PSAM9, 18-23 May 2008, Hong Kong, China

RELIABILITY AND SAFETY ASSESSMENT OF CRITICAL INFRASTRUCTRE SYSTEMS

Gaku SHOJI
University of Tsukuba
Nobutaka Kurozumi
InterRisk Research Institute & Consulting, Inc.

Requirement of Reliability and Safety Assessment of Critical Infrastructure Systems

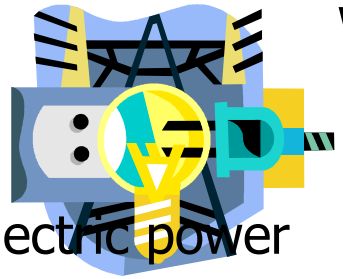
- Functions of critical infrastructure are strongly related to sustaining our societal and economical activity.

⇨ Exposed to functional impairment resulted from a shutdown, an accident and a mechanical failure due to a disaster

RISKS

e.g. Aug 14th, 2003 Major power blackout in New York
Aug 14th, 2006 Major power blackout in Tokyo

System reliability and safety of critical infrastructure systems should be quantitatively evaluated to reduce the associated risks, and to carry out effective risk management.


Electric power


Water


Gas


Communication

Objectives

- Focusing onto functional impairment of critical infrastructure systems, their objective risks due to a disaster are clarified.
  - Electric power supply systems, EPSS
  - Water supply systems, WSS
  - Gas supply systems, GSS
  - Telecommunication network systems, TNS
  - Mobile phone network systems, MPNS

Five subject systems

- ✓ Causes of the consequence with subject systems
- ✓ Risk curves to clarify the relation between the consequence associated with subject systems and its cumulative probability

Analyzed Data

- Functional impairment, FI, resulted from a shutdown, an accident and a mechanical failure due to a disaster

  ⇨ Searched based on digital archived data on Japanese newspapers dealing with the associated articles

Systems	Period of sampling	No. data
Power supply	1985.6～2005.4	548
Water supply	1984.9～2005.5	384
Gas supply	1984.9～2005.4	85
Telecommunication	1984.11～2004.10	191
Mobile phone	1988.5～2006.3	46

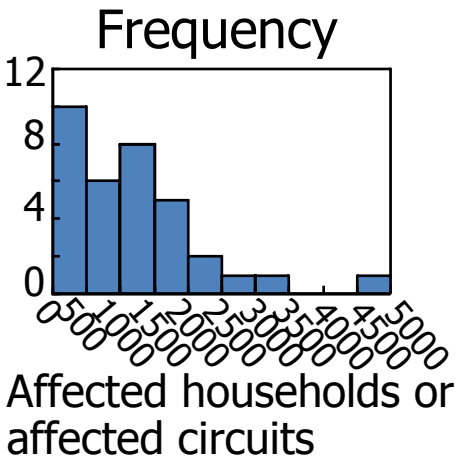
- Measures:
  - EPSS, WSS, GSS: Number of affected households by FI
  - TNS, MPNS: Number of affected circuits by FI

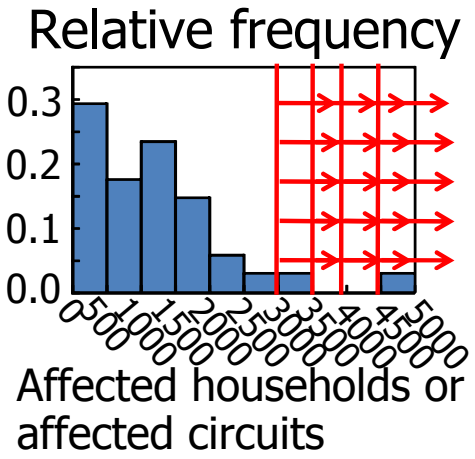
Rate of Exceeding the Given Number of the Consequences

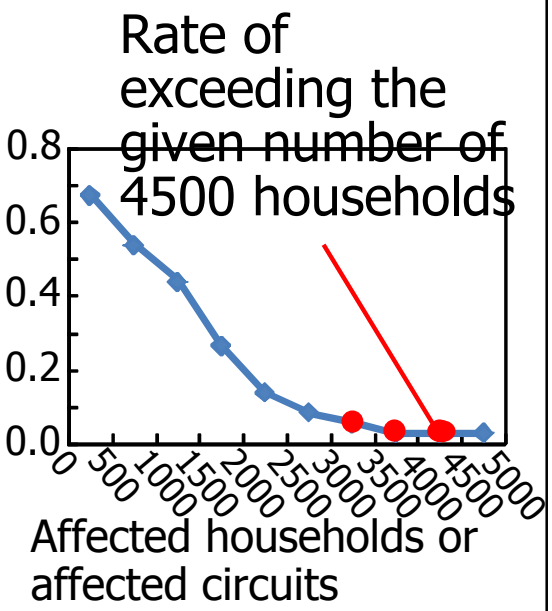
1st step: Frequency of consequences

2nd step: Relative frequency of consequences

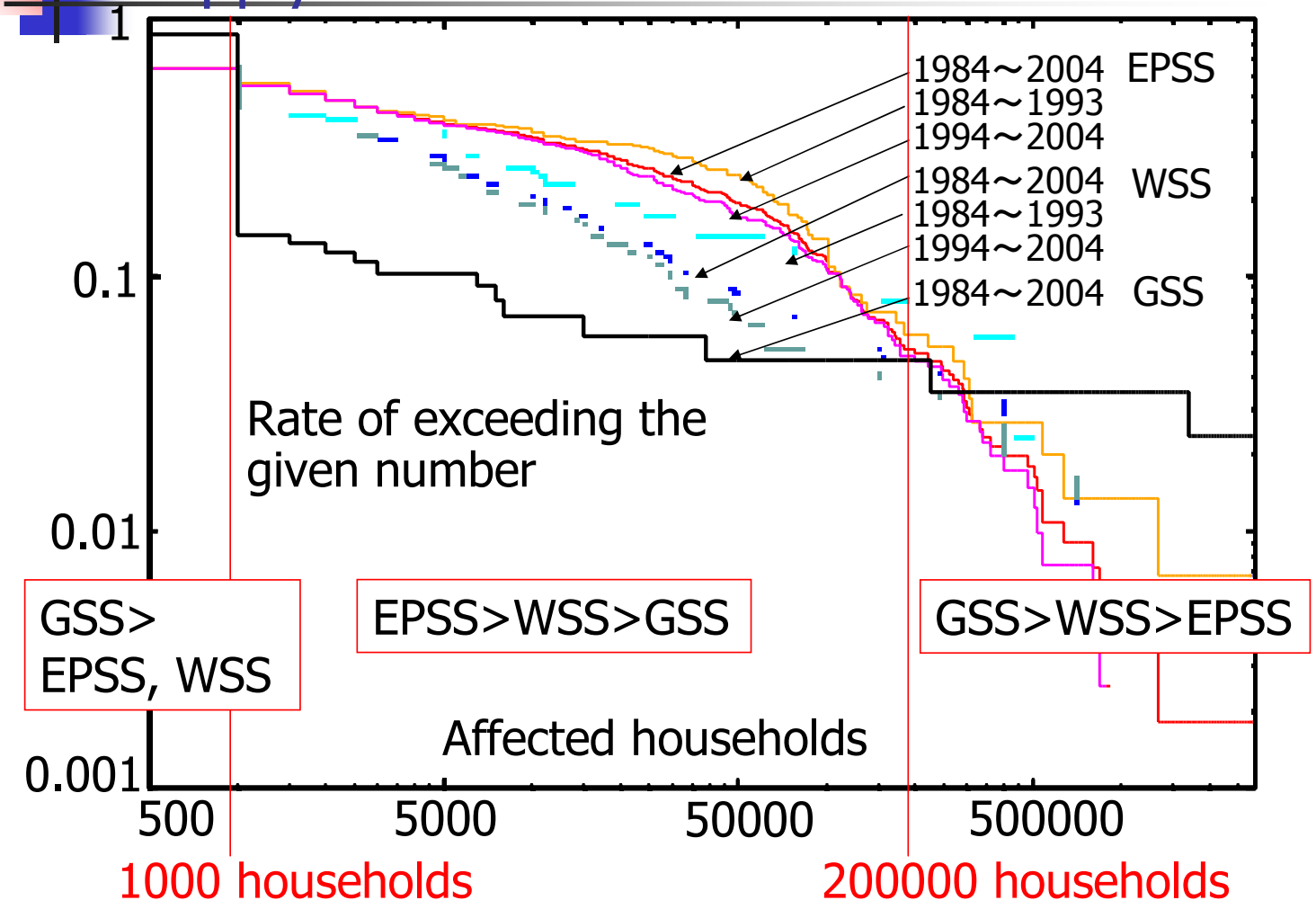
3rd step: Rate of exceeding the given number



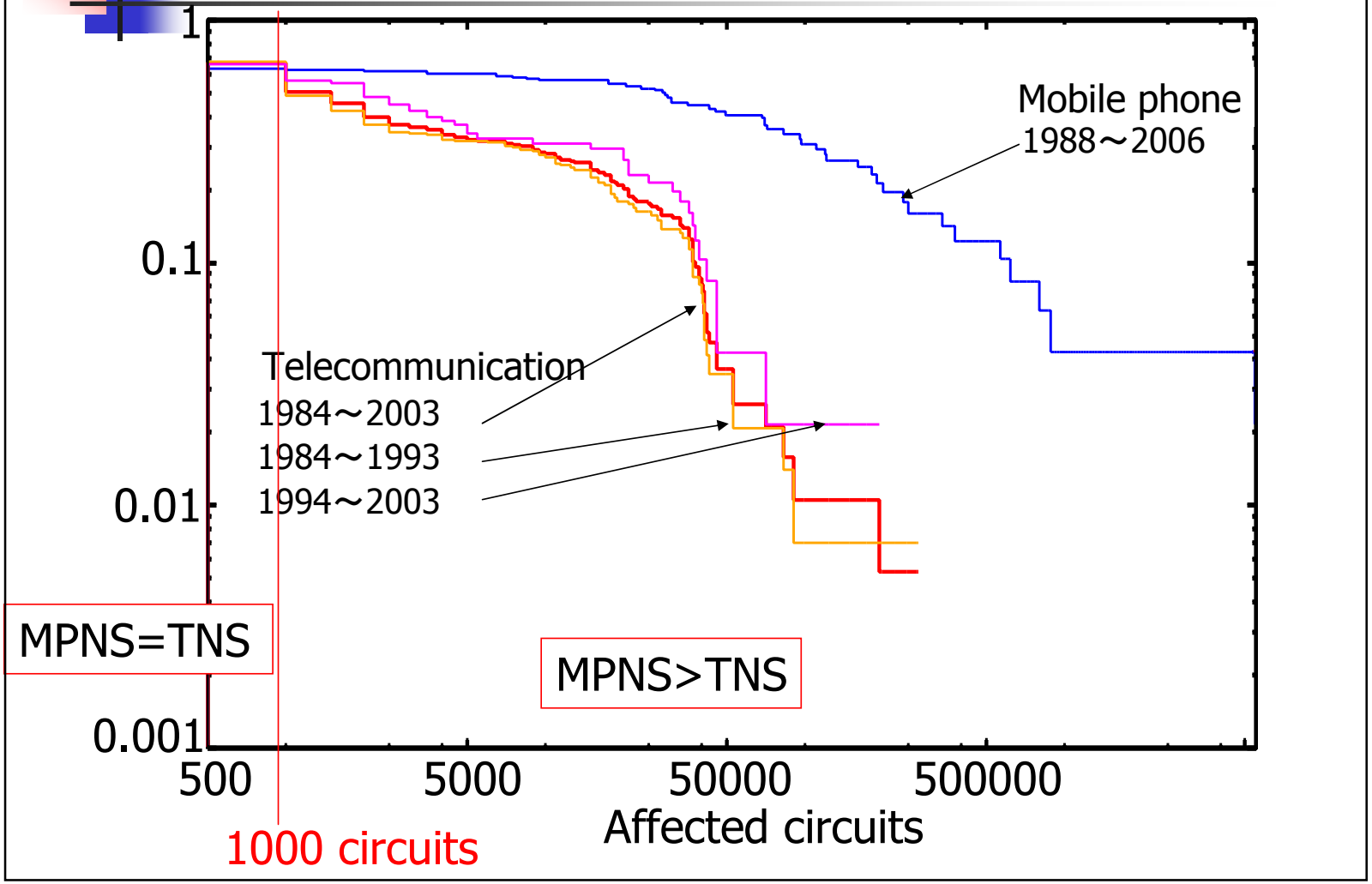




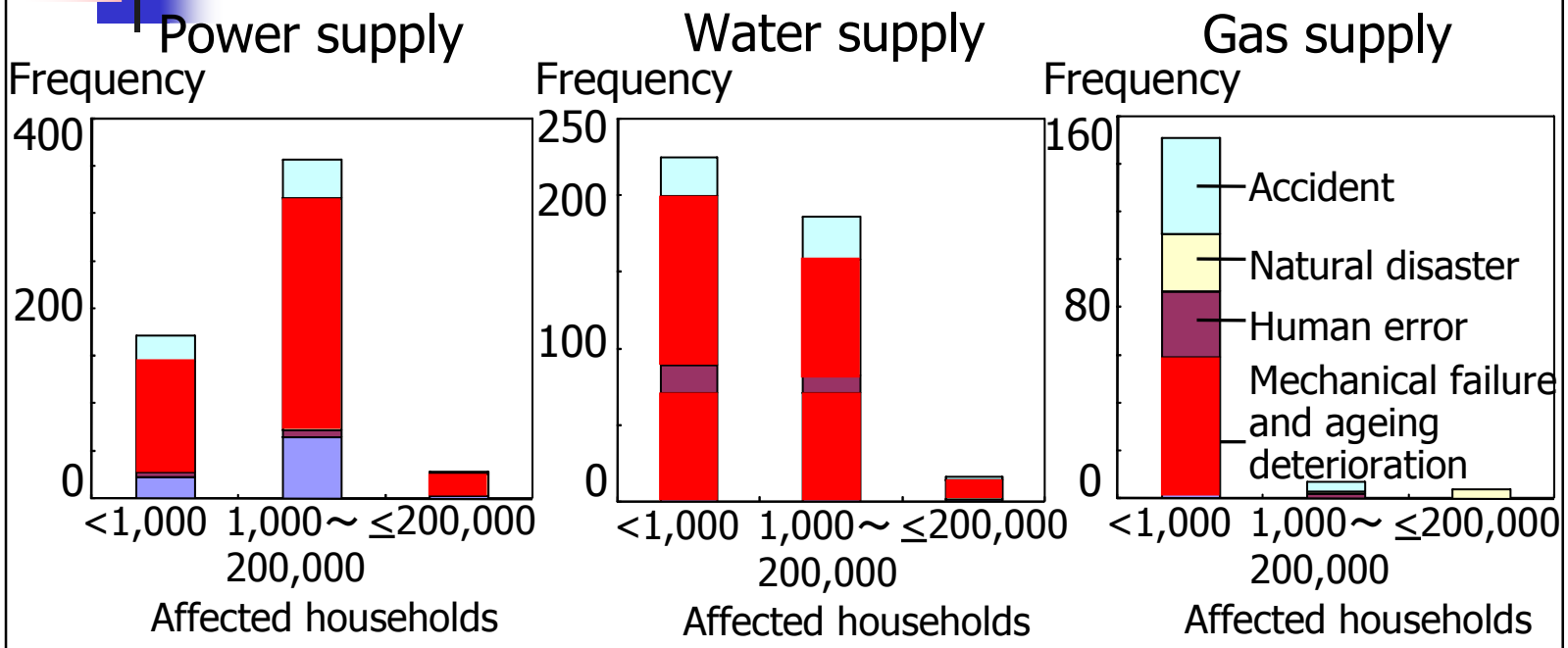
Power Supply, Water Supply and Gas Supply



Telecommunication and Mobile Phone

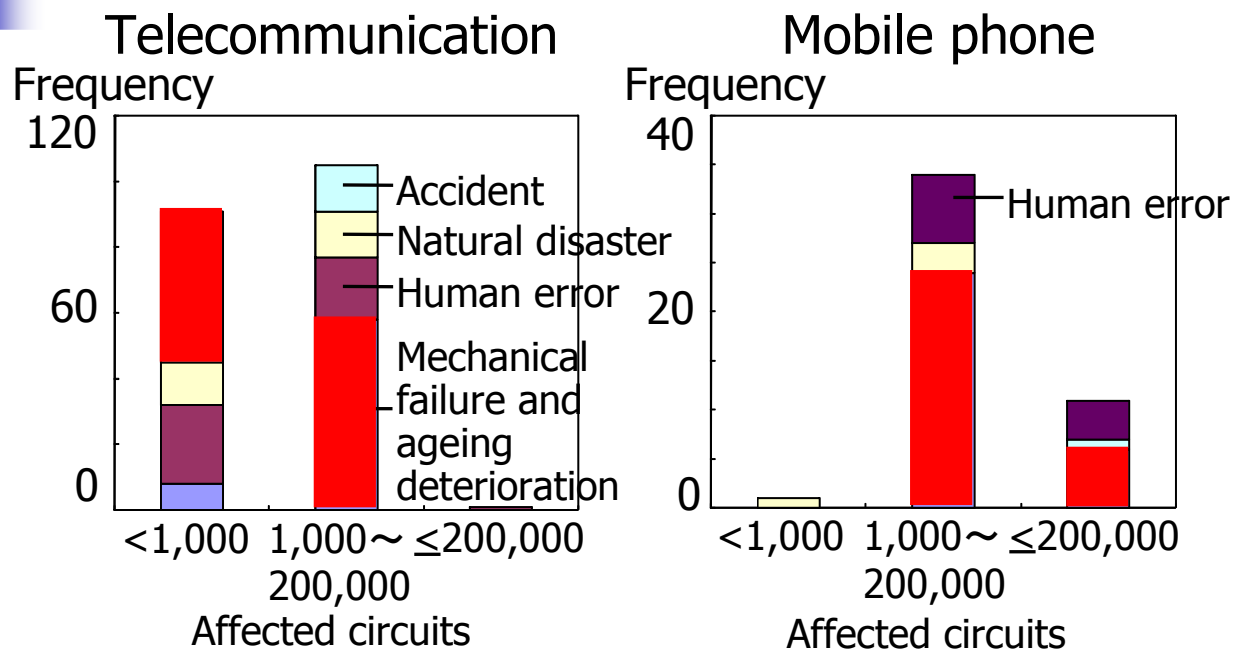


Causes of Functional Impairment



- Natural disaster causes dominantly functional impairment of EPSS and WSS, and for WSS the frequency of causes of mechanical failure and ageing deterioration becomes higher than the others.
- Frequency of causes for GSS becomes higher extremely at the interval of 1,000 lower and their dominant causes are mechanical failure and ageing deterioration, and accident.

Causes of Functional Impairment



- Accident causes dominantly functional impairment of TNS at the interval of 1,000 lower, whereas mechanical failure and ageing deterioration cause dominantly that at the interval from 1,000 to 200,000.
- Mechanical failure and ageing deterioration cause dominantly functional impairment of MPNS, and the frequency of their causes is concentrated at the interval of 1,000 higher.

Probability of Exceeding the Given Number of Consequences

- Probability p_i of occurring the given number of consequences for subject systems at an anticipated interval i

$$p_i = \frac{(\nu_i t)^{n_i}}{n_i!} e^{-\nu_i t}$$

ν_i : Average rate of occurring the given number of functional impairment induced in subject systems at an unit period

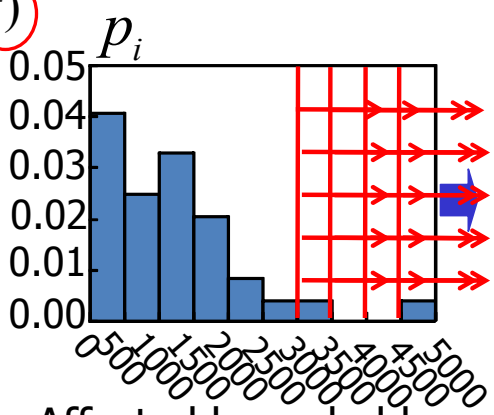
n_i : Number of functional impairment at an anticipated period t

- Redefined as probability p_i whether an associated event occurs or not at an anticipated interval t

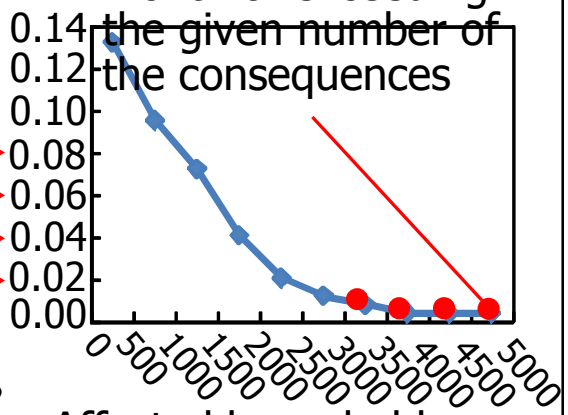
$$p_i = 1 - \exp(-\nu_i t)$$

In a month

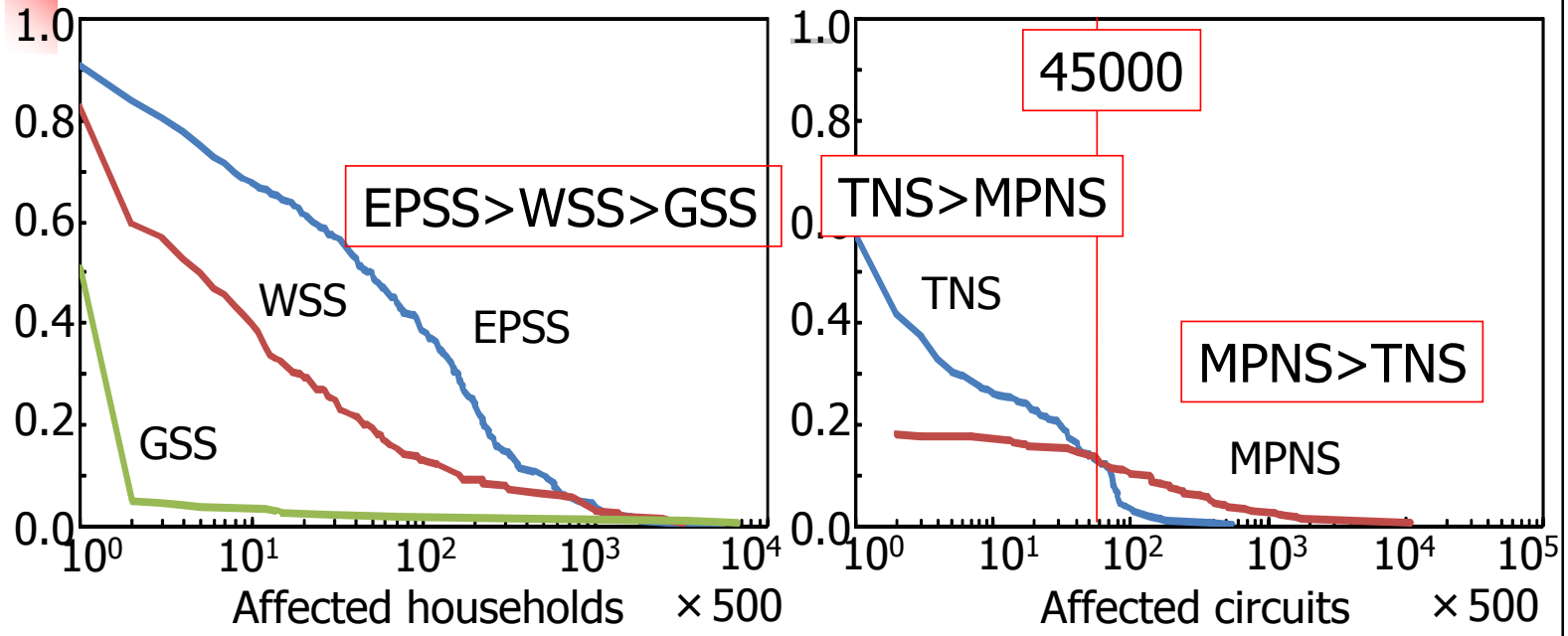
Interval i	Fq.	Average rate ν	p_i
0～500	10	0.5	0.0408
500～1000	6	0.3	0.0247
1000～1500	8	0.4	0.0328
1500～2000	5	0.25	0.0206
⋮	⋮	⋮	⋮



Probability P_i in a month of exceeding the given number of the consequences



Modeling of Risk Curves



- Probability P_M in a month of exceeding the given number D of consequences

$$P_M = \frac{\gamma \exp\{-\alpha(\log D - \beta)\}}{1 + \exp\{-\alpha(\log D - \beta)\}}$$

Parameters		α	β	γ
Power Supply	Case1	2.43	1.96	0.77
	Case2	1.91	1.88	0.84
	Case3	1.39	1.76	0.94
Water Supply		1.30	0.36	1.27
Gas Supply		6.20	-0.88	120.35
Telecommunication	Case1	1.72	0.95	0.58
	Case2	0.70	-7.11	76.70
	Case3	5.87	1.75	0.24
Mobile Phone		2.22	2.15	0.18

Conclusions

- Focusing onto functional impairment of critical infrastructure systems, their objective risks due to a disaster are clarified.
  - Electric power supply systems, EPSS
  - Water supply systems, WSS
  - Gas supply systems, GSS
  - Telecommunication network systems, TNS
  - Mobile phone network systems, MPNS

Five subject systems

- ✓ Causes of the consequence with subject systems
- ✓ Risk curves to clarify the relation between the consequence associated with subject systems and its cumulative probability

リスク受容クライテリアに関する提案モデル

既往の研究

$$p \cdot D = C_r$$

$$\longrightarrow \log p = \log C_r - \log D$$

C_r：クライテリア基準値

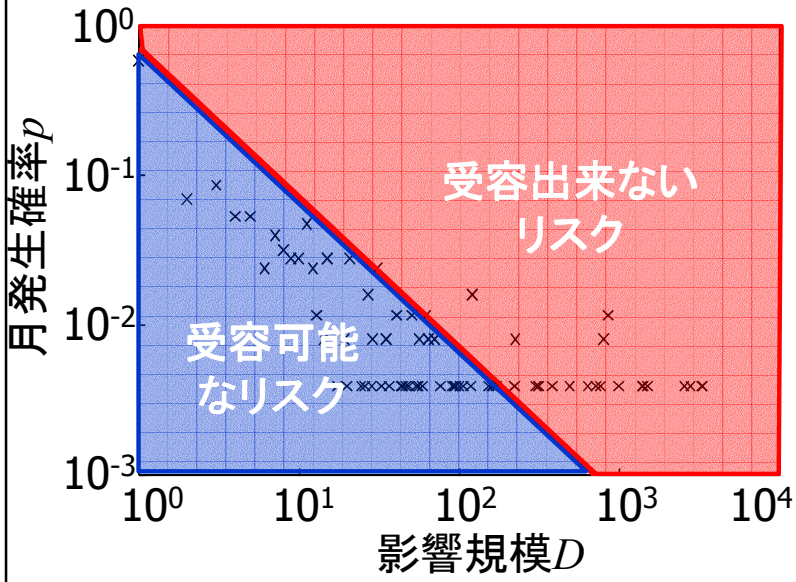
提案モデル

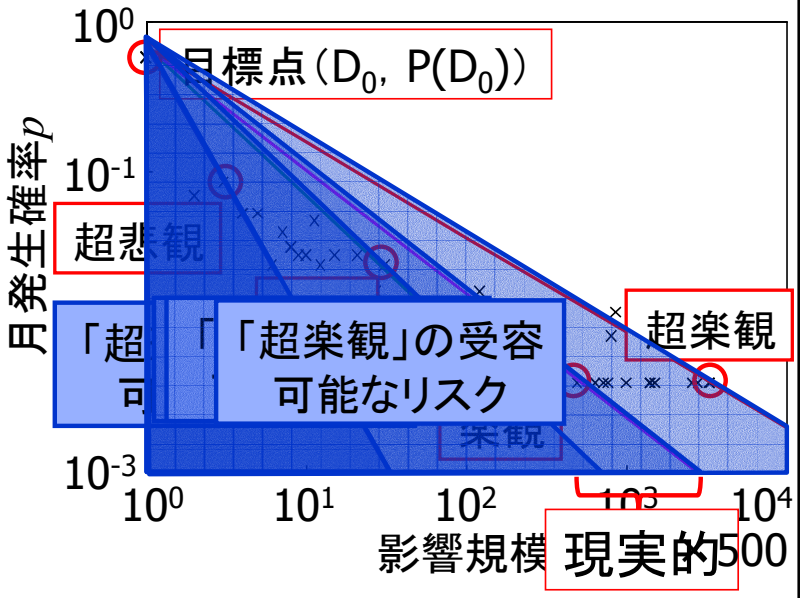
$$p^{\gamma_1} \cdot D^{\gamma_2} = C_r$$

$$\longrightarrow \log p = \frac{C_r}{\gamma_1} - \frac{\gamma_2}{\gamma_1} \log D$$

γ_1：確率の認知に関するバイアス

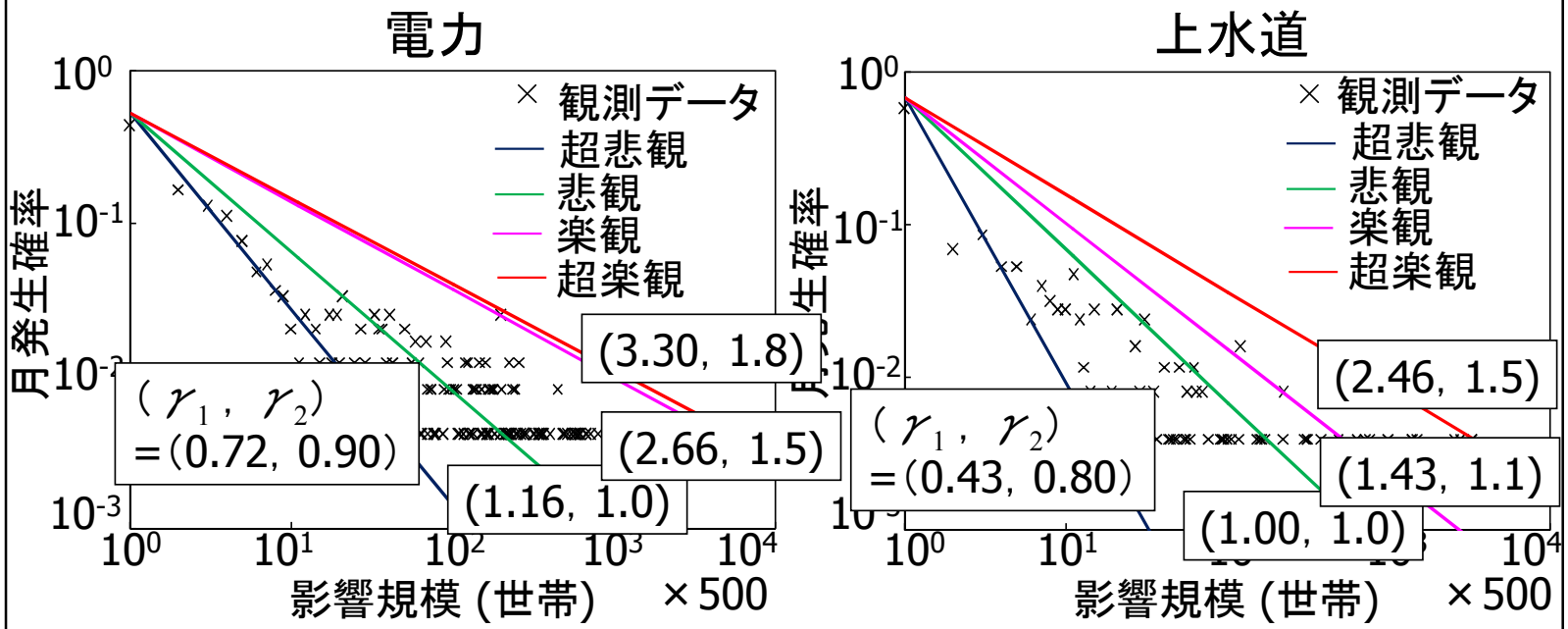
γ_2：損害の認知に関するバイアス





→システム設計者がシステム設計に還元

電力及び上水道ネットワークに関するリスク受容クライテリア



受容される観測データの割合

(%)	超悲観	悲観	楽観	超楽観
電力	9.5	45.3	99.3	100.0
上水道	5.5	68.5	80.8	98.6

リスク受容クライテリアの検討

$$\log p = \frac{C_r}{\gamma_1} - \frac{\gamma_2}{\gamma_1}\log D$$

p：月発生確率，D：影響規模
C_r：クライテリア基準値
γ_1，　γ_2：バイアスを示すパラメータ