:00) Inflow

Takashimadaira

Housing estate
Outflow/Inflow Population at Specific Cell

Outflow  (8:00 – 9:00)  Inflow

Tokyo  Business center
Outflow/Inflow Population at Specific Cell

Outflow (8:00 – 9:00) Inflow

Shinjuku Commercial & business
Outflow/Inflow Population at Specific Cell

Outflow  (8:00 – 9:00)  Inflow

Shinagawa  Business center
Pedestrian Flow at Shinagawa Station

(8:00 – 9:00)
Pedestrian Flow at Shinagawa Station

(8:00 – 9:00)
Temporal Change of Outflow/Inflow Population

Clockwise

Inflow

Outflow

Shinagawa
(Business district)

Counterclockwise

Inflow

Outflow

Ojima
(Large housing complex)
Temporal Change of Outflow/Inflow Population

Clockwise (positive)

Counter-clockwise (negative)
Spatial distribution of value of Surface Area

Clockwise (positive)

Counterclockwise (negative)
Outflow/Inflow on Weekday at Shinjuku Station

(1) Outflow on Weekday from Shinjuku Sta. ($\Delta t = 60$ min.)

(2) Inflow on Weekday to Shinjuku Sta. ($\Delta t = 60$ min.)
Outflow/Inflow on **Weekend** at Shinjuku Station

(3) Outflow on Weekend from Shinjuku Sta. ($\Delta t = 60$ min.) $T_{ij}^{9:00}$

(4) Inflow on Weekend to Shinjuku Sta. ($\Delta t = 60$ min.) $T_{ij}^{9:00}$

[Map showing outflow and inflow patterns]

- Ikebukuro Sta.
- Shinjuku Sta.
- Tokyo Sta.
- Shibuya Sta.

*Holiday*

[Legend for population distribution]

- 0 people
- ~5 people
- ~10 people
- ~20 people
- ~50 people
- 50~
Outline

✓ Background & Motivation

✓ Spatiotemporal Demographic Data (its potential and limitation)

✓ Integration Method (1) for Demographic data (building use / purpose / attribute)

✓ Integration Method (2) for Demographic data (inflow / outflow / static)

✓ Applications for Disaster Mitigation Planning

✓ Summary and Conclusions
Many people lost their lives by **collapsed houses**. At the same time, however, 70% of rescued people were rescued by the **neighbors** including younger people.
They had difficulty in rescue activities without electric power during the night.
Many people who *temporarily came back home* were killed by tsunami.
Framework of Simulation System

- **Spatiotemporal Distribution of People**
  - Personal attributes, departure/arrival location and time, purpose of trip, means of trip
  - Models of human behavior

- **Returning Home**

- **Evacuation**

- **Firefighting & Rescue**

Integration:

- **Estimate the attributes, status, position information, and the amount of evacuees**

- **Visualization / policy evaluation (Spatiotemporal distribution)**

- **Changing the time and day of the week and place**

- **Changing the season, time, earthquake intensity**

Elements of Urban Area (Building, Street, Open space, etc.)

- **Detailed attribute of physical environment**

- **Building collapse**

- **Street blockage**

- **Fire spreading**

Models of property damages
Wooden Densely Built-up Residential Area

① Wooden densely built-up residential area
Detailed GIS data having the individual building information
Completely Destroyed Buildings

② Completely destroyed building
Estimated using fragility curves differing according to building age and structure type
③ Rubble outflow of completely destroyed building
Estimate the spatial distribution of rubble of completely destroyed building
Street Blockage by Rubble Outflow

④ Street blockage by rubble outflow
Estimating roads impassable by rubble outflow
Buildings of Fire Outbreak

Estimated using probability of fire breakout according to building type, season, time of the day, seismic acceleration.
⑥ Fire spreading and wide area evacuation

Estimating fire spreading on the basis of the fire spread rate determined by earthquake acceleration, distance between buildings, wind speed, building structure, etc.
Framework of Simulation System

Spatiotemporal Distribution of People
- Personal attributes, departure/arrival location and time, purpose of trip, means of trip

Evacuation
- Models of human behavior

Firefighting & Rescue
- Changing the time and day of the week and place

Returning Home

Integration
- Estimate the attributes, status, position information, and the amount of evacuees

Building collapse
- Models of property damages

Street blockage

Fire spreading
- Changing the season, time, earthquake intensity

Visualization / policy evaluation (Spatiotemporal distribution)

Elements of Urban Area (Building, Street, Open space, etc.)
- Detailed attribute of physical environment
Fire Spreading and Wide Area Evacuation

[ Legend ]
- Evacuation area
- Collapsed building
- Fire building
- Street blockage
- People in evacuation
- People with difficulty in evacuation

Evacuation Area

Area A

Area B
People with Difficulty in Evacuation

 Percentage of people who could not evacuate among people who tried to evacuate.

Ratio of People with Difficulty in Evacuation

- 0
- 0.1
- 0.2
- 0.3
- 0.4
- > 0.5
People with Difficulty in Evacuation

2006

Percentage of people who could not evacuate among people who tried to evacuate.

Ratio of People with Difficulty in Evacuation

<table>
<thead>
<tr>
<th>0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

100m
Framework of Simulation System

- **Spatiotemporal Distribution of People**
  - Personal attributes, departure/arrival location and time, purpose of trip, means of trip

- **Returning Home**
  - Models of human behavior

- **Evacuation**
  - Changing the time and day of the week and place

- **Firefighting & Rescue**
  - Models of property damages

- **Integration**
  - Estimate the attributes, status, position information, and the amount of evacuees

- **Elements of Urban Area**
  - Detailed attribute of physical environment

  - **Building collapse**
  - **Street blockage**
  - **Fire spreading**

  - Visualiation / policy evaluation (Spatiotemporal distribution)

  - Changing the season, time, earthquake intensity
Tokyo Government has enacted the ordinance for people with difficulty in returning home.

(1) Suppression of returning home behavior from secured places (school/ workplace).
(2) Providing information about disaster situation.
(3) Temporary Shelters for people with difficulty in returning.
(4) Support Stations for people returning home on foot.

Questions:
The number of facilities, size, and arrangement is sufficient?
If not, how can we reduce congestion of facilities?

Evaluation by simulation
Main Roads in Simulation

Tokyo 23 Wards

Tokyo

0 40 km

: Main roads
Facilities to be Analyzed in Simulation

Temporary Shelter
- ex: City hall, Concert hall, High school (Public facilities)

Support Station
- ex: Convenience stores/Gas stations

Train Station
- ex: Large Train stations

These facilities are destinations for those who are going to stay.

People drop in at these facilities while traveling for toilets and a rest on the way returning home.
Temporary Shelters

Ex: City hall, Concert hall, High school
(Mainly public facilities)
Support Stations

Ex: Convenience stores/ Gas stations
Train Stations

Ex: Train stations

- - - : Trains
Questionnaire Survey on People’s Behavior

Responders
Occupation: Ordinal employee / Student
Location of workplace /school: Inside 23 special districts in Tokyo
Means of transportation: Public transportation (Train or bus)
Attributes: Family type, Sex, Age, Address of workplace/school, Address of house
Number of responders: 2,348 persons

Behavior
1: Stay at school or workplace/ Walk toward school or workplace
2: Walk toward home
3: Walk toward evacuation area
4: Walk toward acquaintance’s house
5: Walk to other places on foot

A nested logit model that describes the decision making of stranded people after a large earthquake.
Destinations of Walkers

Whereabouts in the event of a disaster

- School/Workplace
- Other place
- Temporary shelter
- Train station
- Destination

Set the destination based on the estimates of the behavioral intention model and the place where emergency occurred.

- Head for home
- Head for school/workplace
- Head for other place

having no information about location

having information about location
Movement of Walkers to Destinations

Support Stations
Stop by for a break/toilet

Train Stations

Whereabouts in the event of a disaster

Destination
Behavior after Abandon of Movement

When walkers approached a place within 2 km from the walking limit distance...
Behavior after Abandon of Movement

Temporary Shelter

Train Station

People who has reached the walking limit distance stop moving and stay in the street

When walkers approached a place within 2 km from the walking limit distance

Original destination

Whereabouts in the event of a disaster

Having location information

Have no location information

Stay in the street
Spatial Distribution of Disaster Facilities

- : Temporary shelter
- : Support station
- : Train station

Radius 20 km
Demonstration of Simulation

- ●: Walkers,
- ●: Level of Crowding at Temporary Shelter,
- ●: Level of Crowding at Support Station,
- ●: Number of stayers at Train Station

Disaster at 14:00 on weekdays
Example of Specific Person

Sex: Female
Age: 40 years old
Family: Husband + Two Kids
Employment status: Full-time
Workplace: Vicinity of Tokyo station
Location of home: 25 km from workplace
Level of Crowding of Temporary Shelters

- 14:00 on non-business days
- 14:00 on weekdays

Level of Crowding vs. Elapsed time after event occurs (minutes)
Spatial Distribution of Level of Crowding

Level of Crowding of Temporary Shelters is particularly high around large train stations on non-business days after 720 minutes in case of disaster at 14:00.
Number of People taking Rest at Support Station

The value is high 5 to 6 hours after the event occurs on weekdays.

Event occurs at 14:00 on weekdays
9:00 on weekdays
18:00 on weekdays

Event occurs on non-business days

※) Average value of Level of Crowding within 20 km from the city center
The value is high at facilities along the main trunk road from the city center to the suburbs.
Average value of Level of Crowding of facilities located in the 8 to 20 km section from the city center
Number of People Staying at Train Stations

Number of stayers = Number of people using (waiting) toilets + taking a rest + staying at stations

The value is high just after the event which occurs at 8:00 on weekdays.

8:00 on weekdays
9:00 on weekdays
14:00 on non-business days

(Number of stayers at stations)

Elapsed time after event occurs (minutes)
At 8:00 on weekdays, values are high at large train stations such as Shinjuku, Shibuya, Ikebukuro, and at stations on the Yamanote line. 90 minutes after the event occurs, the values are high at Maihama station at 14:00 on non-business days. The values are high at Maihama station at 14:00 on non-business days.
 Returning Home Behavior in Simulation

- ●: Walkers,
- ●: Level of Crowding at Temporary Shelter,
- ●: Level of Crowding at Support Station,
- ●: Number of stayers at Train Station

We need to develop technologies to estimate and control the post-disaster crowd-flow using demographic big data, and AI technology.
Framework of Simulation System

Spatiotemporal Distribution of People
- Personal attributes, departure/arrival location and time, purpose of trip, means of trip

Evacuation

Returning Home

Prediction of human behavior

Firefighting & Rescue

Prediction of physical damage

Integration
- Estimate the attributes, status, position information, and the amount of evacuees

Visualization / policy evaluation (Spatiotemporal distribution)

Elements of Urban Area (Building, Street, Open space, etc.)
- Detailed attribute of physical environment

Building collapse

Street blockage

Fire spreading

Changing the season, time, earthquake intensity

Changing the time and day of the week and place
Tokyo is presumed to be attacked by a large earthquake in probability of 70% in coming next 30 years.

Predicted number of multiple simultaneous fires at a large earthquake in Tokyo (Tokyo Metropolitan Government, 2013)

800 vs. 600

The number of fire engines of Tokyo Fire Department
Web Application of Fire-Spread Simulation
Web Application of Fire-Spread Simulation
Spatial Distribution of Fire-Spread Potential

1. All buildings (2,784,123) in Tokyo Metropolitan
2. Earthquake occurs in a winter evening (18:00)
3. Wind is from the north with a speed of 8 m/s
1. All buildings (2,784,123) in Tokyo Metropolitan

2. Earthquake occurs in a winter evening (18:00)

3. Wind is from the north with a speed of 8 m/s

Spatial Distribution of Fire-Spread Potential

- No building
- 1-10
- 11-50
- 51-100
- 101+

Fire-Spread Potential

Tokyo Metropolitan evening (18:00) speed of 8 m/s
Reduction of Burnt-down Buildings by FSP

**Strategy 2**: FSP ($\mu$, $\sigma$) and the number of available fire engines in each Firefighting Jurisdiction

![Graph showing reduction of burnt-down buildings](image)
Normal Time (without Blockage)

Access time: 2.1 minutes
Street Blockage by Collapsed Buildings

Access time: 5.7 minutes
Disaster Information Collection
(5 minutes by 0.5% of residents)

Access time: 2.4 minutes
Ratio of Collected Information

- 88% collected information
- 0.5% of local residents
- 0.3% of local residents

Time for information collection [minute]
Effects of Information Collection

Possible to reduce the access time, if 0.5% of the residents collect information for 5 minutes.

Significant reduction

0.3% of local residents

0.5% of local residents

all the road-blockage are known

minimum value
Flame Circumference and Fire Brigade

Relation between perimeter of fire surface and surrounding circumference

Source: http://www.ddt33.dpri.kyoto-u.ac.jp/katsudou/h14_happyoukai_pdf/h15_0801_6_2.pdf
Growth of Perimeter of Fire Surface

(a case where one building fires in a certain area)

800 fire outbreak VS. 600 fire engine

Perimeter of Fire Surface

Number of Buildings in Fire

Elapsed Time (minutes)
Outline

✓ Background & Motivation

✓ Spatiotemporal Demographic Data (its potential and limitation)

✓ Integration Method (1) for Demographic data (building use / purpose / attribute)

✓ Integration Method (2) for Demographic data (inflow / outflow / static)

✓ Applications for Disaster Mitigation Planning

✓ Summary and Conclusions
Summary and Conclusions (1)

- We pointed out limitations of the population statistics based on the location information of mobile phone users, in which detailed personal attribute information is being concealed to protect privacy.
- We proposed an integration method for enriching the value of the population statistics by adding the detailed information on the attributes and the purposes of their stays.
- We demonstrated that it is possible to grasp the spatiotemporal characteristics of population distribution attached with detailed attributes information such as their age, gender, and purposes that vary according to the time, location, and building use where they are.
We proposed a method for estimating the spatiotemporal distribution of static and transient populations of urban areas by integrating existing demographic data.

We demonstrated an example of urban analysis from new and never-before employed points of view.

We demonstrated the application examples of integrated demographic data, which include simulation analysis on Returning Home Behavior, Evacuation Behavior, Firefighting Behavior.

There is a growing demand for data that allows highly accurate understanding of the spatiotemporal distribution of both moving and static people in urban areas with detailed attributes.
Future Research

- We need to discuss differences and commonalities in population statistics, which are currently available in other countries, in order to expand the availability of the models for other data sources available in other countries.

- Construct a model to evaluate the influence of large-scale public events or natural disaster on people’s movements, which assists mitigating crowding and avoiding risks, identifying appropriate initial responses, and guiding evacuation.