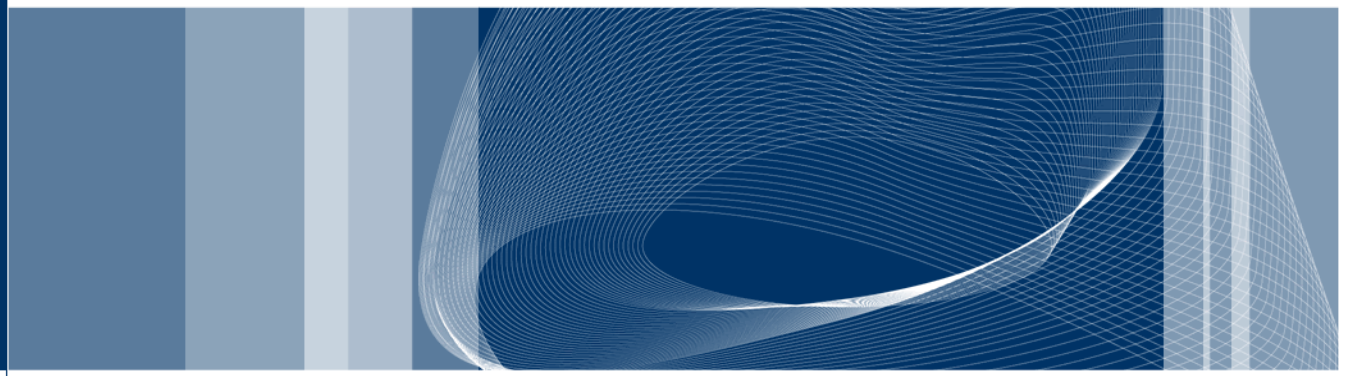
POLITECNICO DI MILANO

9th International
Probabilistic Safety Assessment and Management (PSAM)
Conference

18-23 May 2008 ✷ Hong Kong ✷ China



Resilience Analysis of Civil Defense Organization with Fuzzy Cognitive Maps

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Agenda

1. Resilience in complex socio-technical systems
2. Application of Fuzzy Cognitive Maps to resilience analysis
   - FCM features
   - Static and dynamic analysis
   - Steps of the proposed method
3. Modelling of Civil Defence System with FCM
4. Identification of critical functions and factors
5. Resilience analysis of the First Emergency Response
6. Discussion and future developments

1 Resilience in complex socio-technical systems

- Resilience Engineering represents a new way of thinking about safety

- How to evaluate resilience of **complex socio-technical systems**?
  - Multi-actor and complex organisations
  - Dependencies made of several “soft” factors and interactions
  - Chronic lack of data and direct observations (unique events)

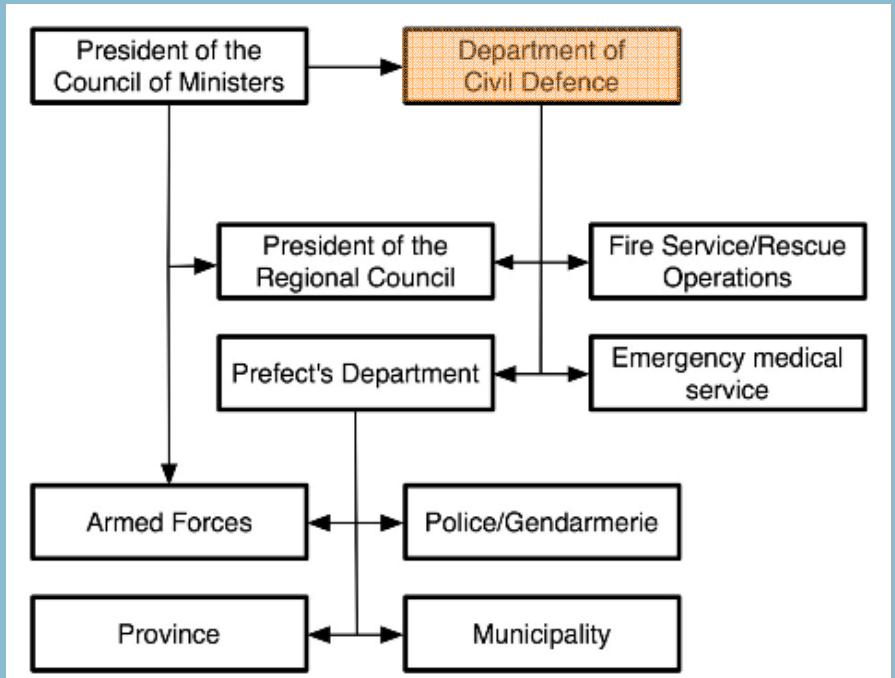
- Resilience in **Social-Ecological Systems** (Holling, 1973; Walker et al., 2004):

  “is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes. A resilient ecosystem can withstand shocks and rebuild itself when necessary”

  as applied to integrated systems has three characteristics
  - The **amount of change** the system can undergo
  - The **self-organization** capability of the system
  - The **capacity for learning and adaptation**

1 The case of Civil defence organizations: actors & functions in the Italian system

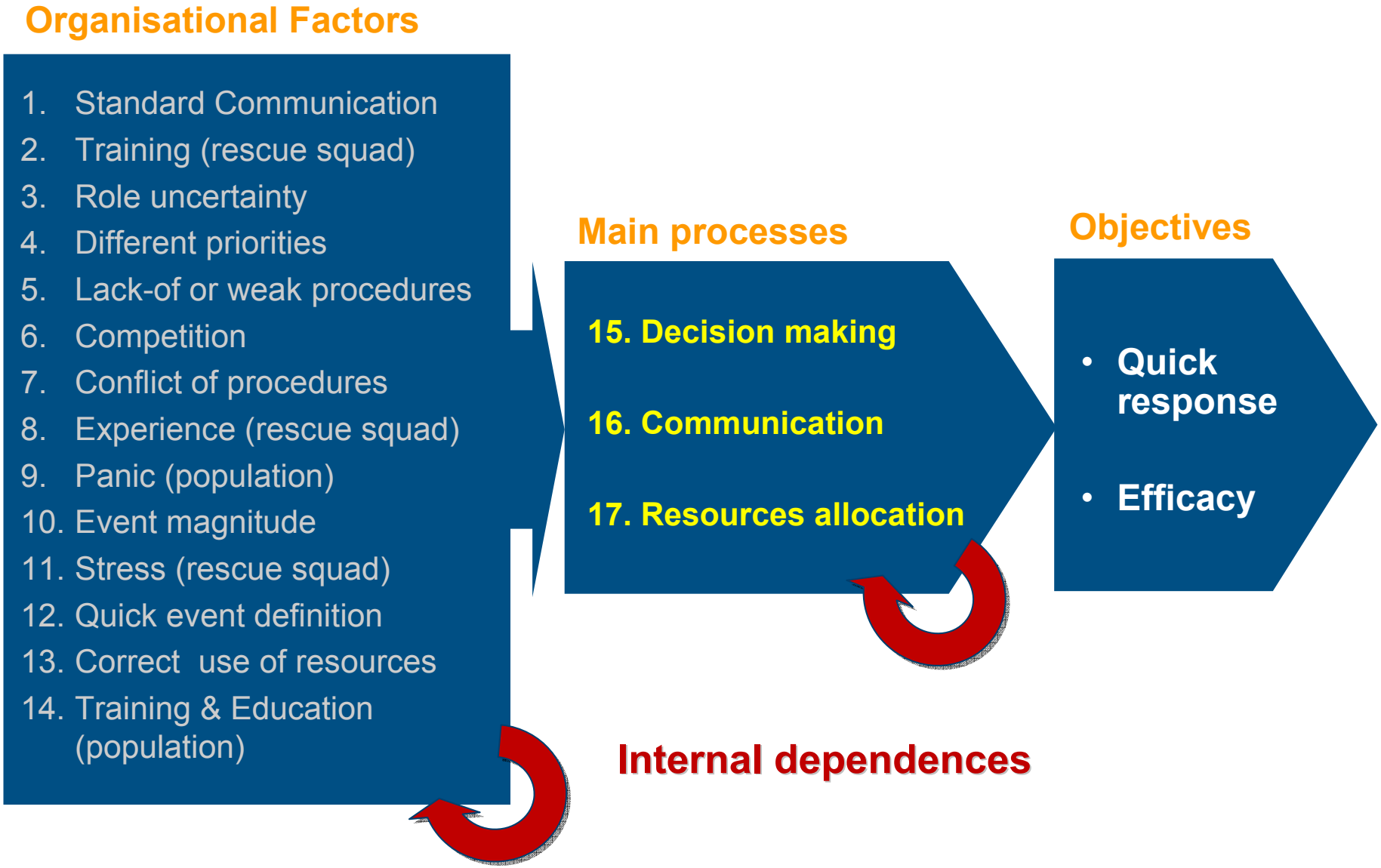
Schematic representation of the socio-technical system:



Main functions during the First Emergency Response (Incident Command System scheme):

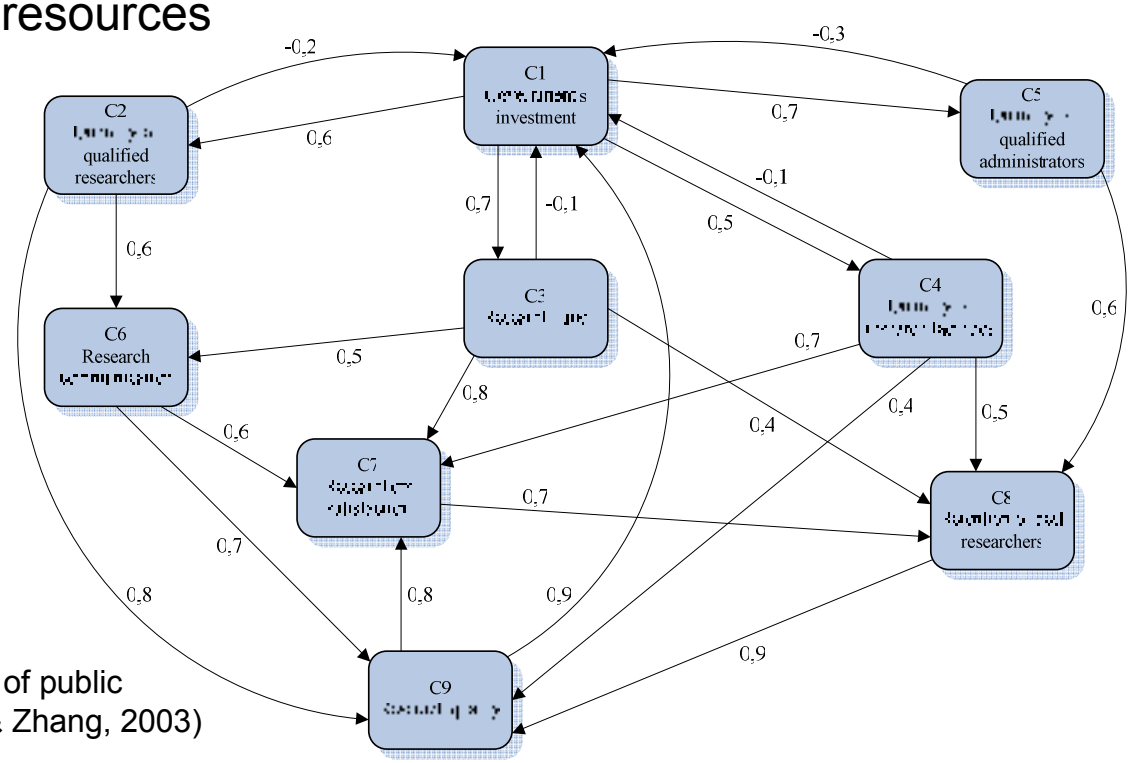
- Safety (Fire Service/ Armed Forces/ Police/ Em.med. service)
- Information (Dept of CD/ Prefect/…)
- Liaison (President/ Dept of CD/…)
- Operations (Fire Service)
- Planning (Dept of CD)
- Logistics (Dept of CD/ Fire Service)
- Finance & Administration (President/ Dept of CD/ Region/…)

1 Goals and main processes of the First Emergency Response (FER)



2 Fuzzy Cognitive Maps

- A **Cognitive Map** is a *signed directed graph* (Axelrod, 1976) used to represent the causal relations (*signed edges*) among concepts (*nodes*)
- **FCM** (Kosko, 1986) is a cognitive map which can be processed based on fuzzy logic
- Main areas of application are:
  - Scenario analysis and Decision Making
  - Management of human resources
  - Process control
  - **FER Management** (Tegarden, 2003; Monmonier, 1997)
  - **FER Training** (Alexander, 2004)

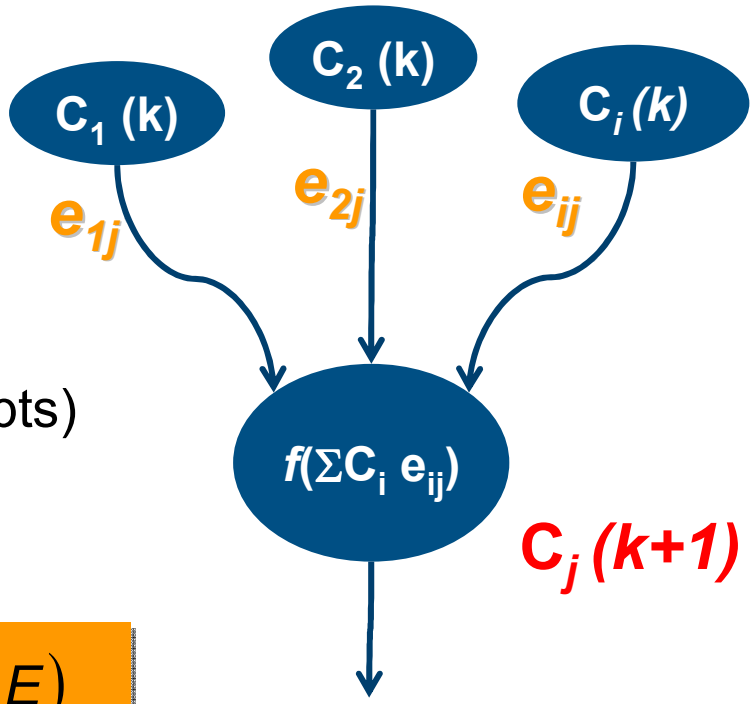


FCM for the evaluation of public research policies (Liu & Zhang, 2003)

2 Fuzzy Cognitive Maps

- Adjacency Matrix (weights of causal relationships)

$$E = \begin{vmatrix} e_{11} & \cdots & \cdots & \cdots & \cdots & e_{1n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & e_{ij} & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ e_{n1} & \cdots & \cdots & \cdots & \cdots & e_{nn} \end{vmatrix}$$



- State vector (activation level of concepts)

$$C = [C_1, C_2, \ldots, C_n]$$

- Iteration in FCM

$$C(k+1) = f(C(k) \cdot E)$$

  - Threshold function (*f*): discrete or continue (logistic or tanh)
  - Continues until a *fixed-point attractor* a *limit cycle* or a *chaotic attractor* is reached

2 Typical analysis with FCM

- Static Analysis
  - **In-degree** is the total strength of the connections coming into a variable

$$id(C_i) = \sum_{i=1}^{n} |e_{ij}|$$

  - **Out-degree** is the total strength of the connections exiting from a variable

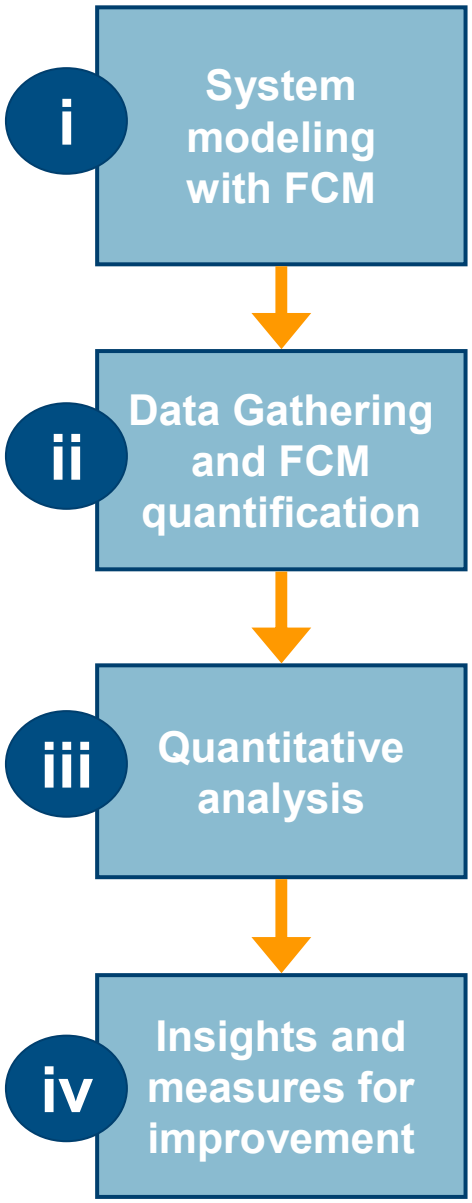
$$od(C_i) = \sum_{j=1}^{n} |e_{ij}|$$

  - **Centrality** (total degree):

$$c(C_i) = id(C_i) + od(C_i)$$

- Dynamic analysis
  - **Forward simulation** is used to analyse the evolution of a FCM when a concept is activated
  - **Backward simulation** is used to identify all the paths within a FCM to achieve a specific objective

2 Overview of the proposed method



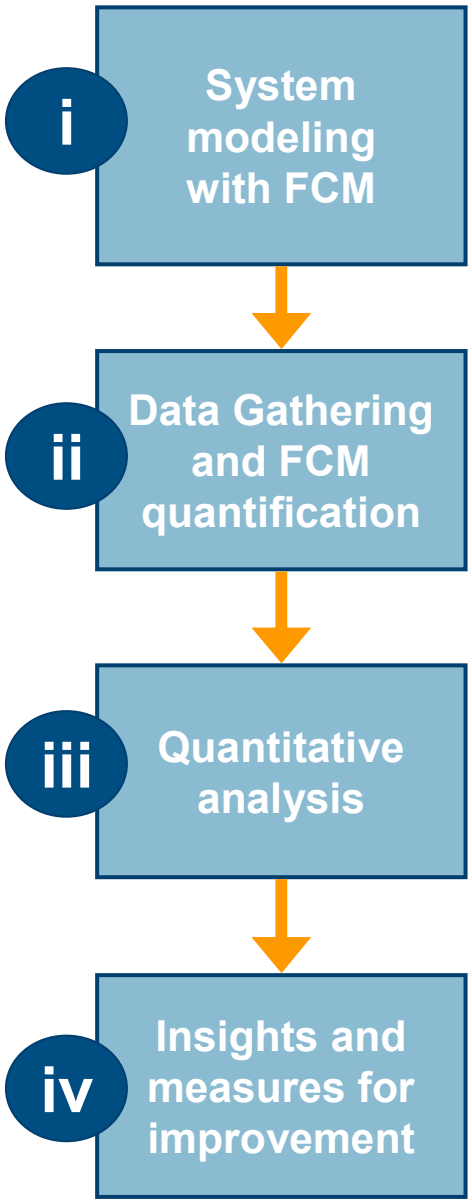
- Setting of system boundaries
- Actors, roles, relevance and objectives
- Selection of concepts
- Classification of internal (decision) parameters and external factors
- Causal relations and preliminary topology of the map

- Questionnaire design
- Experts' judgements elicitation
- Data processing and analysis
- Final FCM quantification

- Static analysis (in-degree, out-degree, centrality)
- Dynamic analysis (forward and backward simulation)
- **Resilience analysis**

- Analysis of results
- Review and discussion of results with experts
- Reporting of main insights
- Identification and evaluation of measures for system improvement

2 Overview of the proposed method



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- **Resilience analysis**

Sequential activation of some concepts to evaluate the capability of adaptation of the system to external or internal disturbances

- Analysis of results
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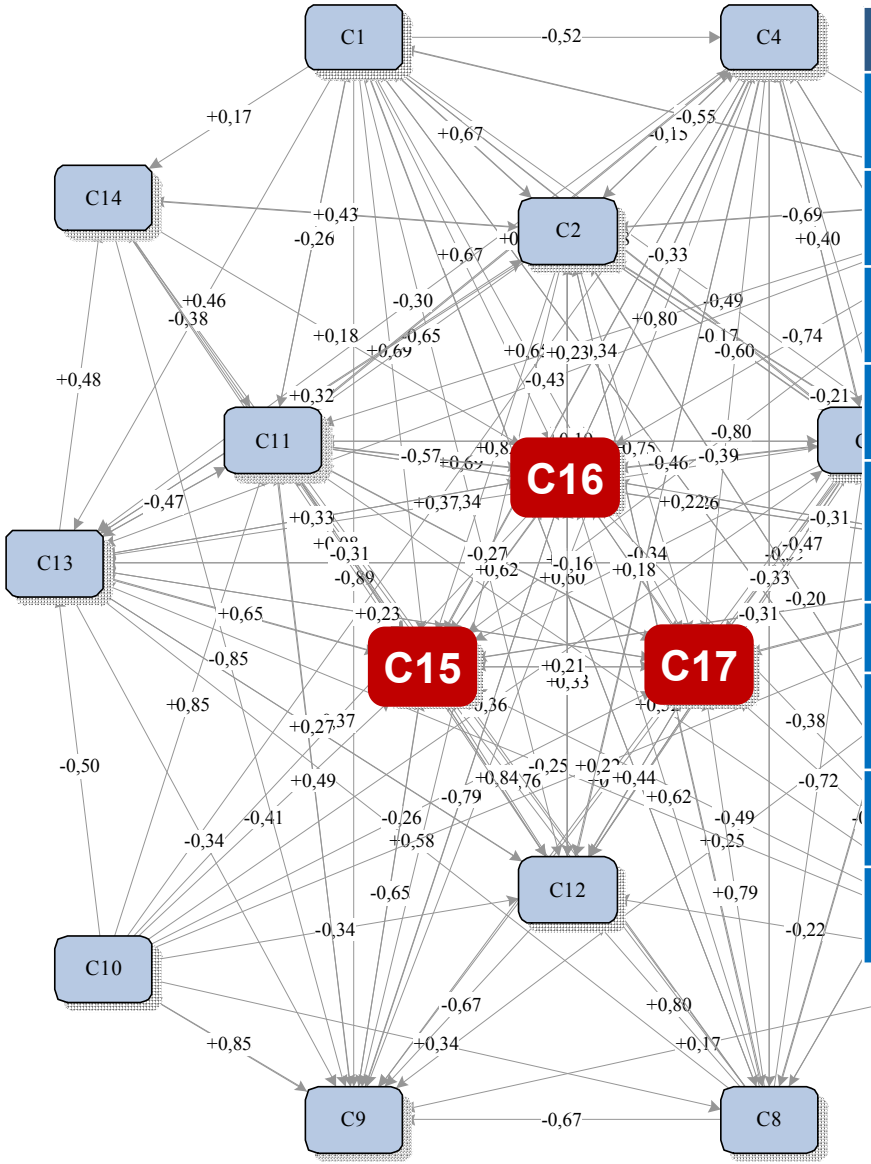
- Reporting of main insights
- Identification and evaluation of measures for system improvement

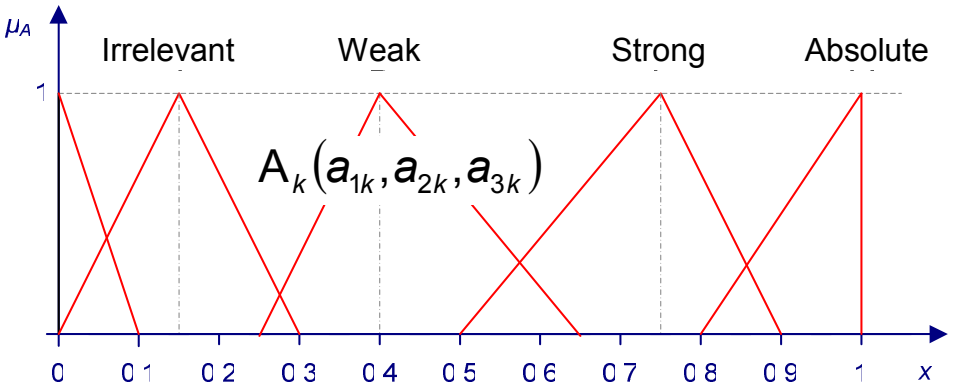
3 FCM of the First Emergency Response

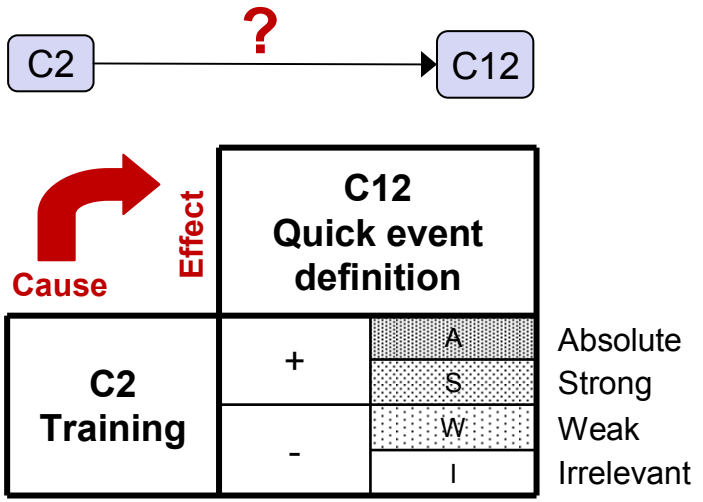


Code	Concept	Code	Concept
C1	Standard Communication	C10	Event magnitude
C2	Training (rescue squad)	C11	Stress (rescue squad)
C3	Role uncertainty	C12	Quick event definition
C4	Different priorities	C13	Correct use of resources
C5	Lack-of or weak procedures	C14	Training&Educatio n (population)
C6	Competition		
C7	Conflict of procedures	C15	Decision making
C8	Experience (rescue squad)	C16	Communication
C9	Panic (population)	C17	Efficient resource allocation

3 Quantification of the CFM for FER

- Fuzzy quantification of relations





- Data analysis

From 8 experts (n) with different (λ)

- Years of experience
- Role and responsibility
- Training and background
- Research collaborations
- Commitment

$$w_i = \frac{\lambda_i}{\lambda_1 + \ldots + \lambda_n} \qquad i = 1,\ldots,n \qquad \sum_{i=1}^{n} w_i = 1$$

$$A = \left(\frac{1}{n}\sum_{k=1}^{n} w_k a_{1k}, \frac{1}{n}\sum_{k=1}^{n} w_k a_{2k}, \frac{1}{n}\sum_{i=1}^{n} w_k a_{3k} \right) \Rightarrow e_{ij}$$

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
C1	0	0,83	-0,66	-0,52	-0,24	-0,49	-0,20	0,31	-0,89	0	-0,59	0,69	0,46	0,17	0,69	0,67	0,65
C2	0,67	0	-0,78	-0,78	-0,64	-0,78	-0,34	0,81	-0,70	0	-0,65	0,53	0,67	0,77	0,82	0,78	0,75
C3	-0,18	-0,17	0	0,78	0,22	0,73	0,10	0	0,71	0	0,74	-0,58	-0,34	0	-0,34	-0,36	-0,59
C4	0	-0,15	0,40	0	0	0,49	0	-0,17	0,11	0	0,37	-0,37	-0,30	0	-0,57	-0,50	-0,60
C5	-0,55	-0,69	0,53	0,50	0	0,58	0	-0,16	0,52	0	0,80	-0,47	-0,43	0	-0,80	-0,74	-0,60
C6	0	-0,21	0,44	0,37	0,20	0	0	-0,08	0,25	0	0,47	0	-0,21	0	-0,52	-0,32	-0,50
C7	-0,26	-0,20	0,57	0,18	0,40	0,47	0	0	0,17	0	0,52	-0,22	-0,25	0	-0,49	-0,38	-0,40
C8	0,60	0,61	-0,72	-0,33	-0,51	-0,37	0	0	-0,67	0	-0,76	0,80	0,58	0,51	0,79	0,62	0,79
C9	0	0	0	0	0	0	0	0	0	0,32	0,70	0	0	0	-0,22	-0,20	0
C10	0	0	0,36	0,37	0	0,22	0	0,34	0,85	0	0,85	-0,34	-0,50	0	-0,41	-0,37	-0,26
C11	-0,26	0	0,10	0,13	0	0,22	0	0	0,49	0	0	-0,61	-0,21	0	-0,65	-0,67	-0,50
C12	0	0	-0,43	-0,46	0	0	0	0	-0,67	0	-0,67	0	0,71	0	0,84	0,61	0,72
C13	0	0,32	0	0	0	-0,16	0	0	-0,34	0	-0,47	0,27	0	0,48	0,32	0,40	0,41
C14	0	0,43	0	0	0	0	0	0	-0,85	0	-0,38	0,08	0	0	0,17	0,18	0
C15	0	0	0	-0,34	0	-0,31	0	0	-0,65	0	-0,31	0	0,65	0	0	0,28	0,83
C16	0	0,23	-0,39	-0,33	0	-0,31	0	0	-0,79	0	-0,57	0,33	0,33	0	0,62	0	0,42
C17	0	0	0	0	0	-0,23	0	0	0	0	-0,27	0,44	0,23	0	0,21	0,18	0

4 Identification of critical factors

Code	Concept	Indegree	Outdegree	Centrality
C2	Training (rescue squad)	3,83	10,47	14,30
C11	Stress (rescue squad)	9,09	3,83	12,92
C15	Decision making	8,45	3,37	11,82
C16	Communication	7,27	4,32	11,59
C3	Role uncertainty	5,37	5,84	11,21
C12	Quick event definition	5,74	5,11	10,85
C1	Standard Communication	2,52	8,06	10,58
C8	Experience (rescue squad)	1,88	8,67	10,54
C9	Panic (population)	8,66	1,43	10,09
C5	Lack of or poor procedures	2,22	7,37	9,59
C17	Efficient resource allocation	8,00	1,58	9,58
C4	Different priority	5,09	4,03	9,13
C13	Correct use of resources	5,88	3,16	9,04
C6	Competition	5,34	3,57	8,91
C10	Event magnitude	0,32	4,87	5,18
C7	Conflict of procedures	0,64	4,50	5,14
C14	Training & Education (population)	1,93	2,08	4,01

5 Resilience Analysis with FCM

- System resilience to external disturbances
  - An increased **event magnitude (C10)** results in a reduction of FER performance …

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
C10	-1	-1	1	1	1	1	1	-1	1	**1**	1	-1	-1	-1	-1	-1	-1

… but a simultaneous **quicker event definition (C12)** would absorb the disturbance

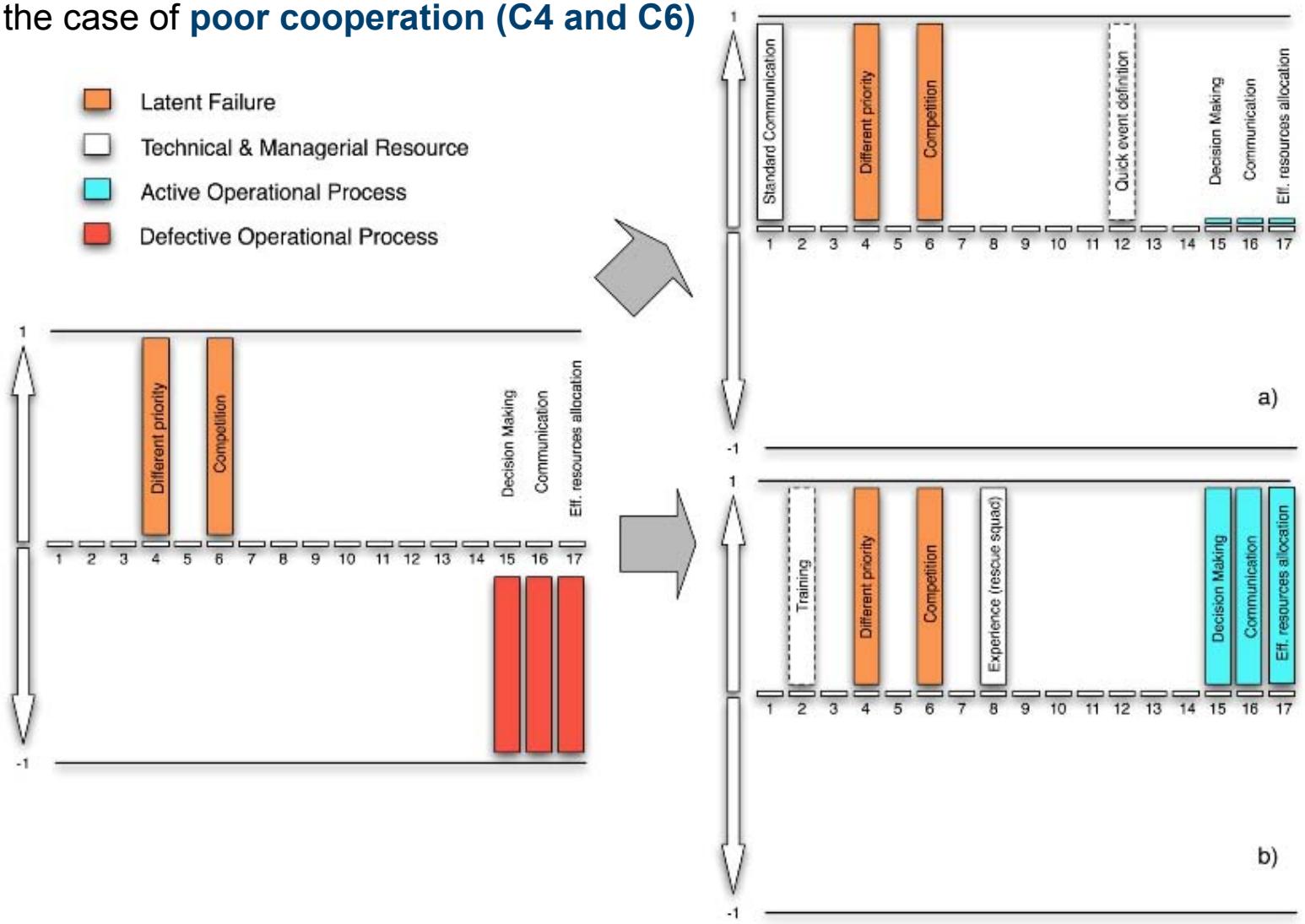
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
C12	0	0	0	0	0	0	0	0	0	**1**	0	**1**	0	0	0	0	0

  - The **resolution of conflicts** within procedures **(C7)** or a more efficient **allocation of resources (C17)** are not effective resources for system resilience

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
C7	-1	-1	1	1	1	1	**-1**	-1	1	**1**	1	-1	-1	-1	-1	-1	-1
C17	-1	-1	1	1	1	1	1	-1	1	**1**	1	-1	-1	-1	-1	-1	**1**

5 Resilience Analysis with FCM

- System resilience to internal organizational failures:
  - the case of **poor cooperation (C4 and C6)**



6 Discussion and future developments

- The Fuzzy Cognitive Map supported the identification of:
  - Training exercises and test runs as the most critical function of the FER (highest value of centrality)
  - Other functions and resources for FER resilience against internal failures:
    - tools and processes for a quick definition of the event (C12)
    - standardization of communication means and protocols (C1)
    - good mixed experience of rescue squad (C8)

- Further developments of the proposed method are in progress:
  - Extended set of factors (concepts)
  - Better knowledge capitalization (more extensive experts' elicitation);
  - Validation procedure to assess the degree of coherence of the knowledge captured by the FCM.

	Direct paths		Indirect paths	
Influenced concepts	*Number*	*%*	*Number*	*%*
Decision Making (C15)	6	37,50%	10	62,50%
Communication (C16)	4	25,00%	12	75,00%
Resource allocation (C17)	3	18,75%	13	81,25%
Total	13	27,08%	35	**72,92%**

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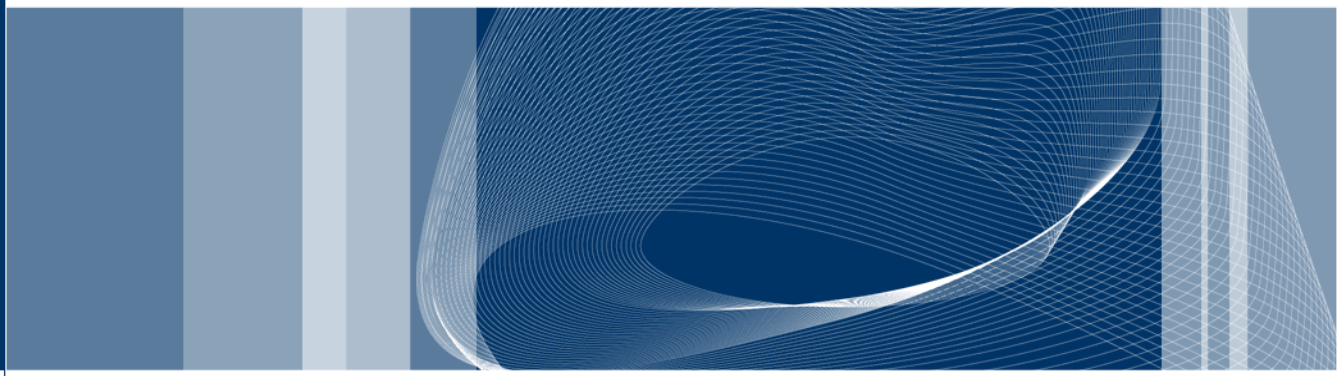

THANK YOU!

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