The first JSCE-ASCE Symposium on Infrastructure Resilience

Date: May 22-23, 2019
Venue: Japan Society of Civil Engineers, Auditorium

Session 3: Systems Resilience and Economic Impact

Lifeline Resilience Model and its Application

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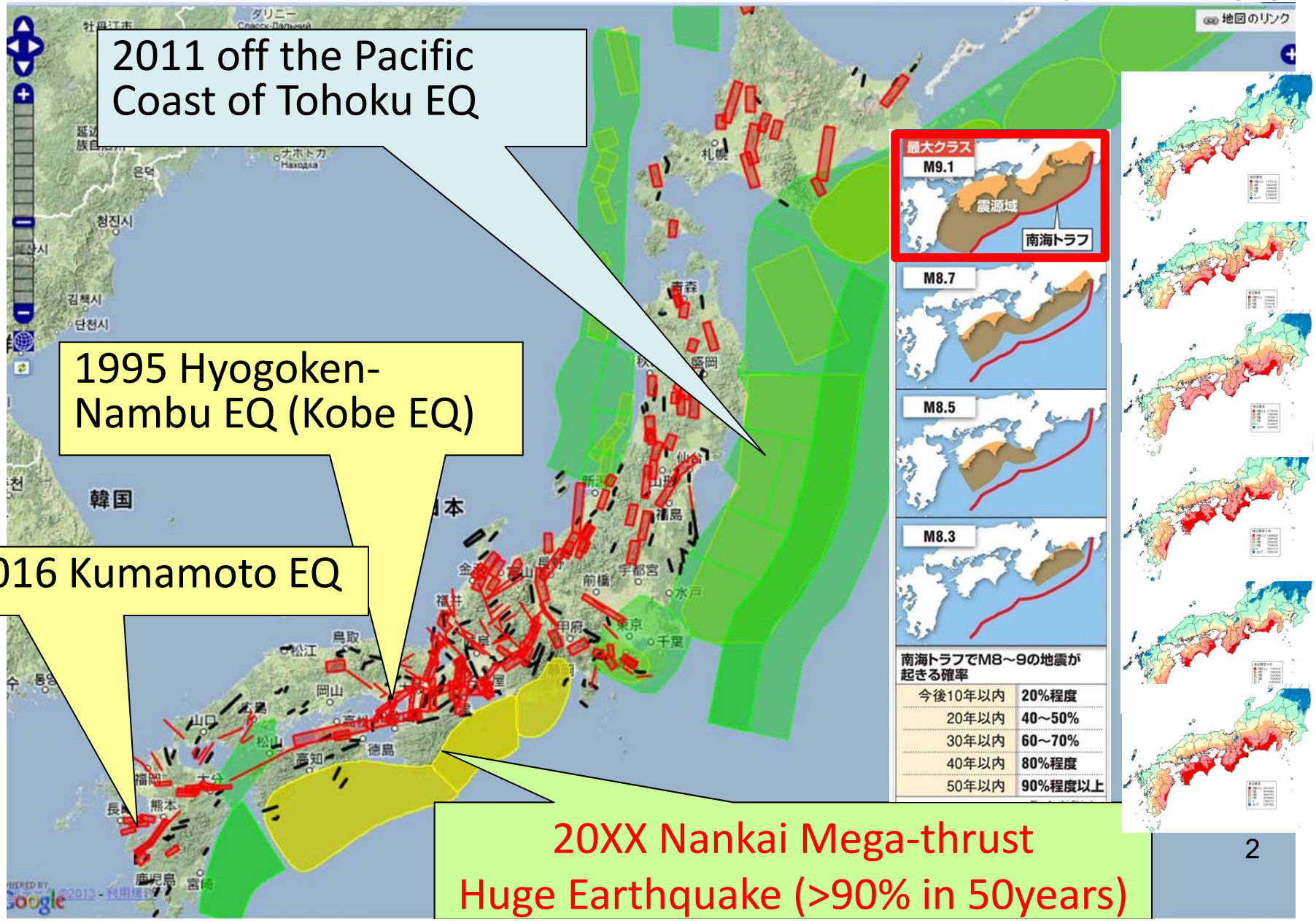
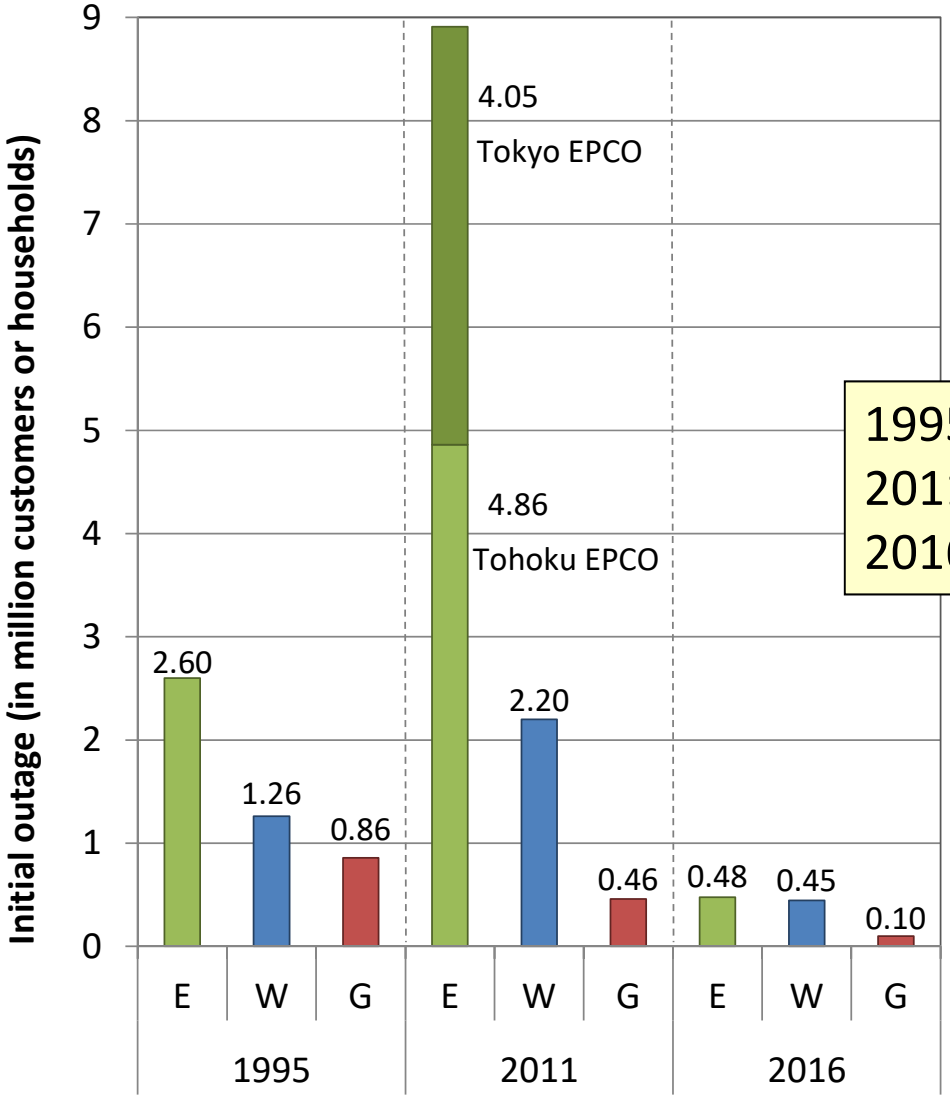
Gifu University

Seismogenic Zones in and around Japan

http://www.j-shis.bosai.go.jp/



Initial outage of lifeline services (number of households in million)



E : Electric power supply
W : Water supply
G : City gas supply

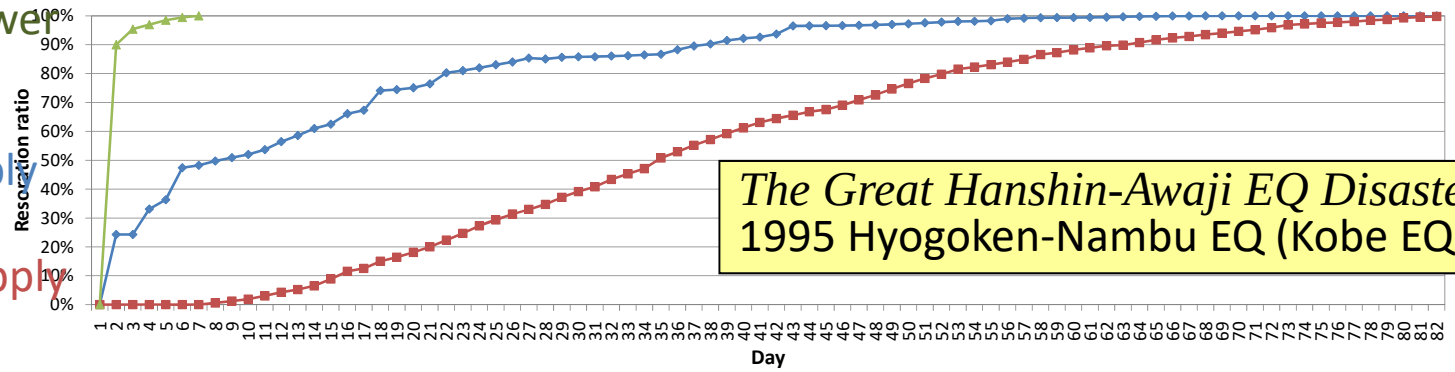
1995: Hyogoken-Nambu EQ (Kobe EQ)
2011: Off the Pacific Coast of Tohoku EQ
2016: Kumamoto EQ

Normalized restoration curves (Resilience of each lifeline)

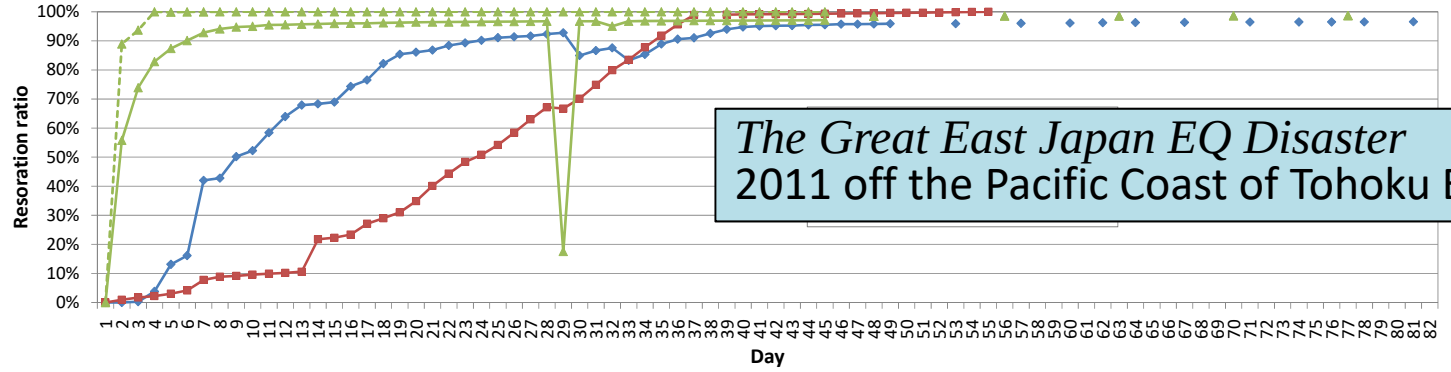
Electric power supply

Water supply

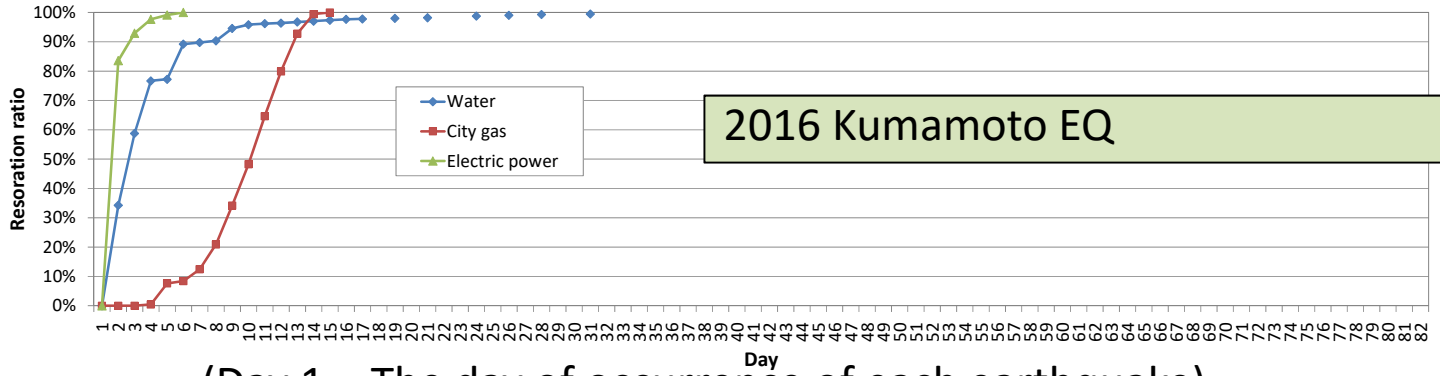
City gas supply



The Great Hanshin-Awaji EQ Disaster
1995 Hyogoken-Nambu EQ (Kobe EQ)



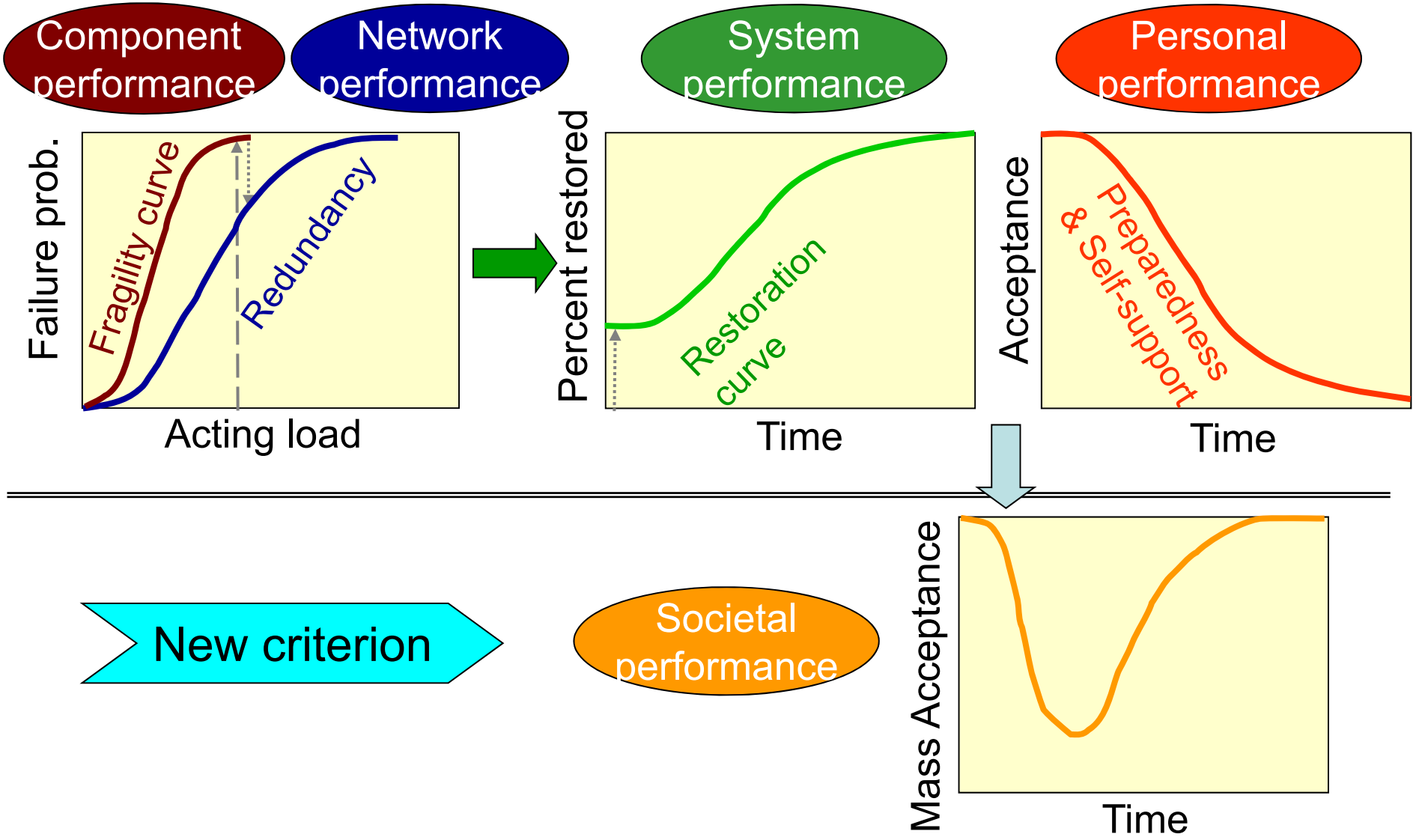
The Great East Japan EQ Disaster
2011 off the Pacific Coast of Tohoku EQ



2016 Kumamoto EQ

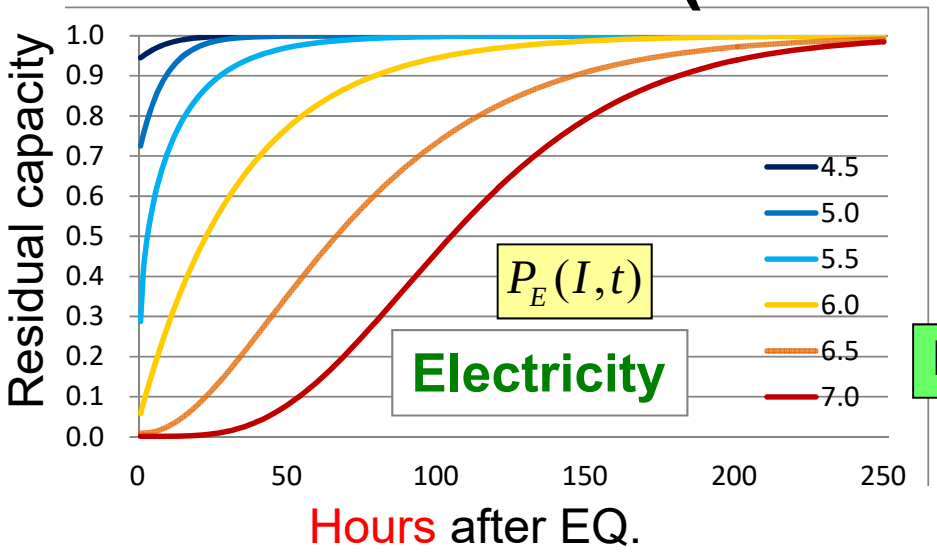
(Day 1 = The day of occurrence of each earthquake)

Framework for assessment of indirect impact due to lifeline disruption



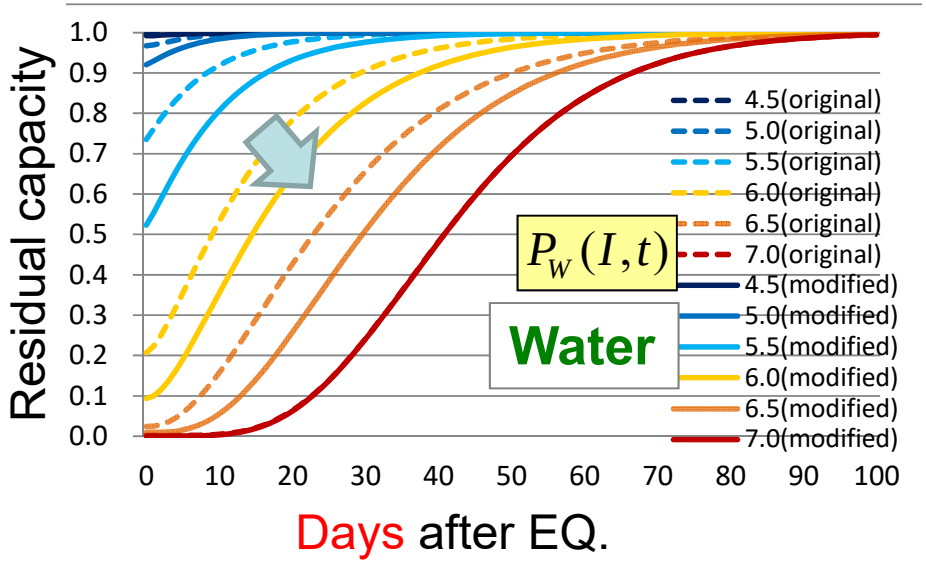
Post-earthquake lifeline serviceability model (modified, example)

(Nojima et al., 2012)

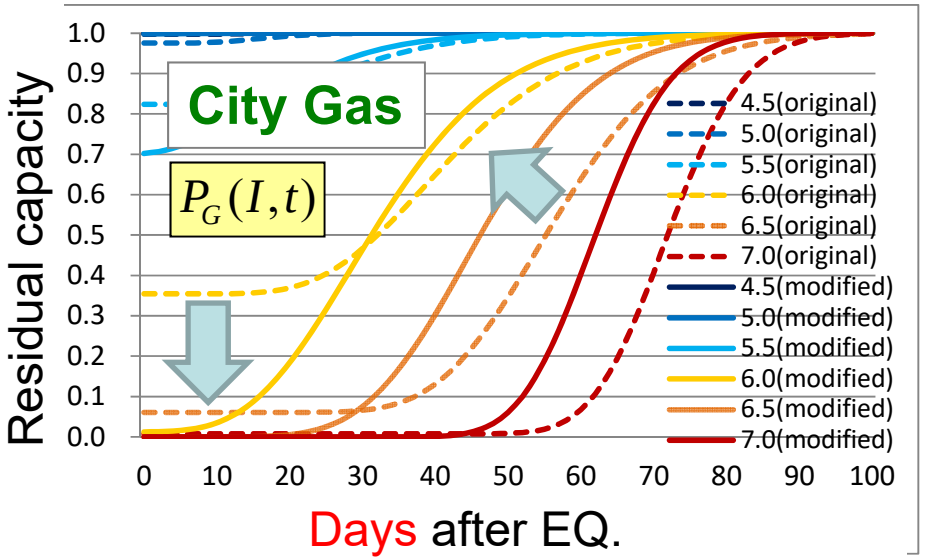


$$P(I,t) = \underbrace{\{1 - p(I)\}}_{\text{Restored performance level}} + \underbrace{p(I) \cdot F(t \mid I)}_{\text{Deteriorated performance level after the EQ}}$$

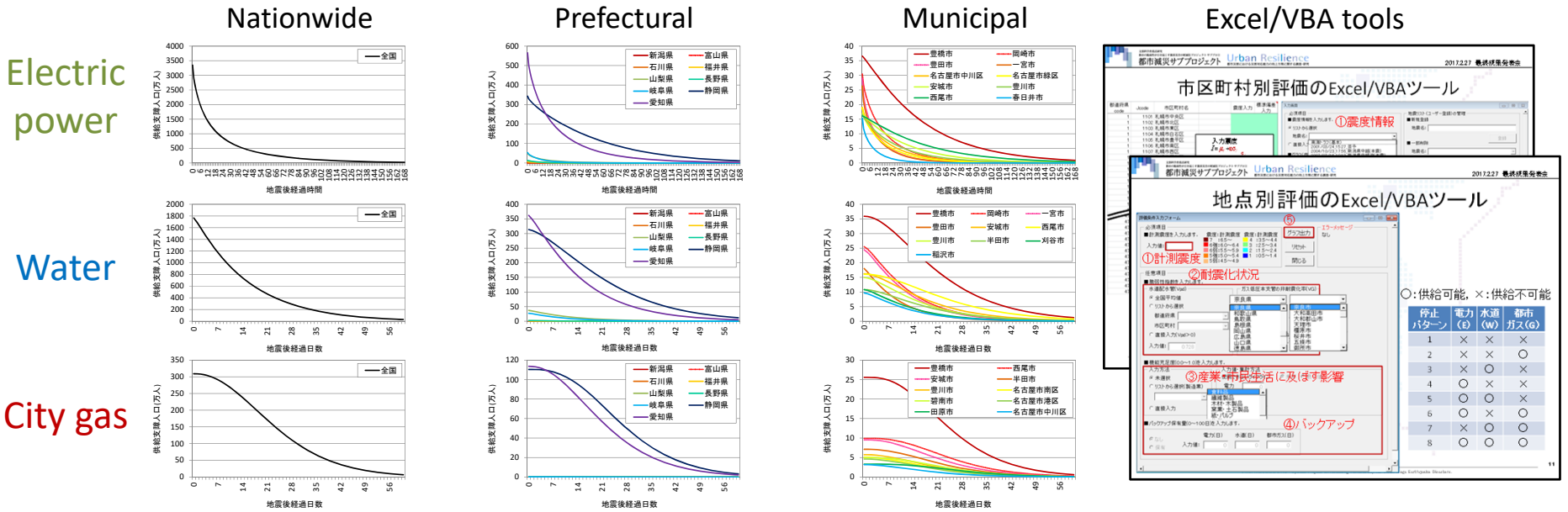
Effects of the vulnerability of pipelines compared to Kobe region in 1995

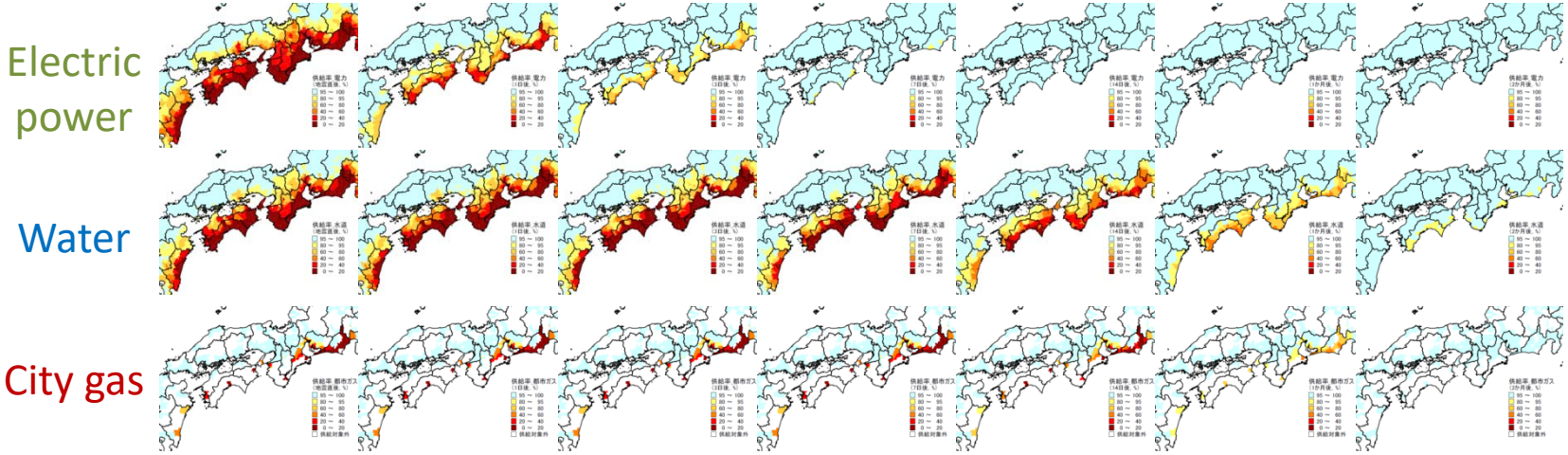


Emergency shutoff regulations and prompt first response compared to 1995

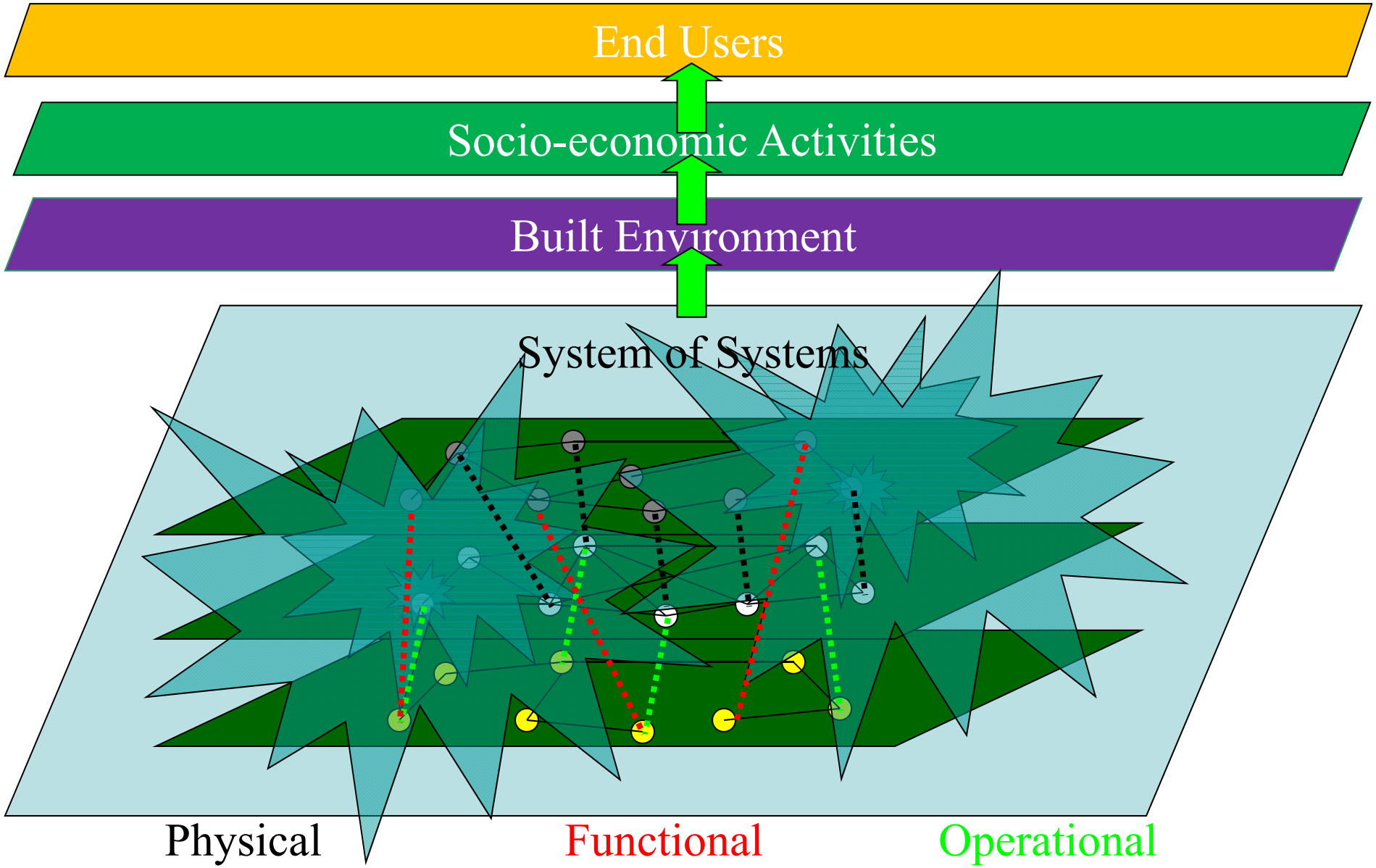


Assessment of Lifeline Disruption in the Nankai Trough Huge Earthquake (Mw9.0)

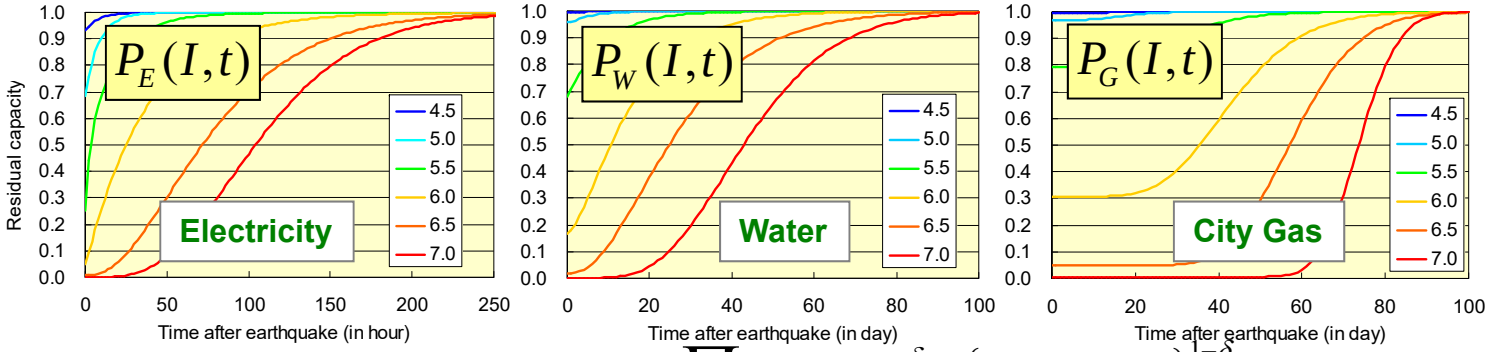




Infrastructure system of systems



Probability of appearance of 2^3=eight disruption patterns



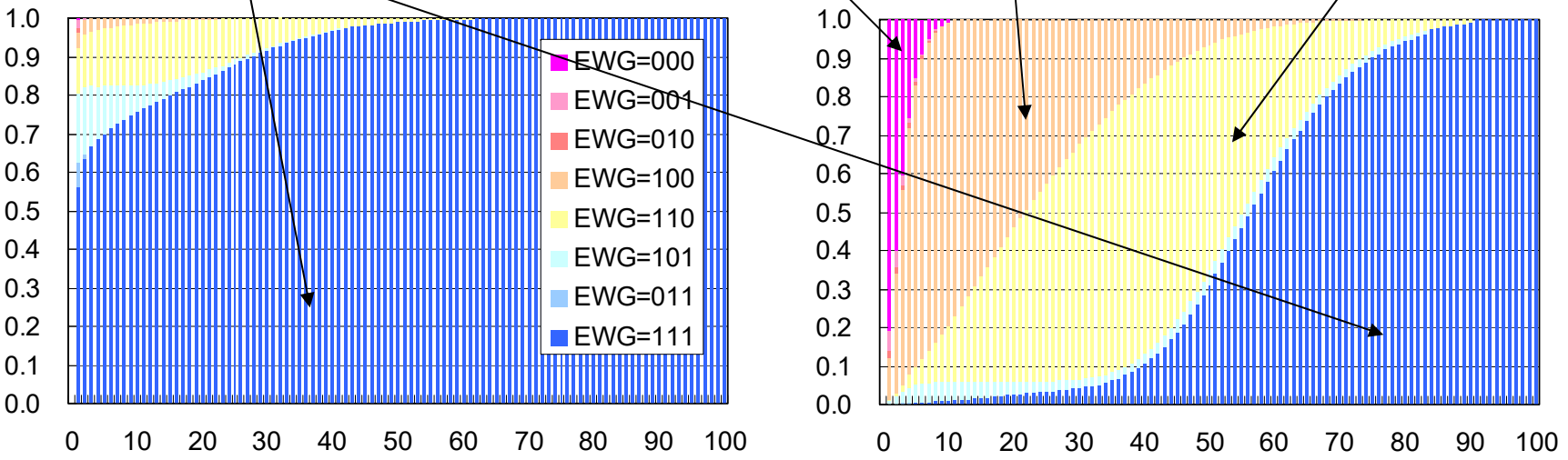
$$Q(\delta_E,\delta_W,\delta_G;I,t)=\prod_{k=E,W,G}P_k(I,t)^{\delta_k}\cdot\{1-P_k(I,t)\}^{1-\delta_k}$$

EWG=111 : All utilities are operational

EWG=000 : All utilities are non-operational

EWG=100 : Only electricity is operational

EWG=110 : Electricity and water are operational



Seismic intensity 5.5 (severe)

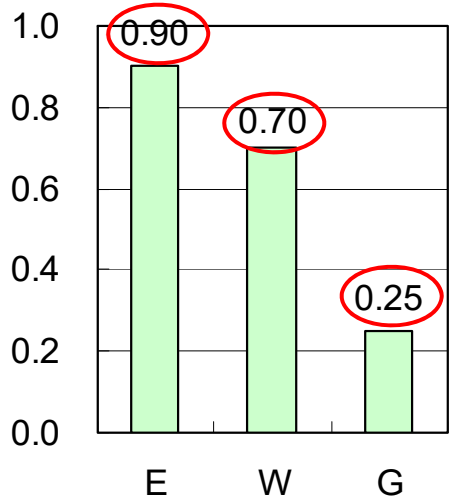
Seismic intensity 6.5 (very severe)

Rate of satisfaction of industrial sector
(Food manufacture subsector)

Lifeline importance weights (ATC-25)

More important

Less important

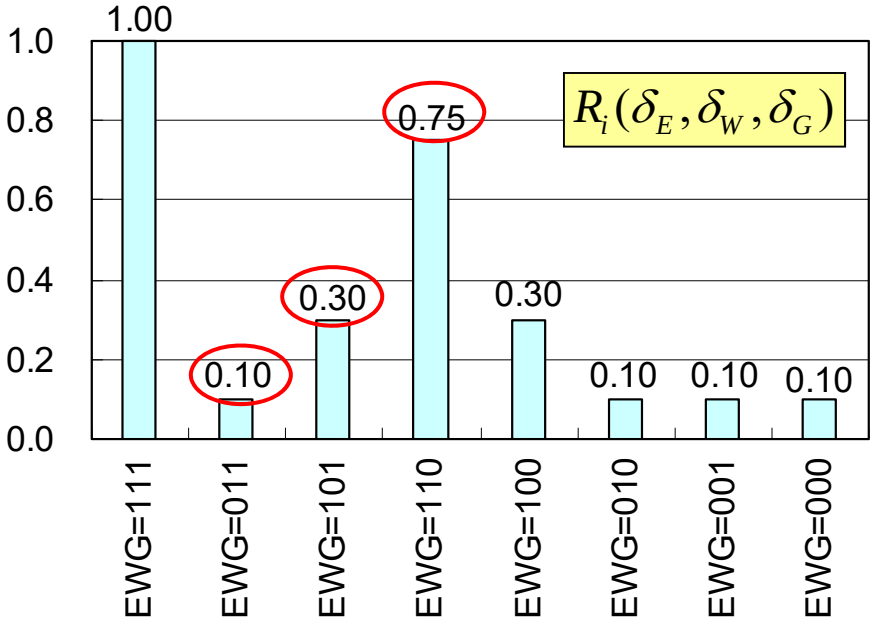


E : Electric power supply
W : Water supply
G : City gas supply

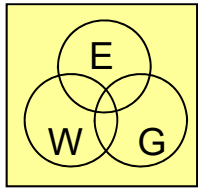
Rate of satisfaction (Resiliency factor)

Intact

Complete loss



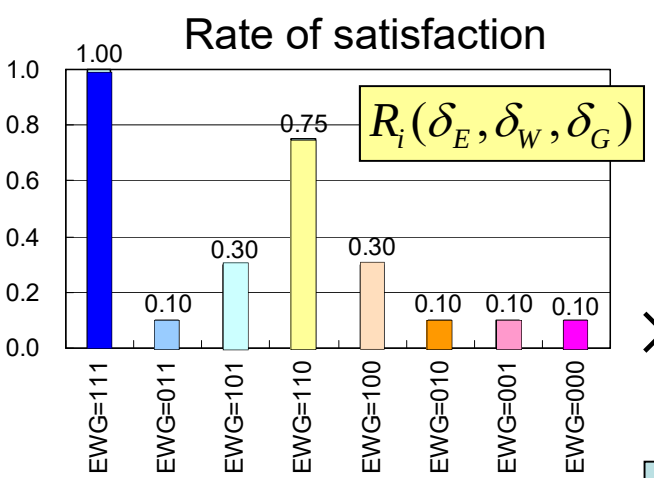
2^3=Eight disruption patterns



Which pattern appears? When?
1) *seismic intensity level*
2) *restoration process*

1 : Operational
0 : Non-operational

Time function of average rate of satisfaction



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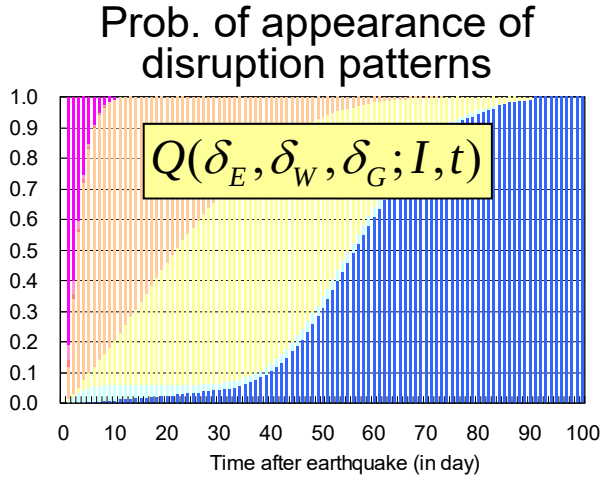
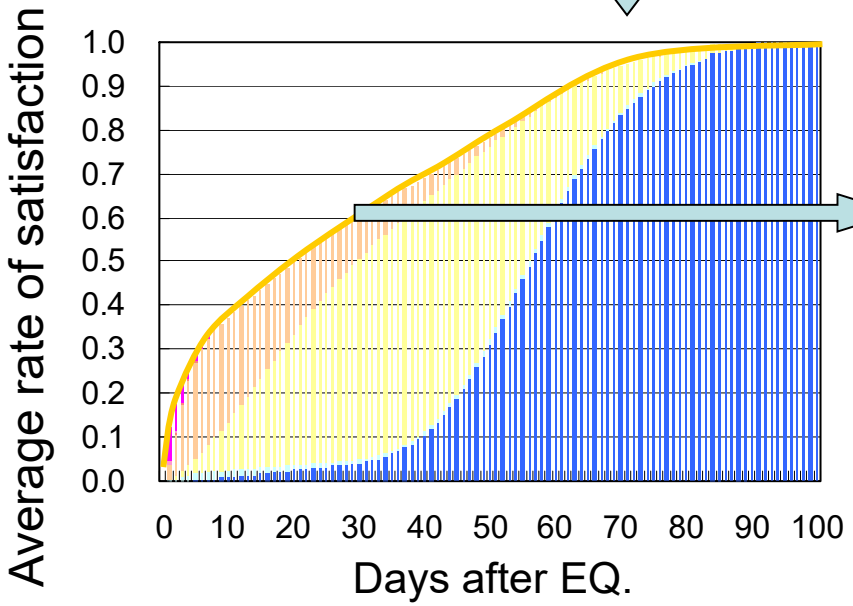
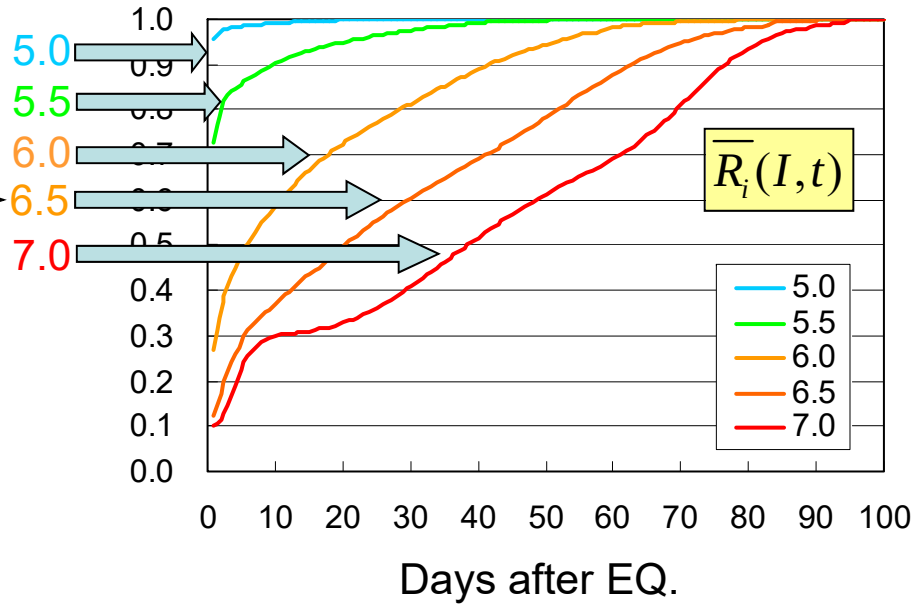


Weighted sum

$$\overline{R_i}(I,t)=\sum_{\text{all}(\delta_E,\delta_W,\delta_G)} R_i(\delta_E,\delta_W,\delta_G)\cdot Q(\delta_E,\delta_W,\delta_G;I,t)$$

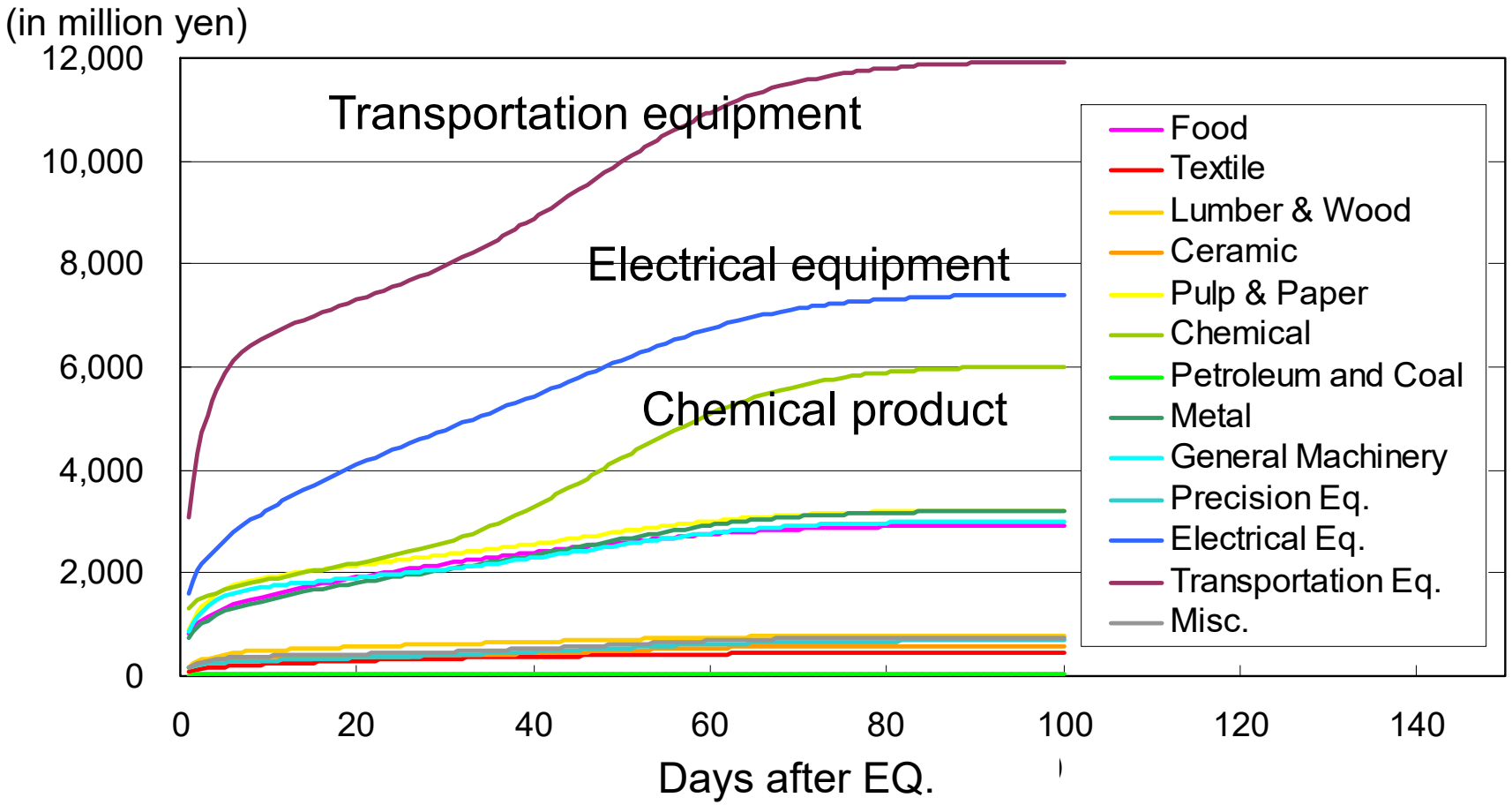


Seismic intensity 6.5 (very severe)



Various seismic intensity

Post-earthquake daily shipment values for various industrial subsectors



In Shizuoka prefecture for the hypothetical Tokai earthquake

MODELING POST-EARTHQUAKE SERVICEABILITY OF RAILSWAY SYSTEM BASED ON THE DATABASE OF THE GREAT EAST JAPAN EARTHQUAKE DISASTER

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Abstract

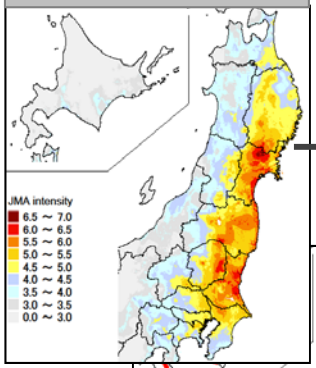
Estimation of possibility and duration of suspension of railway service is an important issue. In this study, statistical analyses have been carried out for evaluation of post-earthquake serviceability of railway systems in the 2011 Great East Japan Earthquake Disaster on the basis of JMA seismic intensity. By following the two-step evaluation model for serviceability of utility lifelines proposed by the authors, an empirical model has been statistically-derived to predict railway service suspension in anticipate earthquake scenarios.

KEYWORDS: ***Railway service suspension; Initial outage and duration; The Great East Japan Earthquake Disaster***

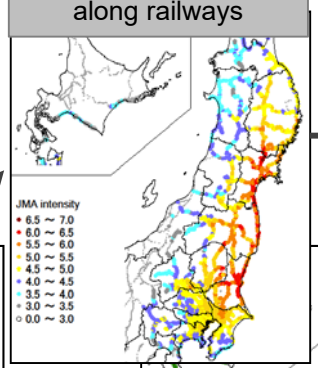
Data compilation

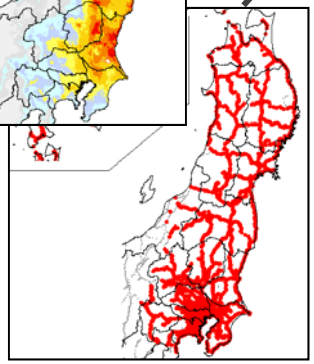
- A database was compiled with regard to GIS data on railway lines and stations, service suspension caused by ground shaking and tsunami inundation.
- Shaking intensity maps in terms Japan Meteorological Agency (JMA) seismic intensity scale were also compiled.

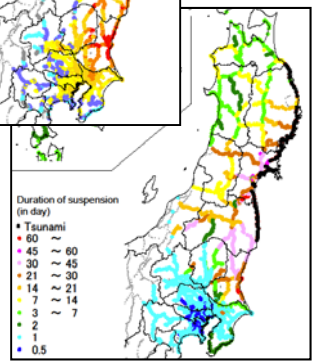
JMA seismic intensity



JMA seismic intensity along railways



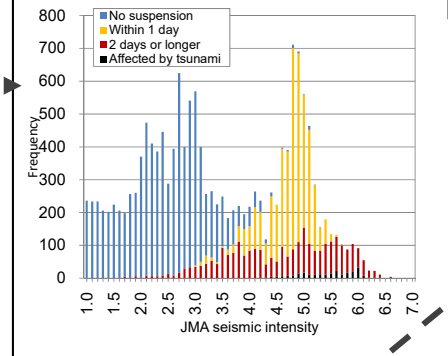




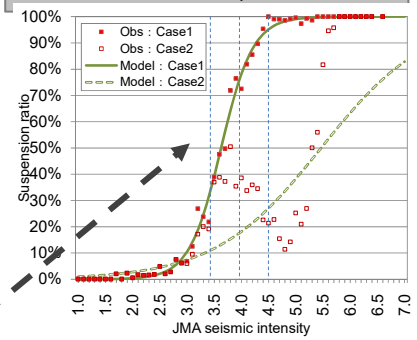
Model development (Step 1: Initial probability of suspension)

- The relationship between the incidence of railway service suspension and shaking intensity was evaluated.
- A logit model was fitted to predict the probability of occurrence of service suspension as a function of shaking intensity.

Histogram of duration of suspension in terms of JMA seismic intensity



JMA seismic intensity vs. suspension ratio (Observed ratio and logit model)



$$p(I) = \frac{\exp[b_0 + b_1 \cdot I]}{1 + \exp[b_0 + b_1 \cdot I]}$$

Seismic intensities for operation control

Case 1: all data (excluding tsunami damage)
Case 2: excluding suspension within 1 day and tsunami damage

Model development (Step 2: Duration of suspension given that suspension occurred)

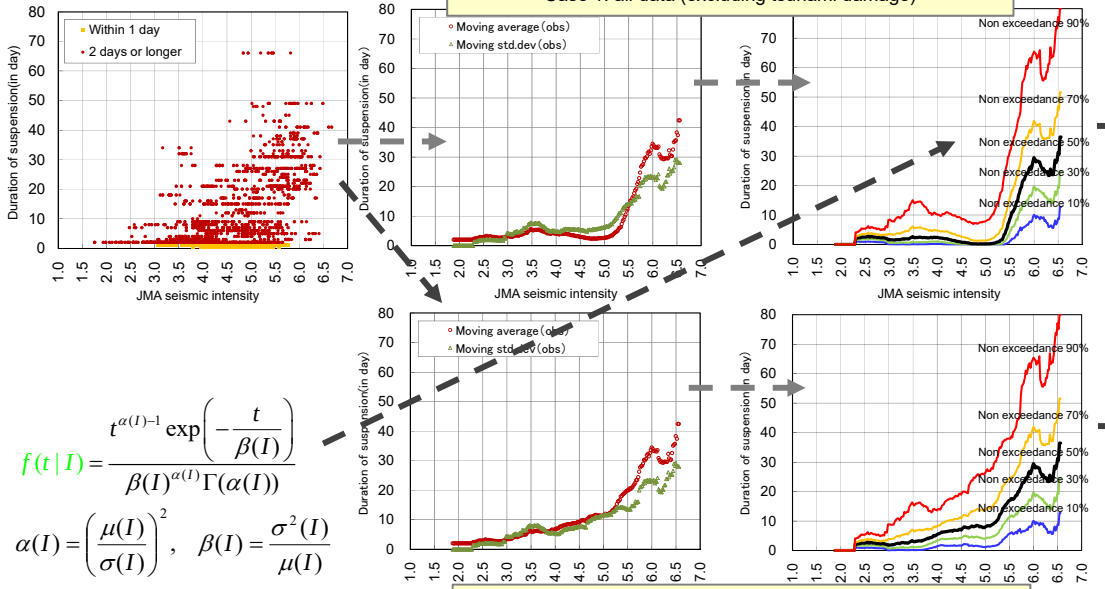
- The relationship between the duration of suspension and shaking intensity was evaluated.
- Gamma distribution was fitted to predict the duration of suspension under the condition that service suspension occurs.

JMA seismic intensity vs. duration of suspension

Moving average and moving standard deviation of duration of suspension

Statistical model of duration of suspension represented by gamma distribution

Case 1: all data (excluding tsunami damage)



$$f(t \mid I) = \frac{t^{\alpha(I)-1} \exp\left(-\frac{t}{\beta(I)}\right)}{\beta(I)^{\alpha(I)}\Gamma(\alpha(I))}$$

$$\alpha(I) = \left(\frac{\mu(I)}{\sigma(I)}\right)^2, \quad \beta(I) = \frac{\sigma^2(I)}{\mu(I)}$$

$$F(t \mid I) = \int_0^t f(\tau \mid I) d\tau$$

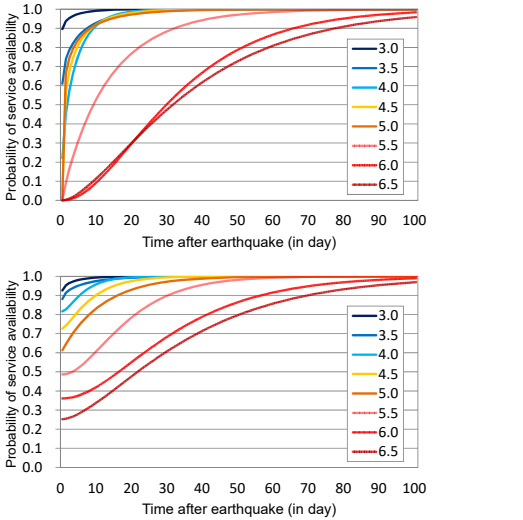
Case 2: excluding suspension within 1 day and tsunami damage

Model development (Step 3)

- By combining two sub-models in steps 1 and 2, a prototype of an integrated of post-earthquake serviceability curve for railway systems was derived.

Prototype of post-earthquake serviceability curves of railways for various JMA intensities.

Case 1: all data (excluding tsunami damage)



Case 2: excluding suspension within 1 day and tsunami damage

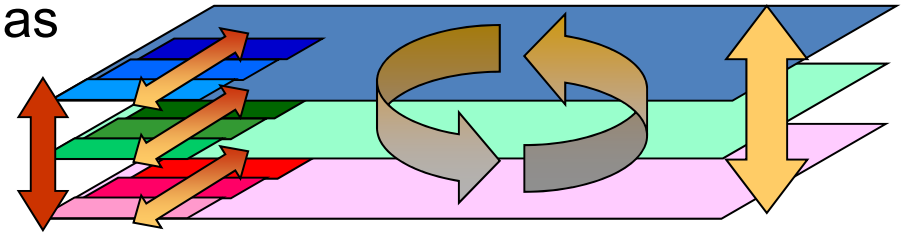
$$P(I,t) = \{1 - p(I)\} + p(I) \cdot F(t \mid I)$$

Conclusions

1) Based on the relationship between occurrence of railway service suspension and JMA seismic intensity, functional fragility functions were derived for two cases: Case 1: “whether there was suspension or not,” and Case 2: “whether there was suspension with 2 days or longer.” Case 1 showed high goodness-of-fit, although suspension ratio is too high at low seismic intensity. On the contrary, Case 2 showed low goodness-of-fit.
2) The relationship between the duration of suspension and JMA seismic intensity. Case 1 showed clear tendency of increasing duration of suspension with increasing intensity in the range from 5.0 to 6.0. Case 2 showed such increasing tendency for wider range of intensity. The coefficients of variation were as large as almost 100%. Gamma distribution was fitted to predict the duration of suspension under the condition that service suspension occurs.
3) By combining two sub-models, a prototype of post-earthquake serviceability curve for railway systems was derived in term of JMA seismic intensity. Because of the statistical fluctuation of parameters, some irregular tendency can be seen, which should be eliminated in the model for practical use. For improving the model, further analysis is needed to consider additional factors and incorporate appropriate explanatory variables.

Lifeline System Interactions

Supply : Water/Electricity/Gas
Disposal : Sewage/Garbage
Transportation : Road/Railway
Communication : Telephone



Physical/Functional/Operational interconnection

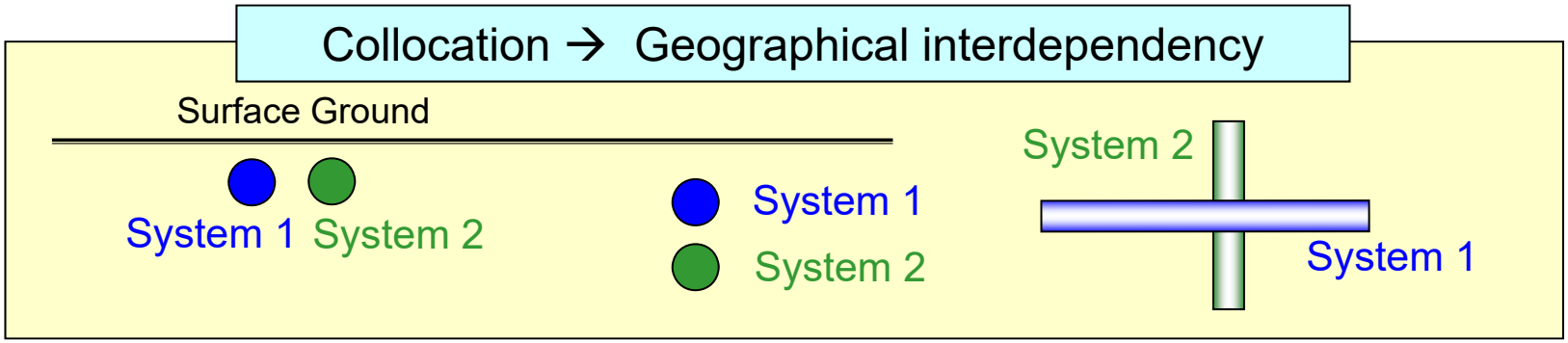
System interactions

Pre-EQ | Earthquake | Time

Physical spread | Functional spread | Impeding recovery works

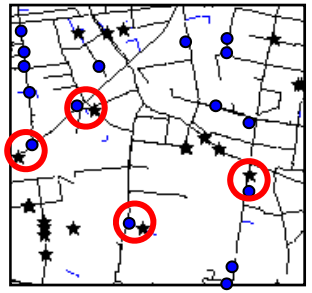
Inter-dependent total system

Lifeline System Interactions due to Geographical Proximity of Network Facilities



- Water → Road :
  - Leak of water can wash out a road.
- Sewer → Water :
  - Leak of wastewater from pipe breaks can contaminate drinking water.
  - Use of water may be restricted until damaged sewer system is restored.
- Water ←→ Gas ←→ Sewer ←→ Electric power
  - Conflicts of repair works may degrade recovery efficiency.
  - Organizational coordination may be required so as to avoid conflicts.

How many coincident damages occur to the multiple lifeline systems in an earthquake?



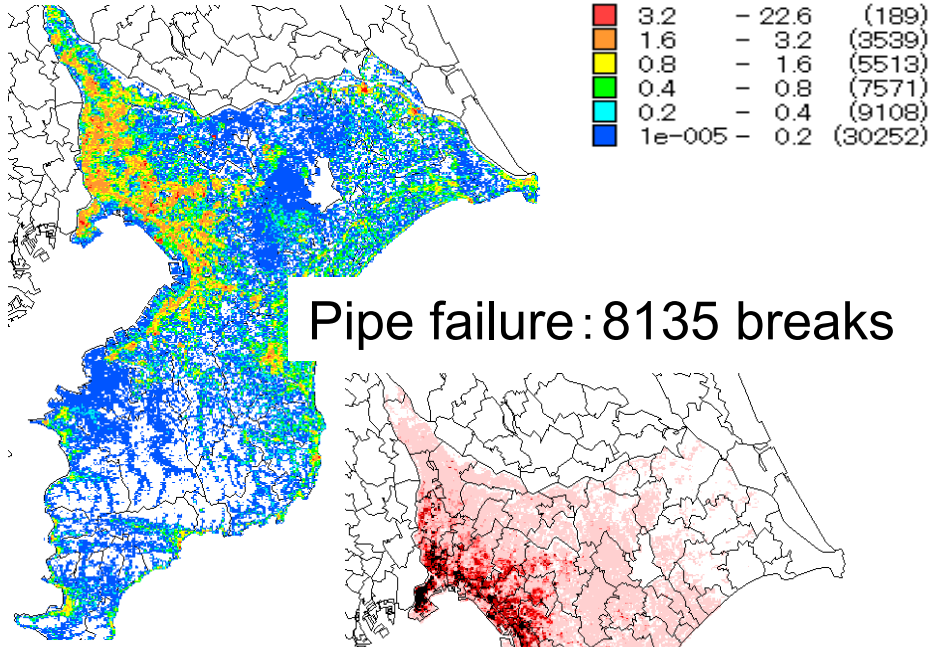
Water Distribution and Sewer Lines

The Hypothetical Northern Tokyo Bay Earthquake (M=7.3)

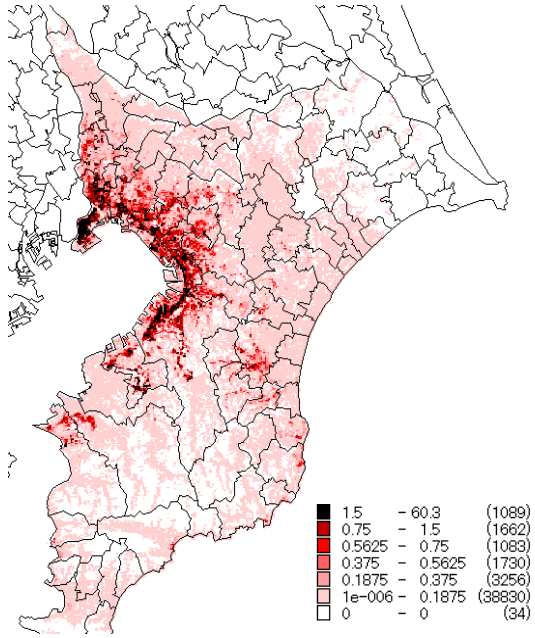
Water delivery network

(Extended length: 23,600km)

Penetration ratio=93%



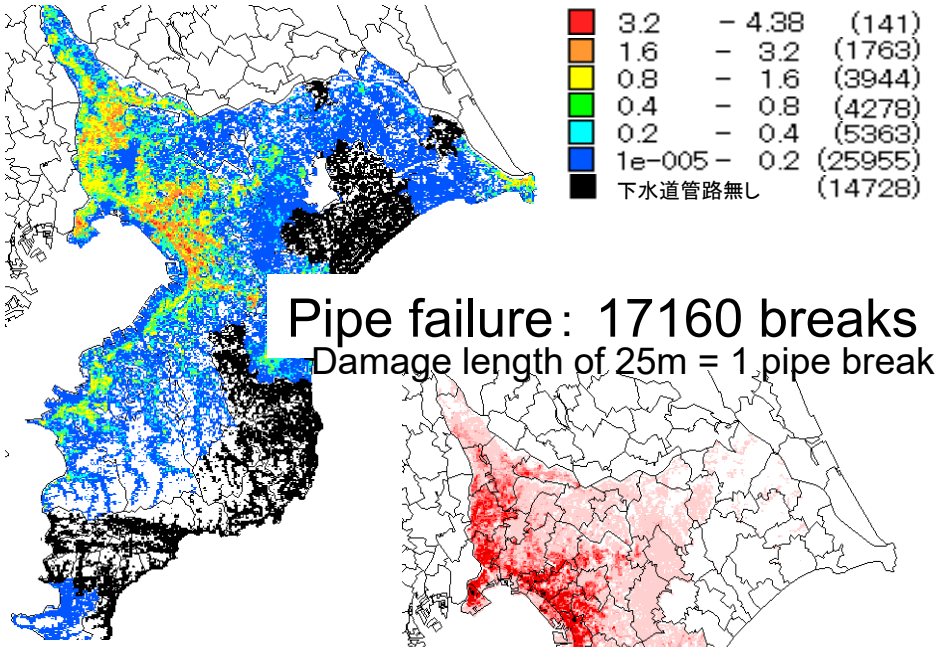
Pipe failure：8135 breaks



Sewer network

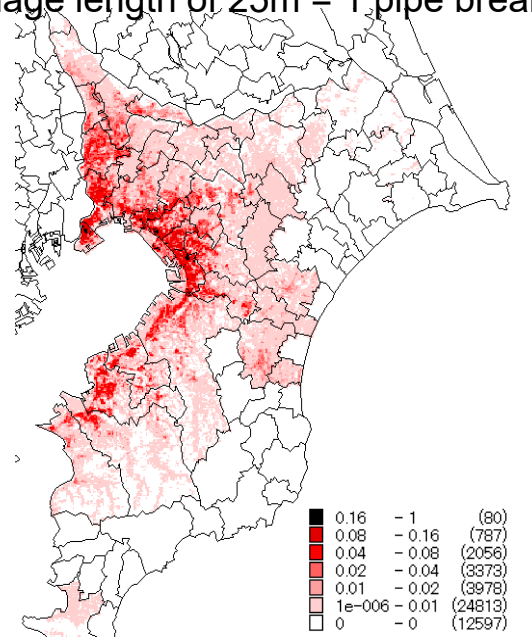
(Extended length: 14,400km)

Penetration ratio=64%



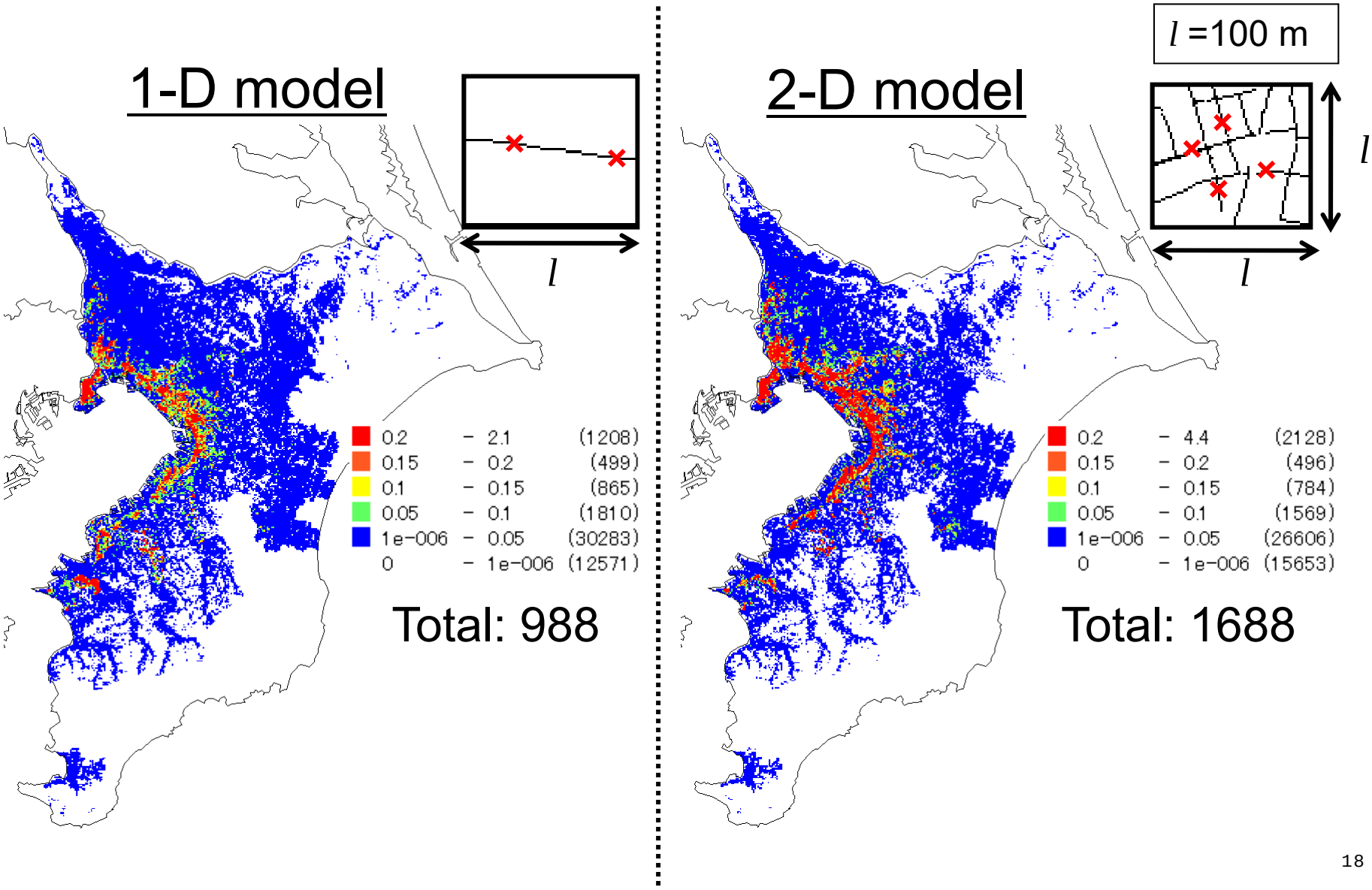
Pipe failure： 17160 breaks

Damage length of 25m = 1 pipe break



Data source: Chiba Prefectural Government Offices and Chiba University

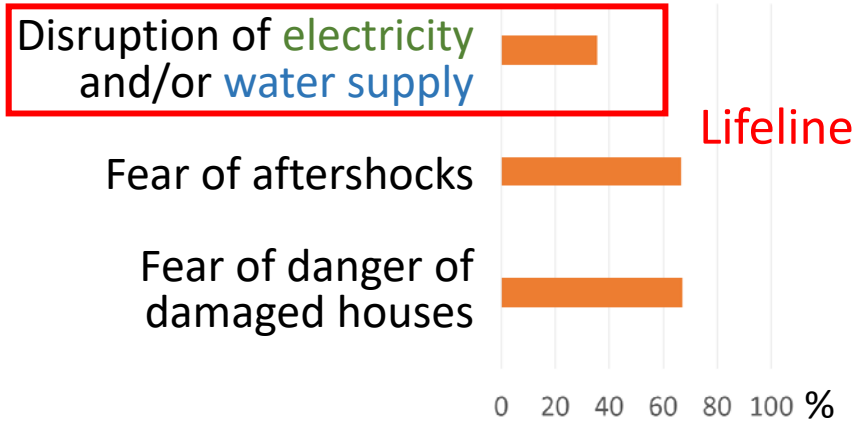
Coincident Damage to Water Delivery and Sewer Systems



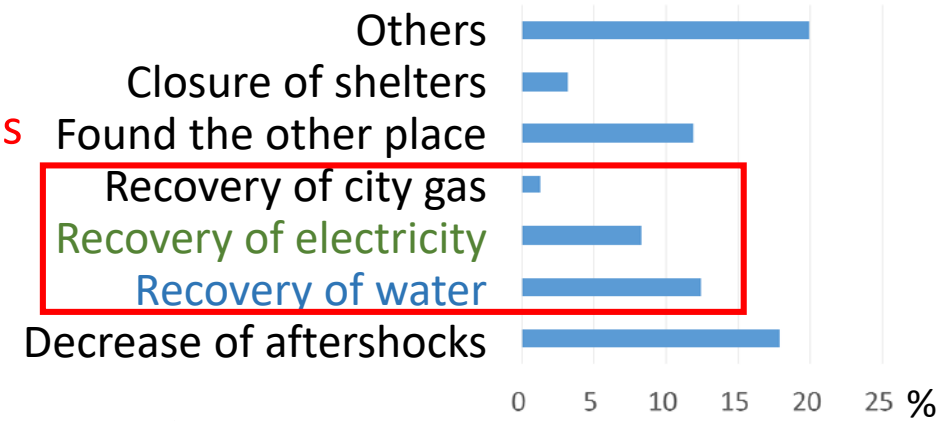
Reason of evacuation in 2016 Kumamoto EQ

Questionnaire survey conducted by Kumamoto City Office

The reasons to evacuate to shelters (Multiple answer, top 3)

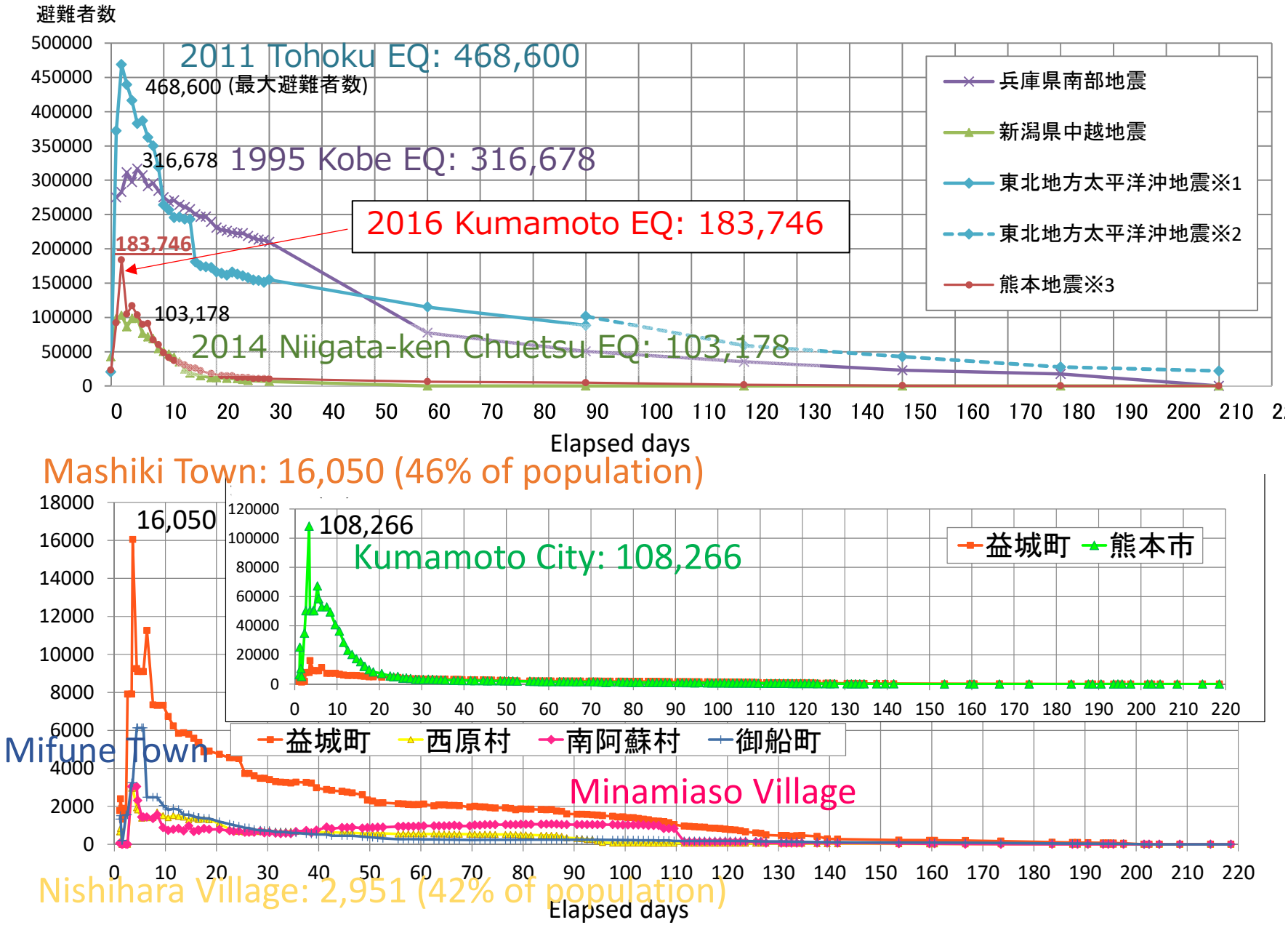


The reasons to return home from shelters (Single answer)

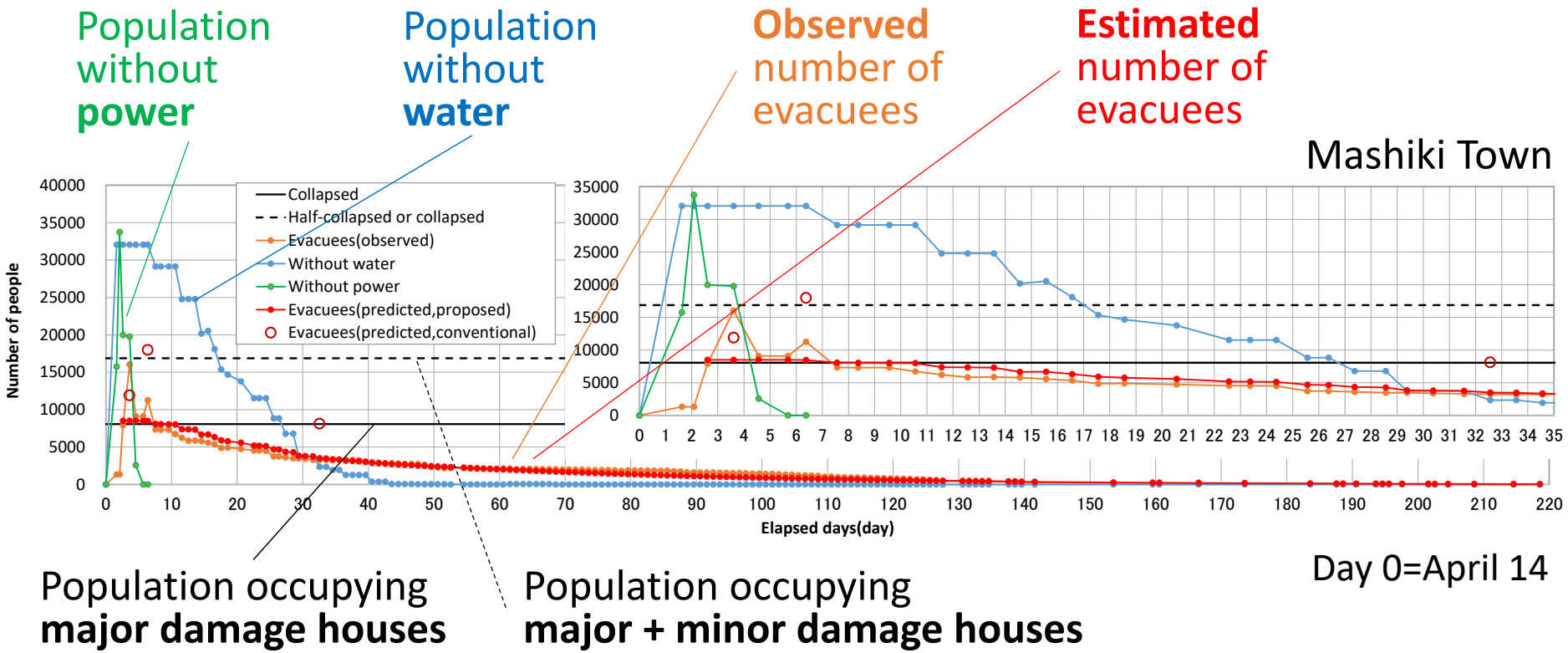


Source: Mainichi Daily News

Number of evacuees in EQ disasters



Observed and estimated number of evacuees



$$N_E(t) = \underbrace{(M_C + e_H M_H) \times e_S \times R_{es}(t)}_{\text{Building damage}} + \underbrace{\frac{(M - M_C - e_H M_H)}{M} \times \max\{M_E(t), M_W(t)\} \times e_{EW}}_{\text{Disruption and recovery of water and electricity}}$$

$R_{es}(t)$: **Resilience time function** describing the long-term effect

$M_E(t)$: Population without **electric power supply**

e_{EW} : Evacuation ratio under disruption of electric power and/or water supply

Multi-disciplinary mitigation options