Methods of Technical Risk Assessment in a Regional Context

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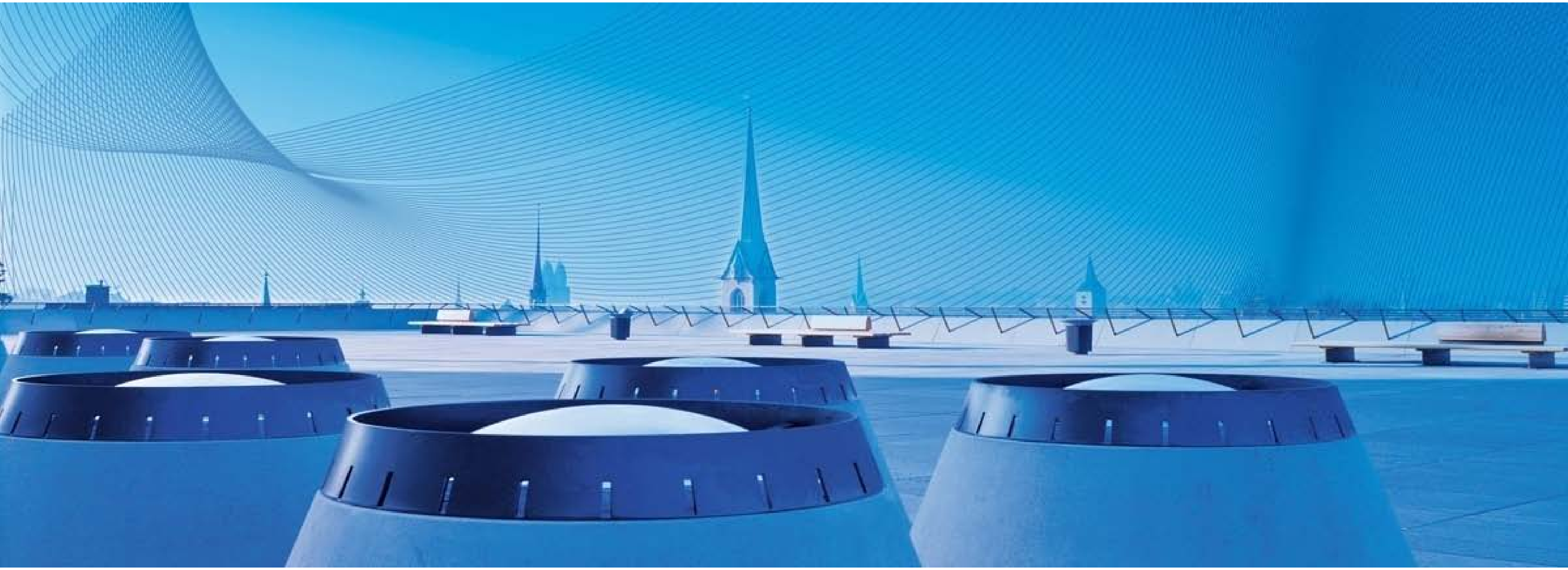


Contents

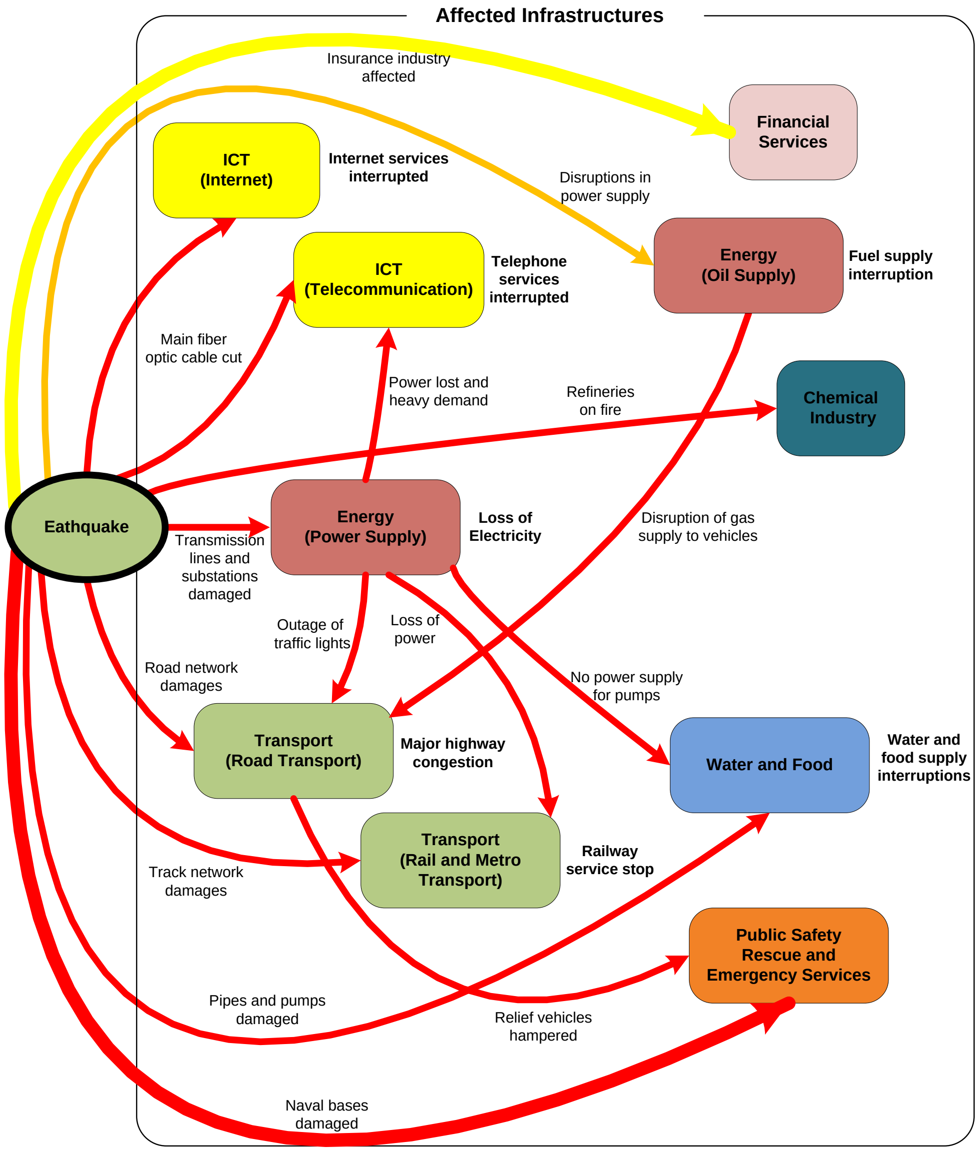
Vulnerability:

- Definition of terms
- Vulnerability model and scenarios
- Assessment models

Concept of vulnerability (Verletzbarkeit) – definition of terms (I)

Disasters in the past revealed that “hazard-centric” perception / concepts are too limited as “a hazard of low intensity could have severe consequences, while a hazard of high intensity could have negligible consequences. The level of vulnerability was making the difference” (White, 1974).

Kocaeli earthquake (August 17, 1999 - a Mw 7.4 earthquake in northwestern Turkey.)



Kocaeli earthquake - Impacts

Impact on Transportation Sector: The main motorway connecting Istanbul and Ankara suffered damages along a 50 km section. Rail lines were buckled at fault crossings but repairs were quickly effected, and rail service restored within several days.

Impact on Water and Food Sector: Local distribution systems in Gölcük, Izmit and other areas were generally not functional due to local pipe failures. Water needs of the population were being served by tanker trucks throughout the area as well as by purified water supplied by military ships. Extensive damage to the pump stations and pipelines cut the supply of water into Turkey's largest refinery that was at the same time also on fire.

Impact on ICT Sector: The main fiber optic cable between Istanbul and Ankara was cut by the fault crossing just east of Izmit and widespread usage the day after the earthquake overloaded the already damaged telephone system, causing it to fail completely. Repair was swift, however, and the link was restored within 24 hours.

Impact on the Chemical Industry: Over 1,000 individual plants were shaken, including the country's largest refinery and the seventh largest plant in Europe with an annual refined petroleum output of 270 000 m^3. The earthquake caused a collapse of a tower and a subsequent fire which burned for six days after the earthquake.

Impact on the Energy Sector: Because the country's power grid was built with redundancy in the main transmission lines, authorities were able to reroute the grid to restore power to Istanbul and other regions shortly after the earthquake. There is no domestic underground gas piping in the area and so no damages were on the gas sector.

Impact on Public Safety, Rescue and Emergency Services: There was extensive damage at the Turkey Naval Base in Gölcük, with collapsed buildings killing several hundred military personnel. Damages along a 50 km section of the Istanbul-Ankara highway hampered relief vehicles for more than a day, until the roadway was cleared and temporarily repaired.

Impact on Financial Services: The insurance industry was heavily affected. Estimates of losses are between 600 million and 2 billion USD in physical damage to insured industrial facilities and between 300 and 750 million USD for other insured risks.

Properties and characteristics of hazards

Hazard is a potential source of danger and risks

Hazard's characteristics	Description
Nature	Natural, socio-natural, technological, sociopolitical, man-made hazards
Magnitude	Only those occurrences that exceed some common level of magnitude are extreme
Location or geographical extent	Space covered by the hazardous event
Spatial dispersion	Pattern of distribution over the space in which its impact can occur
Speed of onset	Length of time between the first appearance of an event and its peak
Duration	Length of time over which a hazardous event persist, the onset to peak period
Frequency/Probability	The sequencing of events, ranging along a continuum from random to periodic.

Source: S. Bouchon, after Gravley, 2001

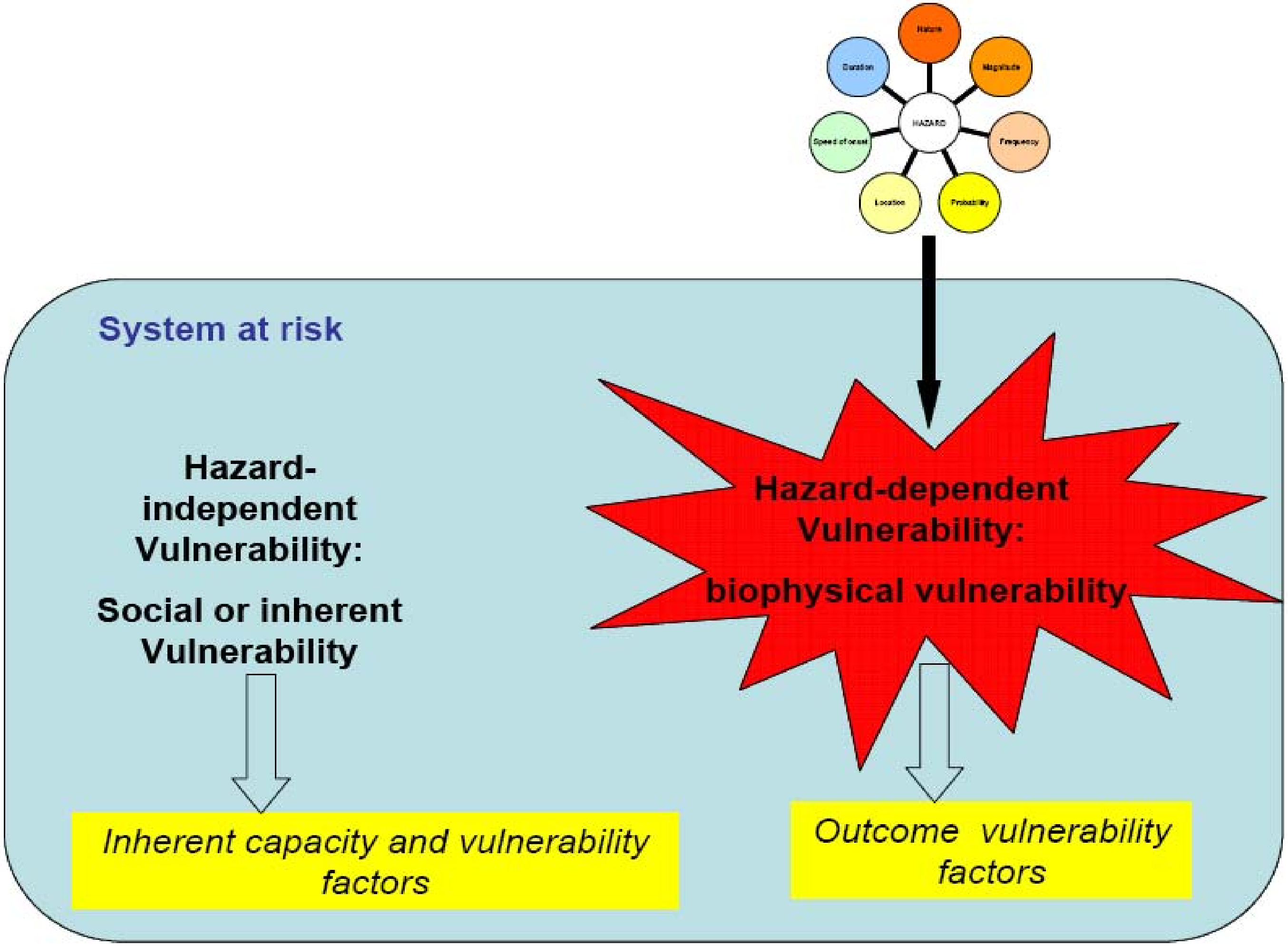
Concept of vulnerability – definition of terms (II)
No consensus definition of vulnerability to date

We define **vulnerability** as a flaw or weakness (inherent characteristic including resilience capacity) in the design, implementation, operation and/or management of an infrastructure system or its elements that renders it susceptible to destruction or incapacitation when exposed to a hazard or threat.

The concept of vulnerability develops in three main steps and finally focuses on three elements:

- degree of loss and damages due to the impact of a hazard (technical dimensions),
- degree of exposure to the hazard, i.e., likelihood of being exposed to hazards of a certain degree and the susceptibility of an element at risk to suffer loss and damages (element at risk could be a technical system),
- degree of capacity of resilience, i.e., the ability of a system to anticipate, cope with/absorb, resist and recover from the impact of a hazard (technical) or disaster (social).

Categories of vulnerability



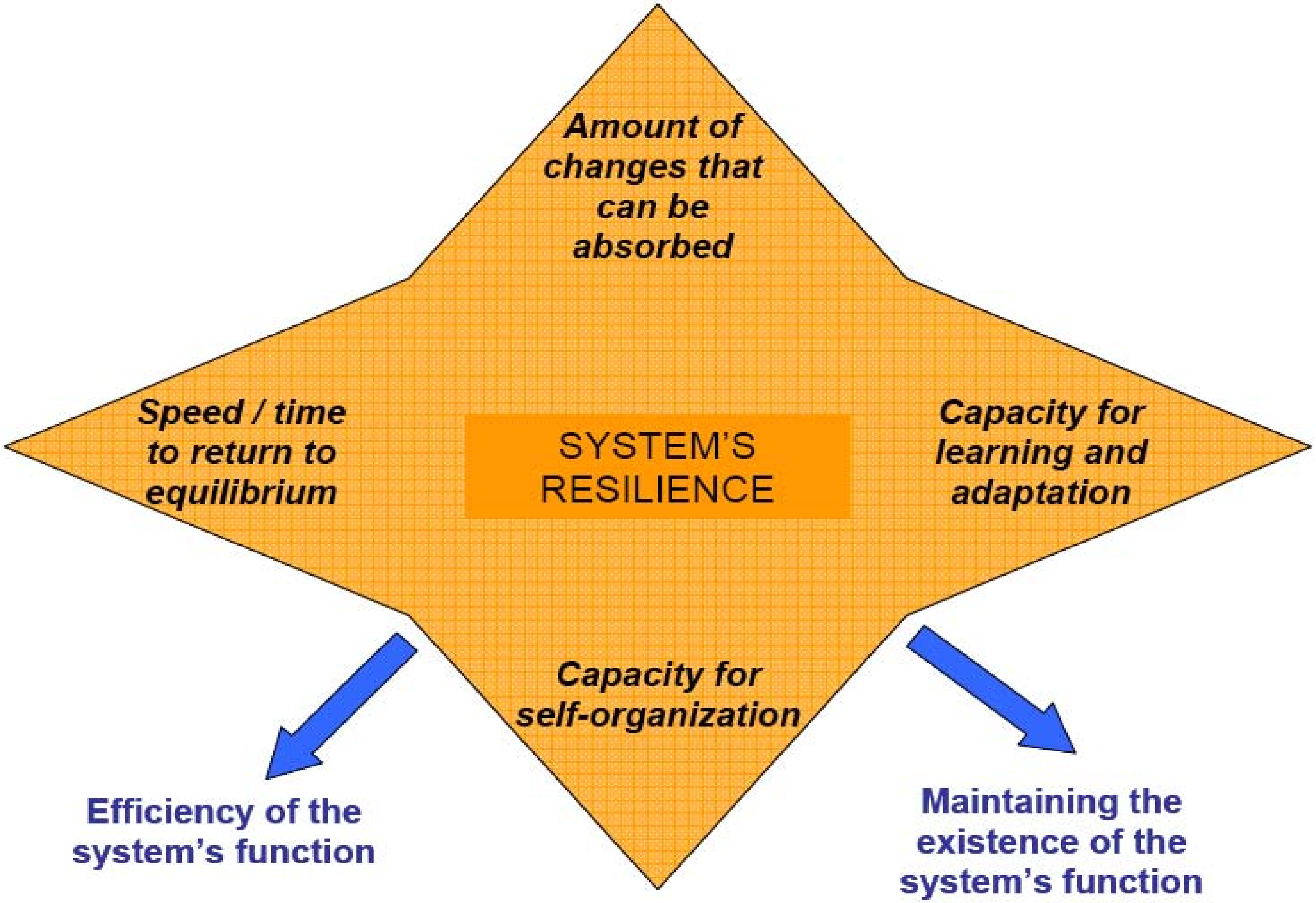
Source: S. Bouchon

Concept of vulnerability – definition of terms (III)

Distinction between two categories viewing vulnerability either

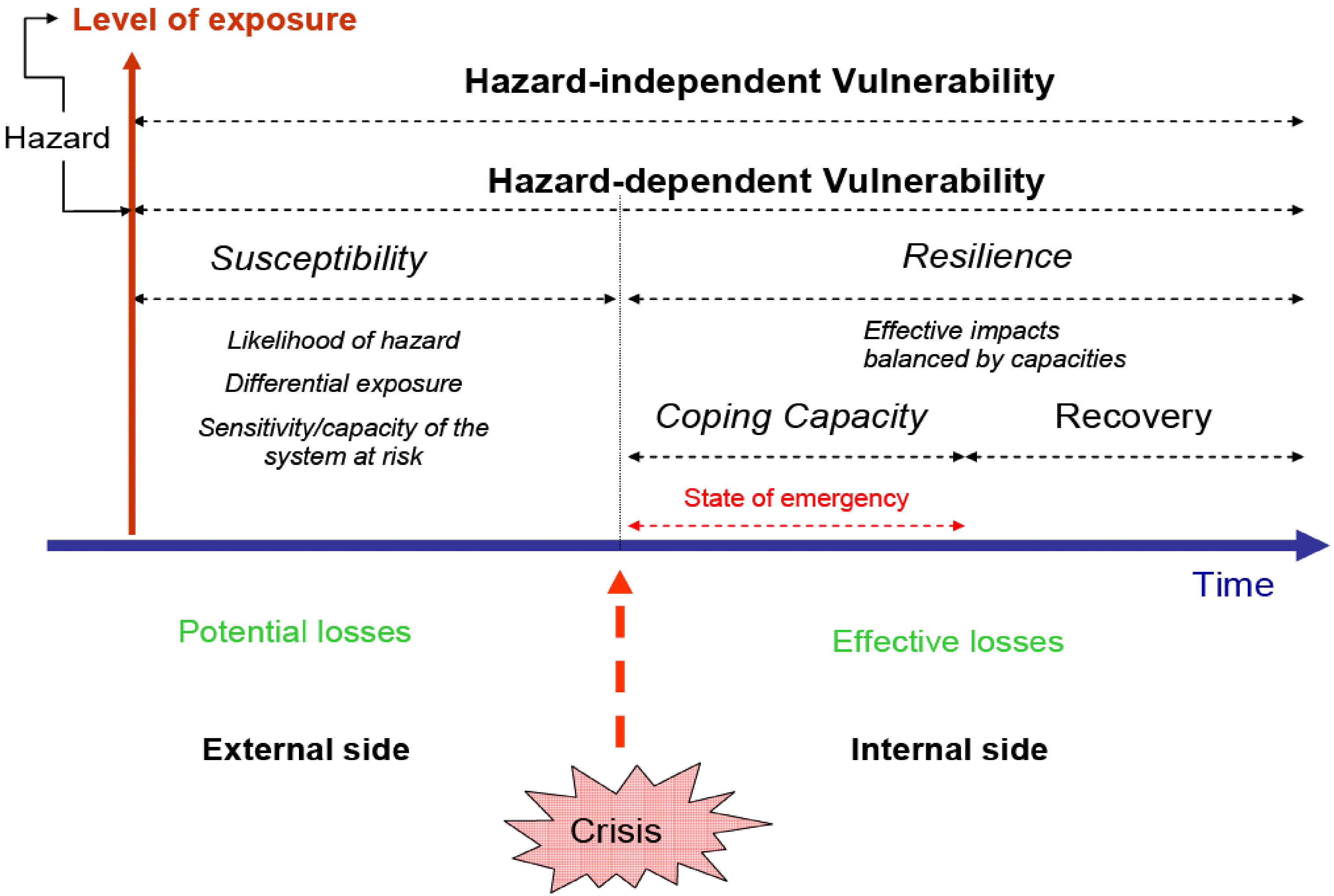
1. as the amount of (potential) damages caused to a system by a particular hazardous event (hazard dependent, biophysical vulnerability)
2. as a state that exists within a system before it encounters a particular hazardous event (hazard independent, inherent vulnerability)

Features of system's resilience



Source: S. Bouchon

Vulnerability model



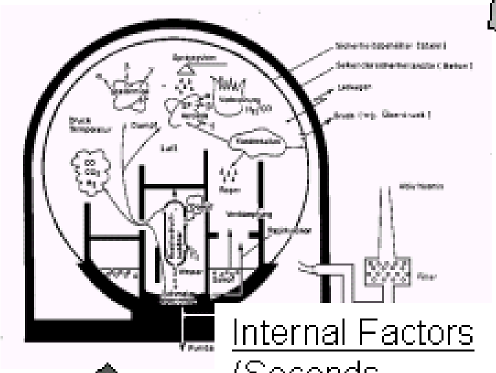
Source: S. Bouchon

Vulnerability-Technical Example

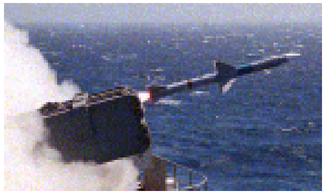
External Threats

Short Distance Threat
(700 km/h)

Short or Long Distance Threat / Intentional Software Attack (Speed of Light)



Internal Factors
(Seconds, Minutes, Hours)



Long Distance Threat
(10 m/s)

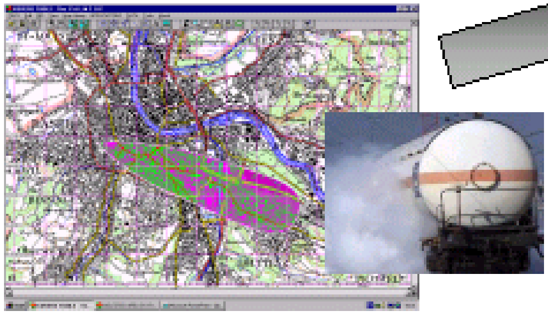
Earthquake

- Information gathering
- Beyond the existing experience
- Intentional attack (sabotage and /or war)

Vulnerability-Societal Example

Intentional Attack (Cargo Airplane)

External Threats



Accidental Situation
(Transportation Dangerous Goods)

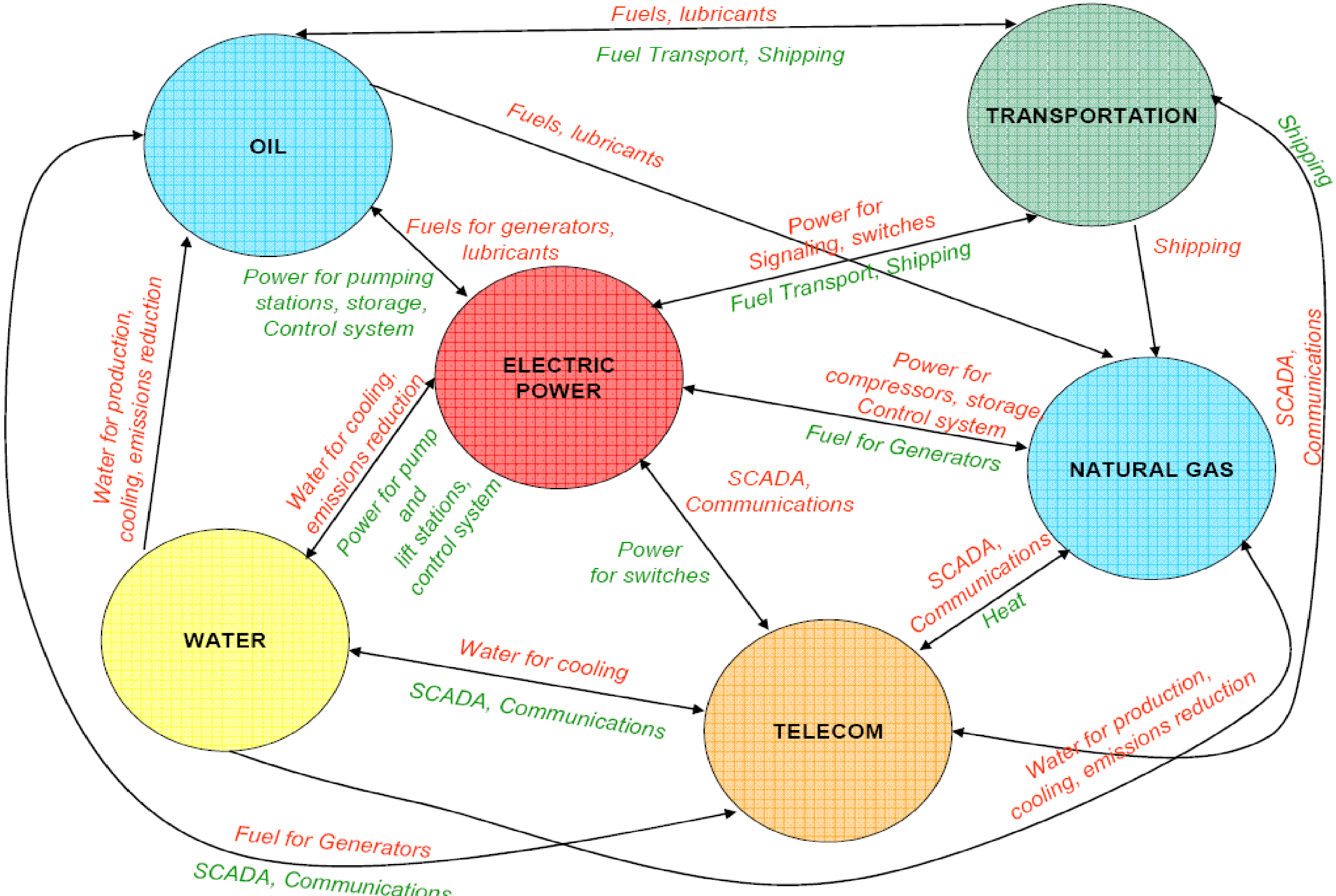
Internal Factors

- Technical Failure
- Panic
- Un-managed police intervention
- Weak management of the establishment

Congested and/or crowded areas

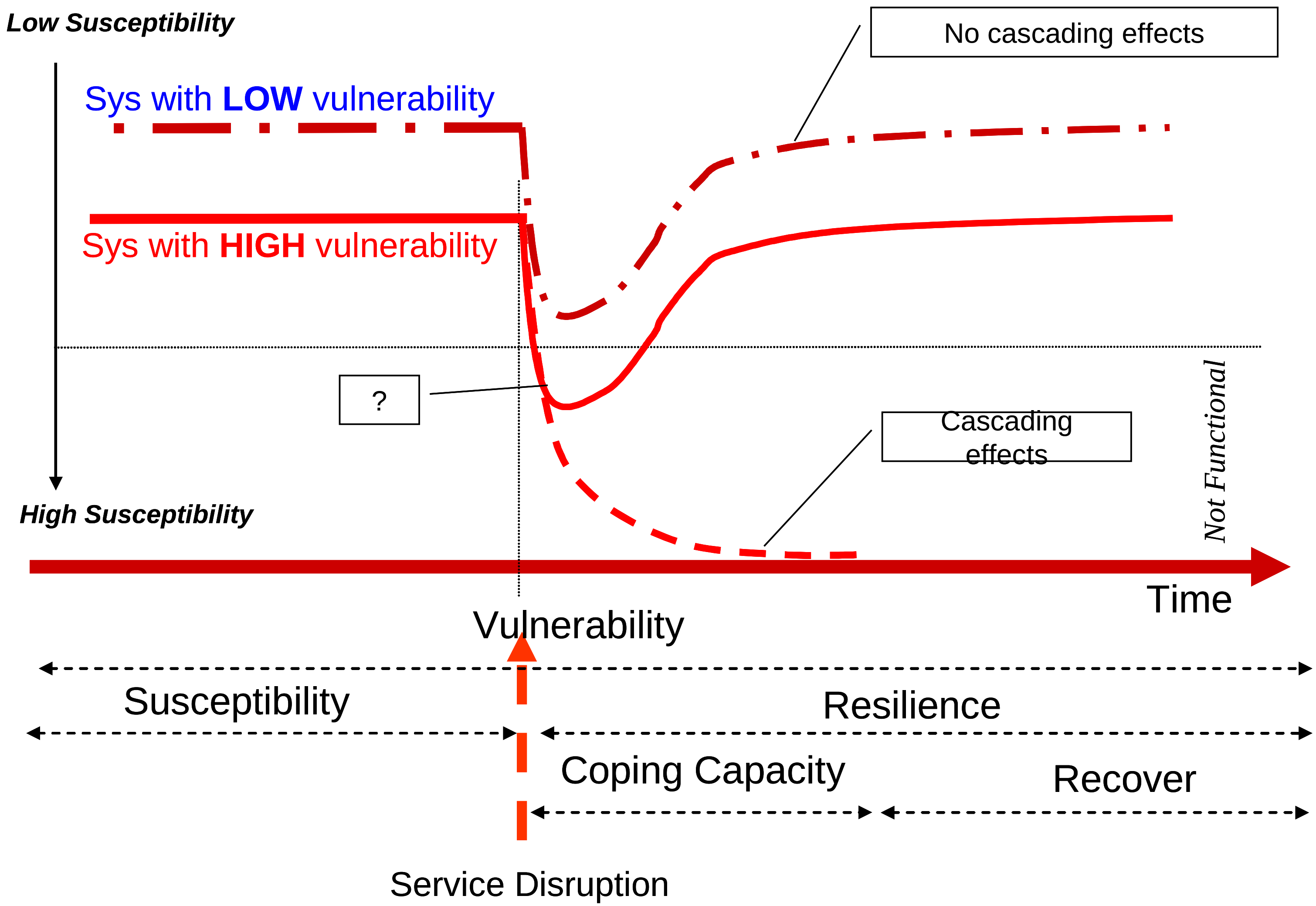
Vulnerability Assessment

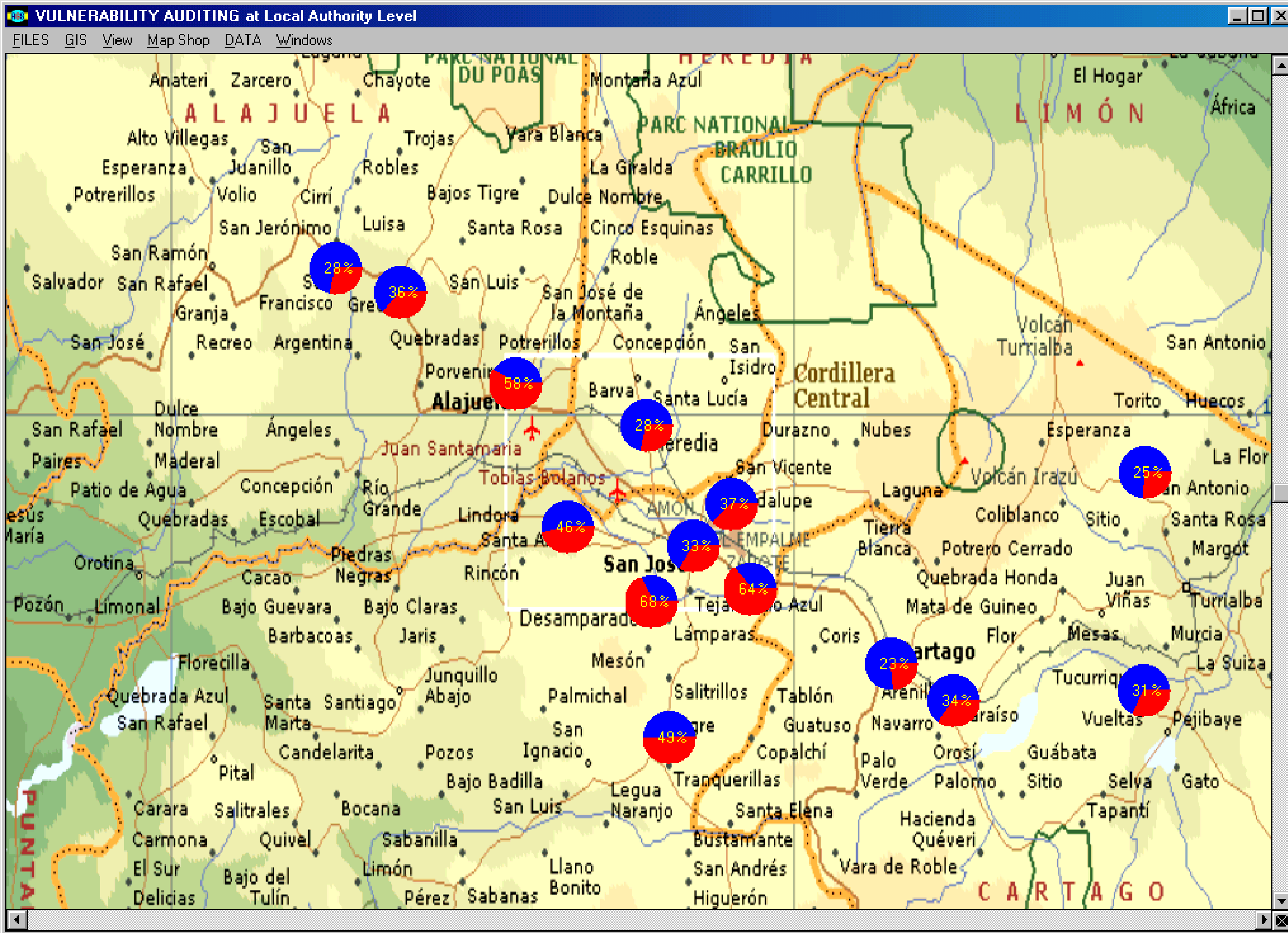
Critical infrastructures and their interdependencies

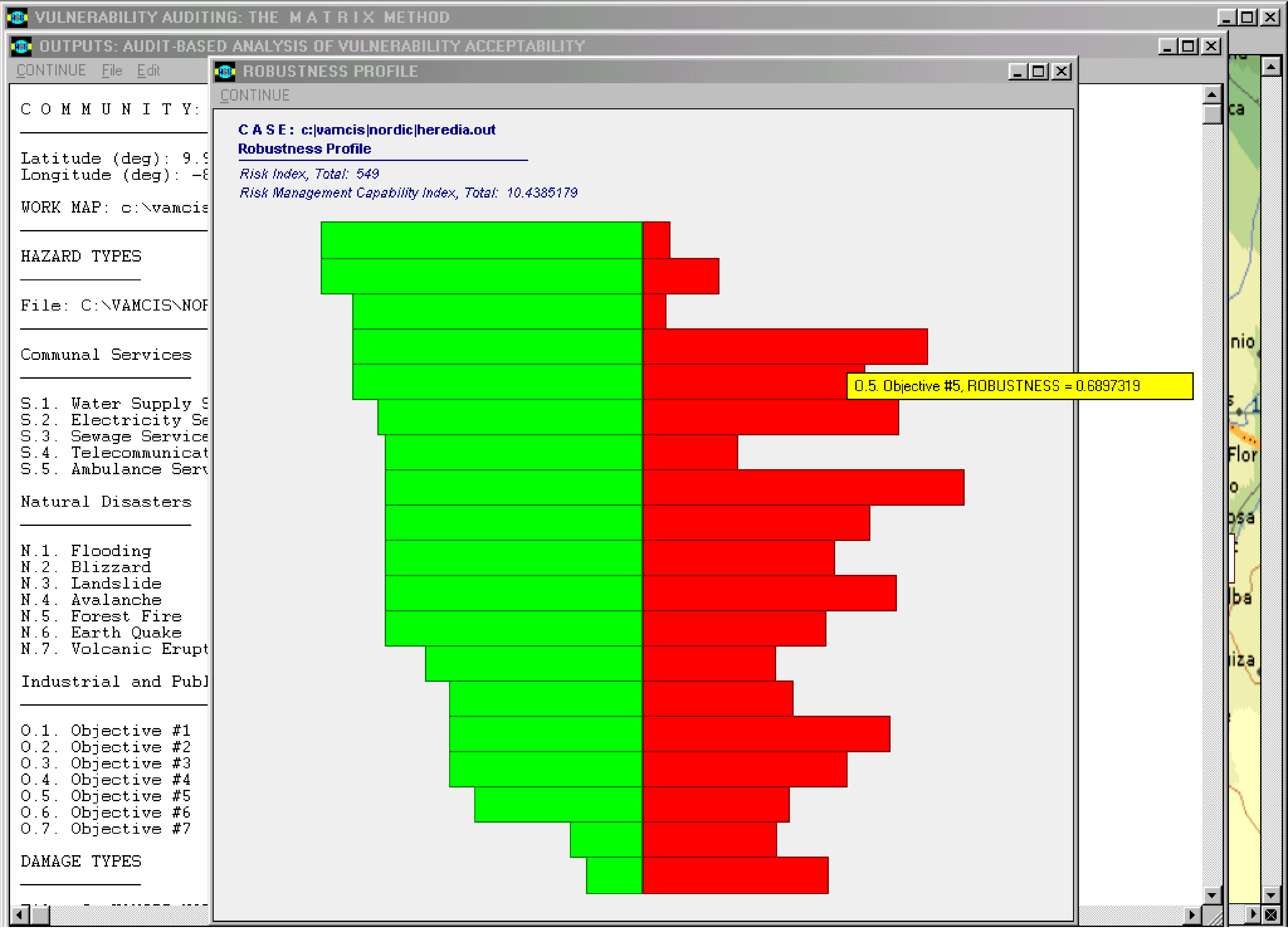


Source: Rinaldi, Peerenboom, Kelly, 2001

Vulnerability scenarios




VULNERABILITY AUDITING at Local Authority Level
FILES GIS View Map Shop DATA Windows
ALAJUELA
HEREDIA
LIMÓN
CARTAGO
PARC NATIONAL DU POAS
PARC NATIONAL BRAULIO CARRILLO
Cordillera Central
Volcán Turrialba
Volcán Irazú
Juan Santamaria
Tobías Bolanos
Alajuela
Heredia
San José
Desamparados
28 %
36 %
58 %
28 %
37 %
46 %
33 %
64 %
68 %
49 %
23 %
34 %
25 %
31 %
Anateri
Zarcero
Chayote
Montaña Azul
El Hogar
África
Alto Villegas
San Juanillo
Trojas
Vara Blanca
Esperanza
Robles
La Giralda
Potrerillos
Volio
Cirrí
Bajos Tigre
Dulce Nombre
San Jerónimo
Luisa
Santa Rosa
Cinco Esquinas
Roble
San Ramón
Salvador
San Rafael
San Luis
San José de la Montaña
Ángeles
Granja
Francisco
Recreo
Argentina
Quebradas
Potrerillos
Concepción
San Isidro
San Antonio
Porvenir
Barva
Santa Lucía
Torito
Huecos
Dulce Nombre
Durazno
Nubes
Esperanza
La Flor
Paires
Maderal
San Vicente
Patio de Agua
Concepción
Río Grande
Laguna
Coliblanco
Sitio
Santa Rosa
Quebradas
Escobal
Lindora
Tierra Blanca
Potrero Cerrado
Margot
Orotina
Piedras Negras
Rincón
Cacao
Quebrada Honda
Juan Viñas
Turrialba
Pozón
Limonal
Bajo Guevara
Bajo Claras
Mata de Guineo
Barbacoas
Jaris
Lámparas
Coris
Flor
Mesas
Murcia
Florecilla
Junquillo Abajo
Mesón
La Suiza
Quebrada Azul
Santa Marta
Santiago
Palmichal
Salitrillos
Tablón
Tucurrique
San Rafael
San Ignacio
Guatuso
Navarro
Vueltas
Pejibaye
Candelarita
Pozos
Copalchí
Palo Verde
Orosi
Guábata
Pital
Bajo Badilla
Tranquerillas
Palomo
Sitio
Selva
Gato
Carara
Salitrales
Bocana
San Luis
Legua Naranjo
Santa Elena
Tapantí
Carmona
Quivel
Sabanilla
Bustamante
Hacienda Quéveri
El Sur
Bajo del Tulín
Limón
Llano Bonito
San Andrés
Vara de Roble
Delicias
Pérez
Sabanas
Higuerón


VULNERABILITY AUDITING: THE M A T R I X METHOD
OUTPUTS: AUDIT-BASED ANALYSIS OF VULNERABILITY ACCEPTABILITY
CONTINUE File Edit
C O M M U N I T Y:
Latitude (deg): 9.9
Longitude (deg): -8
WORK MAP: c:\vamcis
HAZARD TYPES
File: C:\VAMCIS\NOR
Communal Services
S.1. Water Supply S
S.2. Electricity Se
S.3. Sewage Service
S.4. Telecommunicat
S.5. Ambulance Serv
Natural Disasters
N.1. Flooding
N.2. Blizzard
N.3. Landslide
N.4. Avalanche
N.5. Forest Fire
N.6. Earth Quake
N.7. Volcanic Erupt
Industrial and Publ
O.1. Objective #1
O.2. Objective #2
O.3. Objective #3
O.4. Objective #4
O.5. Objective #5
O.6. Objective #6
O.7. Objective #7
DAMAGE TYPES
ROBUSTNESS PROFILE
CONTINUE
C A S E: c:|vamcis|nordic|heredia.out
Robustness Profile
Risk Index, Total: 549
Risk Management Capability Index, Total: 10.4385179
O.5. Objective #5, ROBUSTNESS = 0.6897319

Multicomponents System's Vulnerability – Representation by U, V, t, modeling approach

- **System**
  - consists of a large number, ***M***, of elemental constituents, or members
- **System members**
  - interact with each other with a varying intensity; interaction described by a coupling constant, or intrinsic parameter ***U***, and an exterior factor, or extrinsic parameter ***V***.
  - may assume two distinct states, 1 and 2, normal vs. abnormal, up vs. down, etc., at given time, t
- **Overall state of the system**
  - described via a pair of numbers (M_1, M_2); system dynamics, or motion in its space will follow from variations in M_1 and M_2.

Multicomponents System's Vulnerability (I) (1/2)

Smallest transitions in the system's state involve alterations by one unit in the numbers of members:

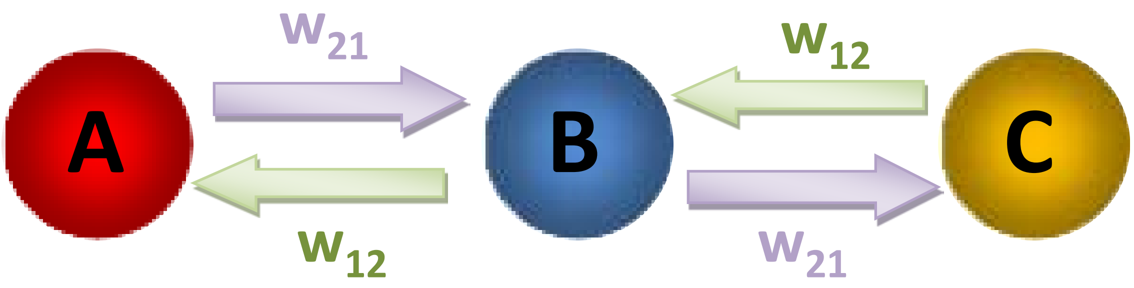
$$(M_1 - 1, M_2 + 1) \underset{w_{21} \rightarrow}{\overset{\leftarrow w_{12}}{\rule{2cm}{0.4pt}}} (M_1, M_2) \underset{\leftarrow w_{12}}{\overset{w_{21} \rightarrow}{\rule{2cm}{0.4pt}}} (M_1 + 1, M_2 - 1) \qquad (1)$$

while w_{12} and w_{21} are governing probabilities.

Let: (M_1-1,M2+1) , be state **A**
(M1,M2), be state **B**
(M1+1,M2-1), be state **C**

Multicomponents System's Vulnerability (I) (2/2)

Admission of the process leads also to the recognition of a function of distribution of the system's states:



$$\frac{\vartheta f(B,t)}{\vartheta t} = W_{21}(A)\cdot f(A) + w_{12}(C)\cdot f(C) - [w_{21}(B) + w_{12}(B)]\cdot f(B) \quad (2)$$

Multicomponents System's Vulnerability (II)

The state (M1, M2) of the system can alternatively be described by the membership fraction

$$\zeta = (M_1 - M_2) \,/\, (2M), \qquad (3)$$

if all system members are in state 1, then $\zeta = ½$, whereas if all members are in state 2, then $\zeta = -½$.

Equation (2) may be re-written as:

$$\frac{\vartheta f(\zeta)}{\vartheta t} = W_{21}\left(\zeta - \frac{1}{M}\right) \cdot f\left(\zeta - \frac{1}{M}\right) + w_{12}\left(\zeta + \frac{1}{M}\right) \cdot f\left(\zeta + \frac{1}{M}\right) - [w_{21}(\zeta) + w_{12}(\zeta)] \cdot f(\zeta) \qquad (4)$$

Multicomponents System's Vulnerability (III)

Transition probabilities w_{12} and w_{21} need to be assumed, e.g. if transitions are a co-operative phenomenon

$$\mathbf{w_{12}(\zeta) = w \cdot M_1 \cdot exp\left(\frac{-U \cdot \zeta + V}{\theta}\right)}$$

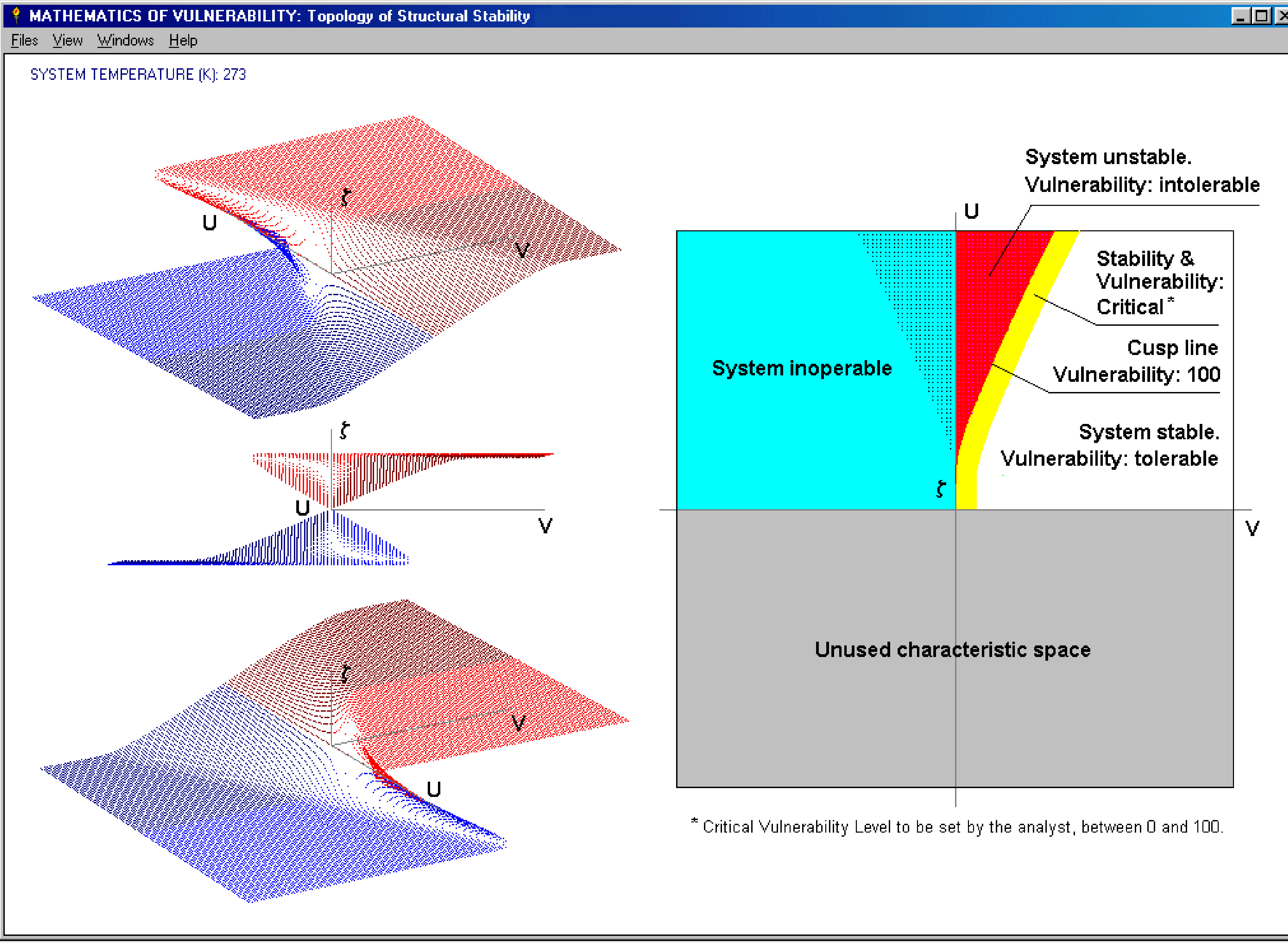
$$\mathbf{w_{21}(\zeta) = w \cdot M_2 \cdot exp\left(\frac{U \cdot \zeta + V}{\theta}\right)} \qquad (5)$$

, where $\boldsymbol{\theta}$ is the generalised 'temperature' of the system

Real solutions ζ

Depending on the degree of interaction between system constituents (members), reflected in the coupling constant U, and on the external influence on all system members - reflected in the field V, and also taking into consideration the temperature θ of the system, the equation may display the following number of real solutions ζ that may relate to the overall system condition:

Number of Real Solutions	System Condition
1	Stable. Smooth transitions in population membership, between state 1 and state 2. **Low and/or acceptable vulnerability.**
3, of which 2 identical	Critical. Sharp transitions in membership between states 1 and 2 are possible. Either state 1 or state 2 may suddenly become improbable. **System is critically vulnerable.**
3, all different from each other	Unstable. Sharp transitions in membership between states 1 and 2 are possible. Frequency of occurrence of states 1 and 2 are comparable. **System is dangerously/ un-acceptably vulnerable.**


MATHEMATICS OF VULNERABILITY: Topology of Structural Stability
Files View Windows Help
SYSTEM TEMPERATURE (K): 273
U
V
ζ
System unstable.
Vulnerability: intolerable
Stability &
Vulnerability:
Critical *
Cusp line
Vulnerability: 100
System stable.
Vulnerability: tolerable
System inoperable
Unused characteristic space
* Critical Vulnerability Level to be set by the analyst, between 0 and 100.

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Course material:

http://www.lsa.ethz.ch/education/vorl