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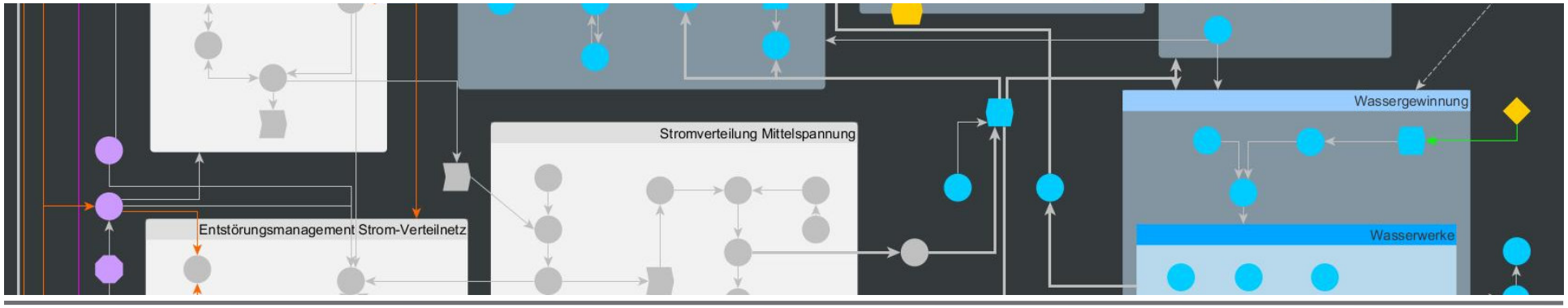

Enhanced Crisis-Preparation of CI through a Participatory Qualitative-Quantitative Interdependency Analysis Approach

Dierich, A.; Tzavella, K.; Setiadi, N.J.; Fekete, A.; **Neisser, F.**

Valencia, May 20th, 2019

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Assumptions

I. Critical Infrastructure (CI) failures are aggravated by **cascading effects due to interdependencies** between different infrastructure systems and with emergency management.

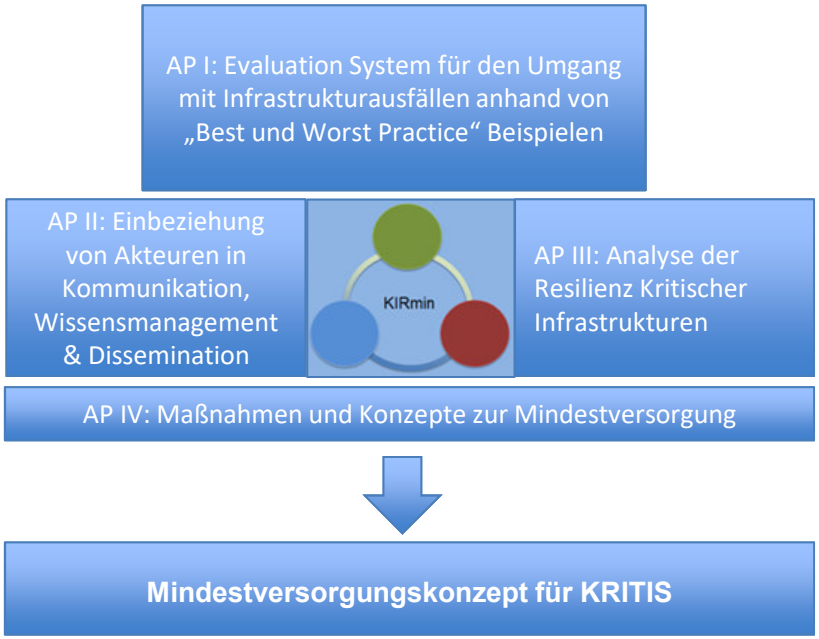
II. To build up resilience of CI, infrastructure operators, public crisis managers and emergency responders need to get a **joint understanding of the entire system of systems**.

III. Preemptive risk management, as well as ad-hoc crisis response **need to consider this interconnectedness**.

CIRMin-Project

Critical Infrastructure Resilience as Minimum Supply Concept

- Four research institutions
- Federal public authority
- Four local public authorities
- German standardization organization
- Seven critical infrastructure operators
- 2016-2019
- Funded by the German Federal Ministry of Education and Research



Source: TH Köln

Concept

Combined Qualitative-Quantitative Interdependency Analysis

a. System analysis, involving all relevant actors

   ⇒ taking inter- and trans-sectoral dependencies into consideration

b. Sensitivity analysis, to assess dynamics and possible feedback effects resulting from disturbances

   ⇒ identifying priority aspects

c. Combination with open-data-based GIS spatial analysis and visualization

   ⇒ localizing key sensitivities, weak spots and resulting demands

Methodological Approach

Combination of Informal Information Exchange with „Fuzzy Logic" and GIS data mining

- Inspired by five dimensions model framework by **Bagheri & Ghorbani (2008)**
  - ⇒ Knowledge discovery (mining of geo- information), qualitative information sharing, system analysis, behavioral analysis and visualisation
- System and sensitivity analysis according to **Frederic Vester (1991, 2012)**
  - ⇒ Reducing information depth with "Fuzzy Logic"
- Analysis of systemic relations according to **Rinaldi et al. (2001) and Turoff (2014)**
- **Up-to-date GIS analyses** through use of available open-source data and authoritative ('official') data

Fuzziness in detail, but focusing on the big picture (Source: inter 3 GmbH)

Bagheri, E. and Ghorbani, A.A. (2008) The state of the art in critical infrastructure protection: a framework for convergence, *International Journal of Critical Infrastructures,* 4(3), 215 - 244.
Vester, F. (2012) Die Kunst vernetzt zu denken. Ideen und Werkzeuge für einen neuen Umgang mit Komplexität. Ein Bericht an den Club of Rome, 9. aktualisierte Ausgabe, DTB, Munich, Germany.
Vester, F. (1991) Ausfahrt Zukunft Supplement. Material zur Systemuntersuchung, Studiengruppe für Biologie und Umwelt GmbH, Munich, Germany.
Rinaldi et al. (2001), Turoff et al. (2014): s. Folie 11

Sources for data

Three Case Studies

Cologne, Rhine-Erft-County with the city of Kerpen and Mülheim upon Ruhr

⇒ Comparison of different settings in three different types of settlement,

⇒ Assessment of transferability of results

Large qualitative information pool

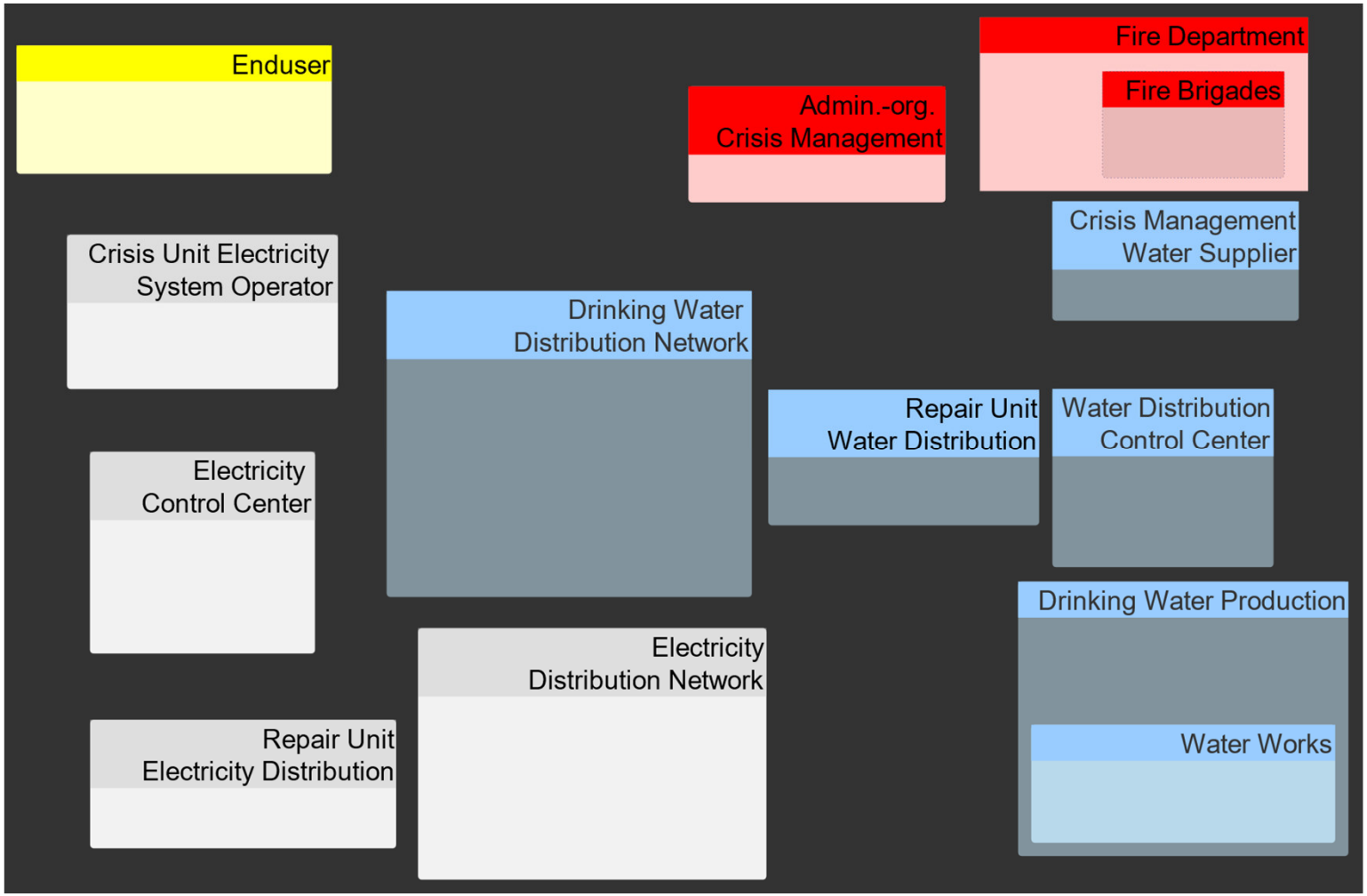
- Involvement of representatives from operating companies in each case study:
  - electricity supply grid and transmission grid operators,
  - water suppliers,
  - wastewater and flooding management and
  - ICT operators
- Involvement of municipal disaster management officials and emergency responders

Overview of Procedural Steps

- **Description of system elements and processes**
- **Analysis of Interdependencies**
- **Criticality Assessment through Sensitivity Analysis**
- **GIS-based Analysis of Quantitative Data**
- **Merging of Qualitative and Quantitative Information**

System Elements and Processes

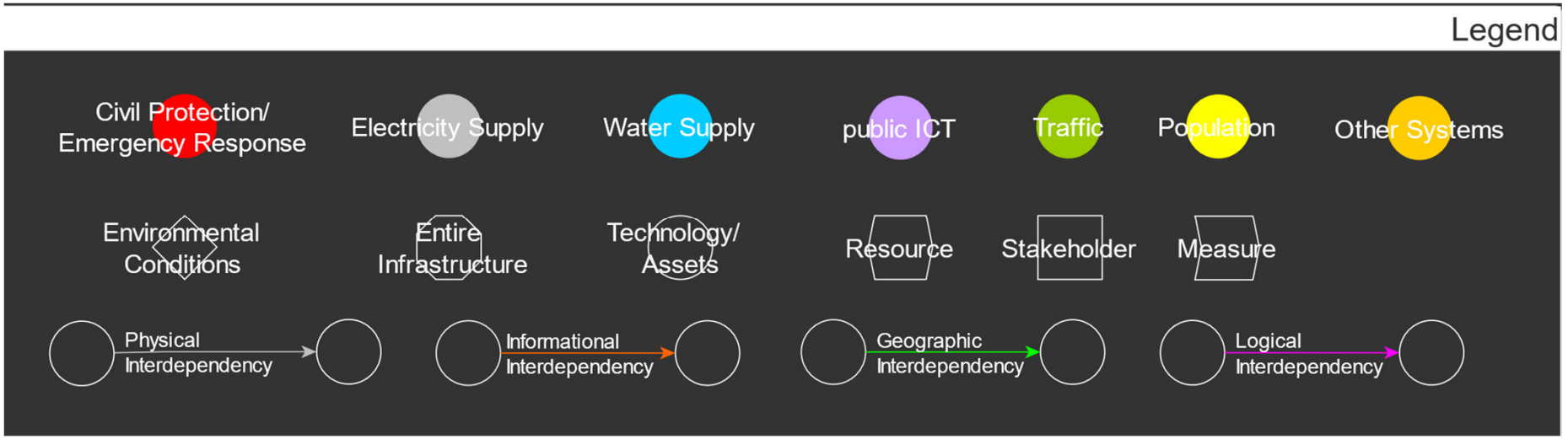
Definition of Subsystems



Source: inter 3 GmbH

System Elements and Processes

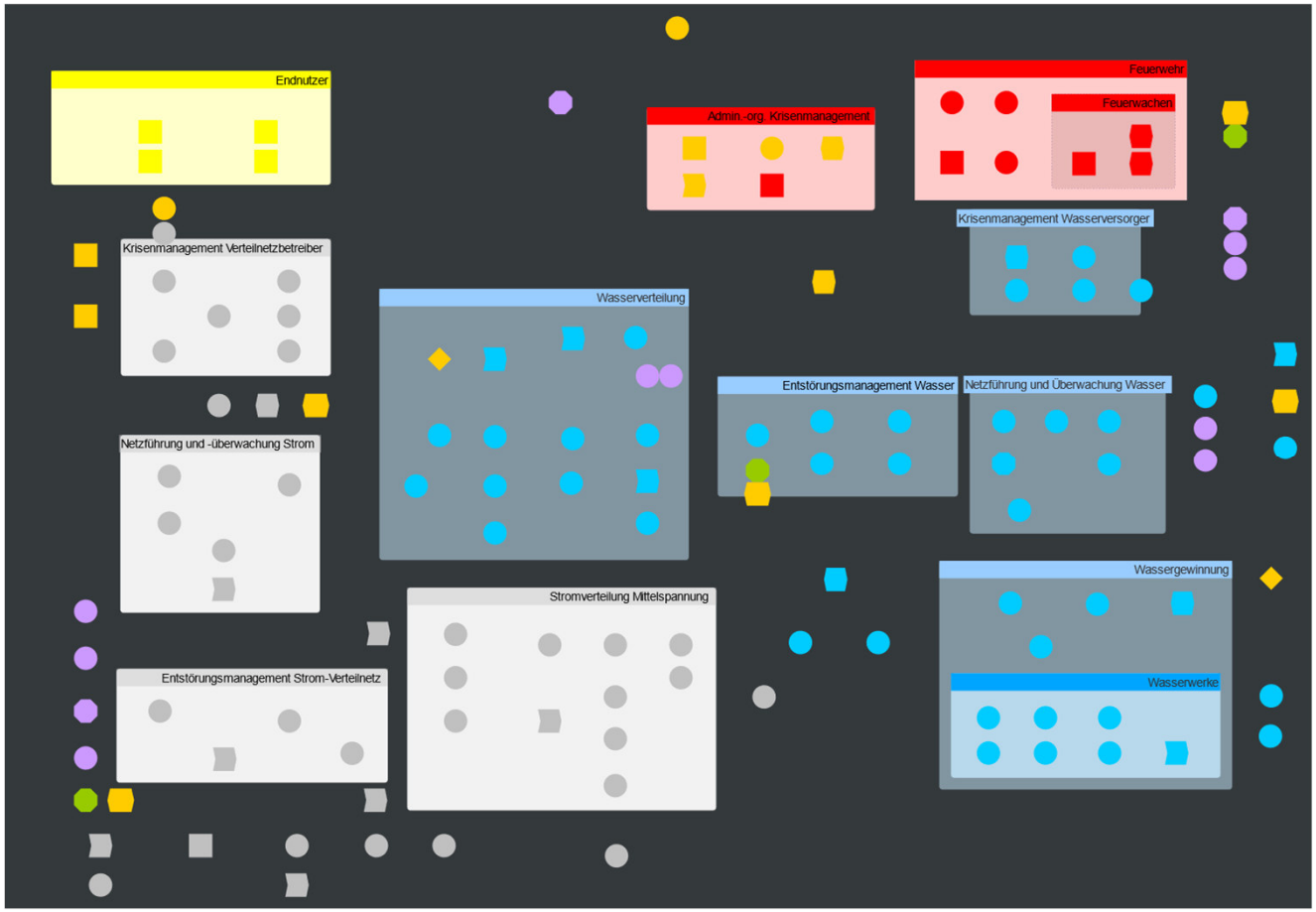
Structuring Processes and Elements in Different Categories



Source: inter 3 GmbH

System Elements and Processes

Structuring Processes and Elements in Different Categories



Source: inter 3 GmbH

System Analysis

Dimensions of interdependency

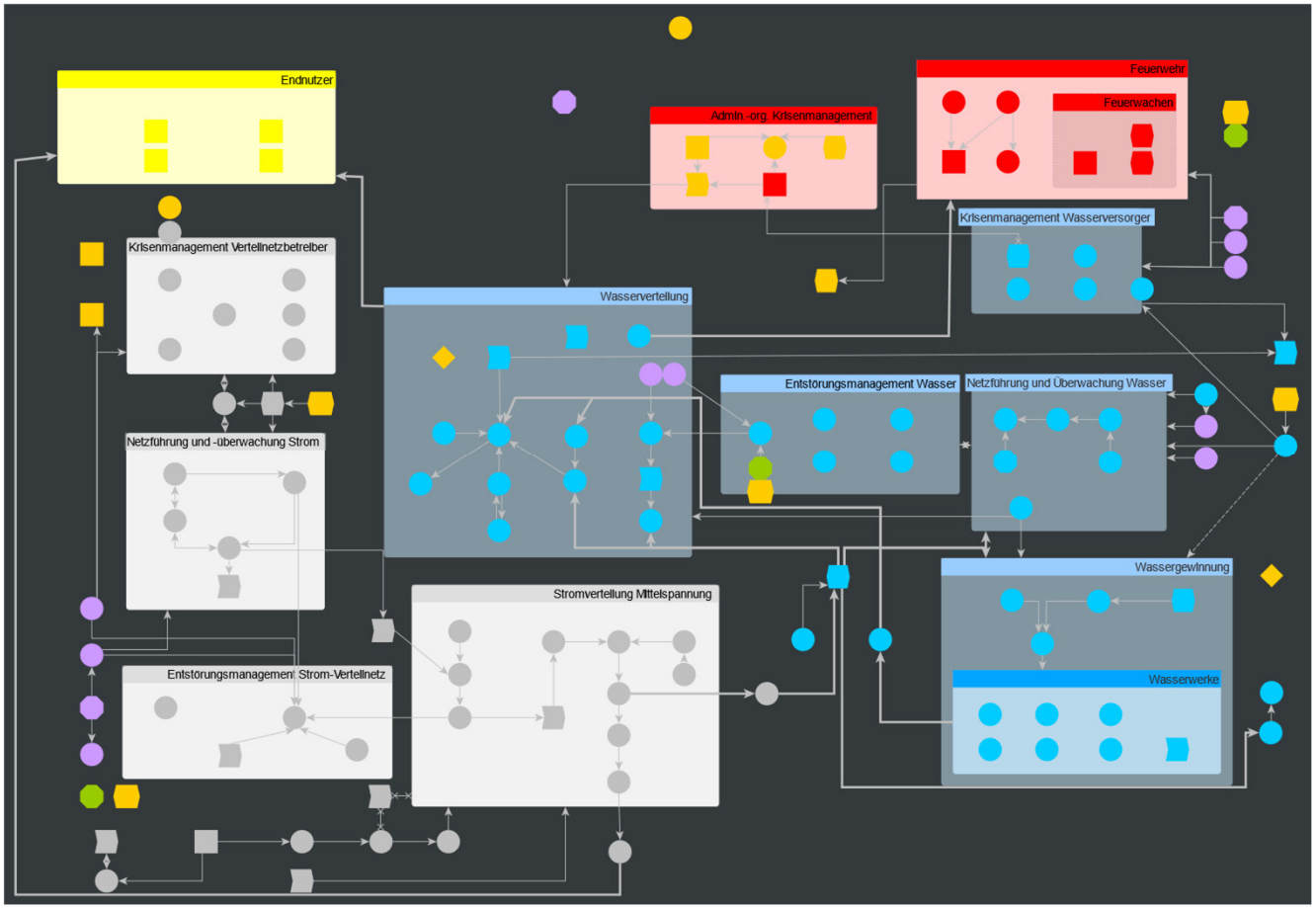
According to Rinaldi (2001) and Turoff (2014)

- **Physical interdependency**: the state of each is dependent on the material outputs of the other
- **Informational (cyber) interdependency**: the state of an infrastructure depends on information transmitted through the information infrastructure
- **Geographical interdependency:** a local environmental event can create state changes in several infrastructures
- **Logical interdependency**: social and political processes

Rinaldi, S. M., Peerenboom, J. P. and Kelly, T. K. (2001) Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies, IEEE Control Systems Magazine, December 2001, 1–25.
Turoff, M.; Bañuls, V.A.; Plotnick, L.; Hiltz, S.R. (2014) Development of a Dynamic Scenario Model for the Interaction of Critical Infrastructures, In Hiltz, S.R., Pfaff ,M.S., Plotnick, L, and Shih, P.C (Eds.) Proceedings of the 11th International ISCRAM Conference, Pennsylvania, USA, May 18-21, 2014, 414-423.

Analysis of Interdependencies

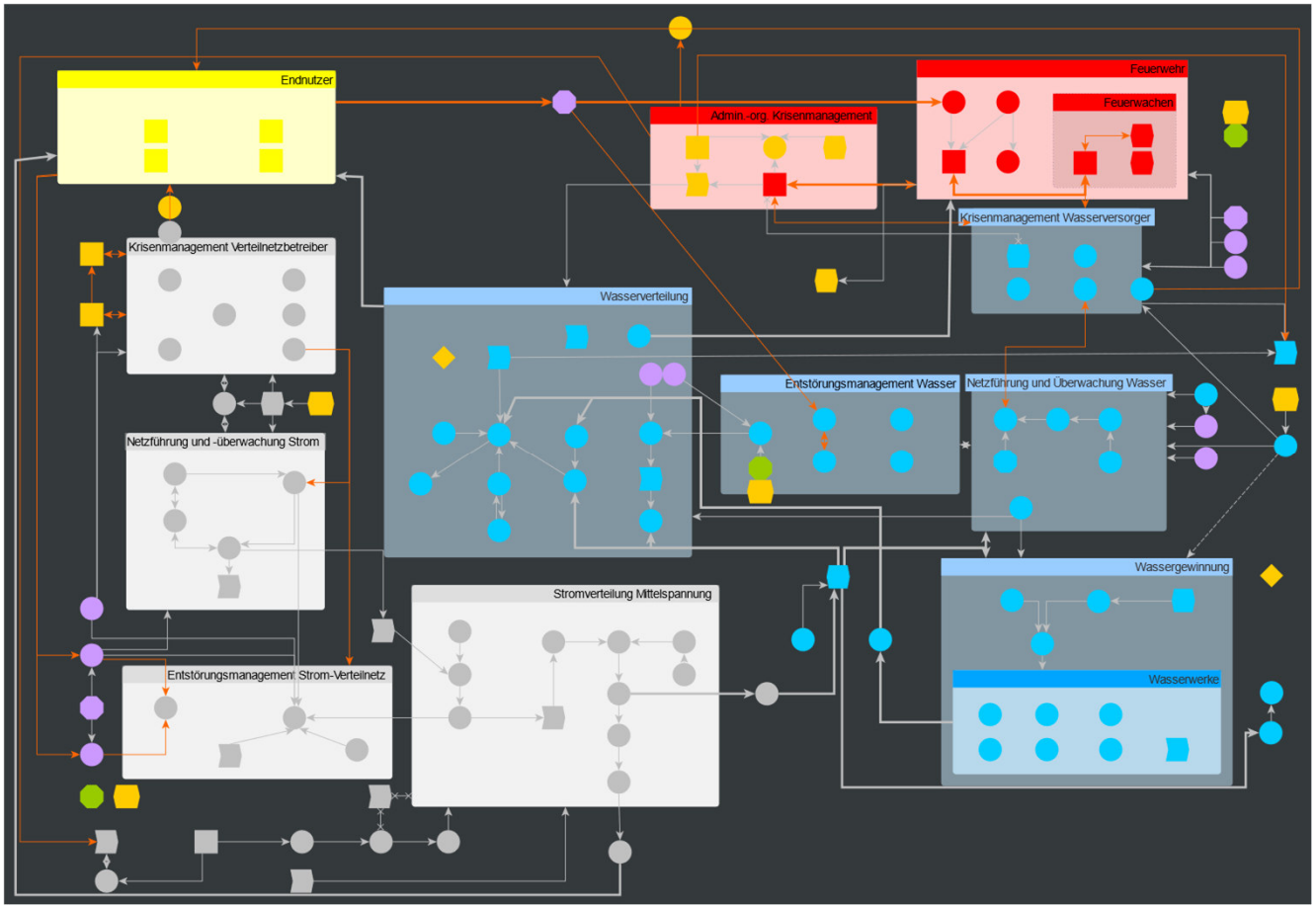
Physical Interdependencies



Source: inter 3 GmbH

Analysis of Interdependencies

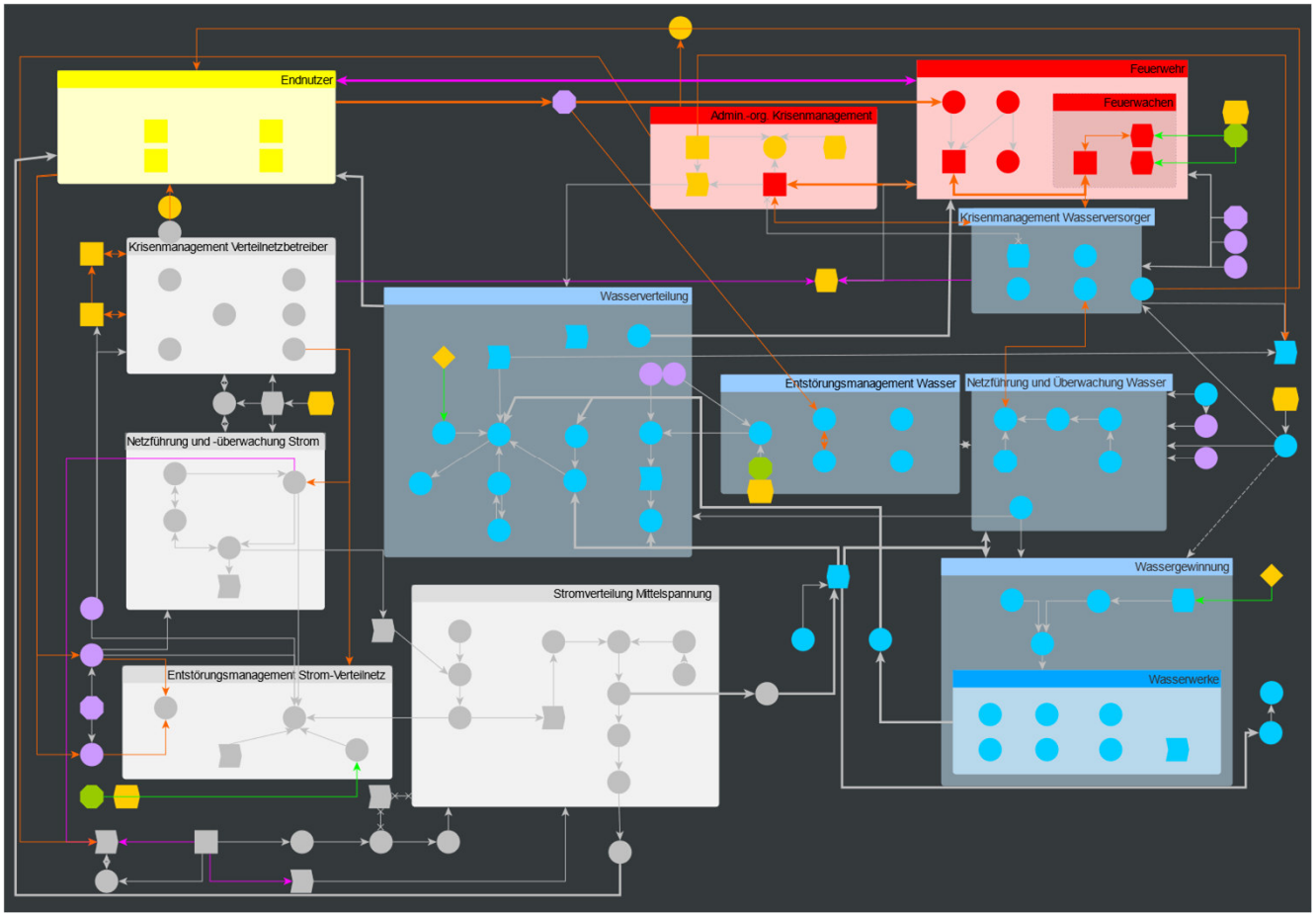
Informational Interdependencies



Source: inter 3 GmbH

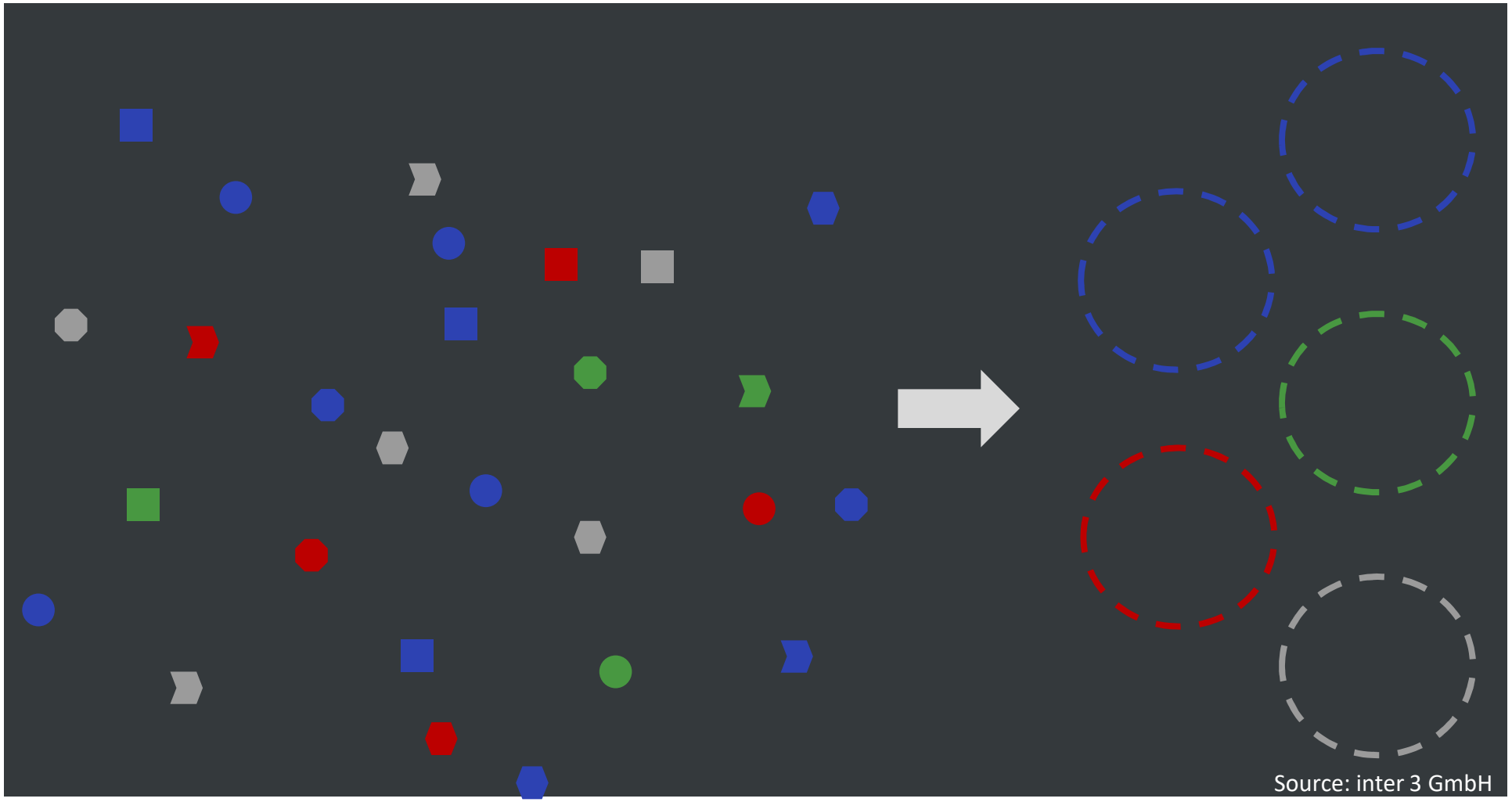
Analysis of Interdependencies

Geographical and Logical Interdependencies



Criticality Assessment

Clustering of Elements to Impact Factors



Criticality Assessment

Cross-Impact-Assessment

Cross-Impact-Matrix for anonymized city

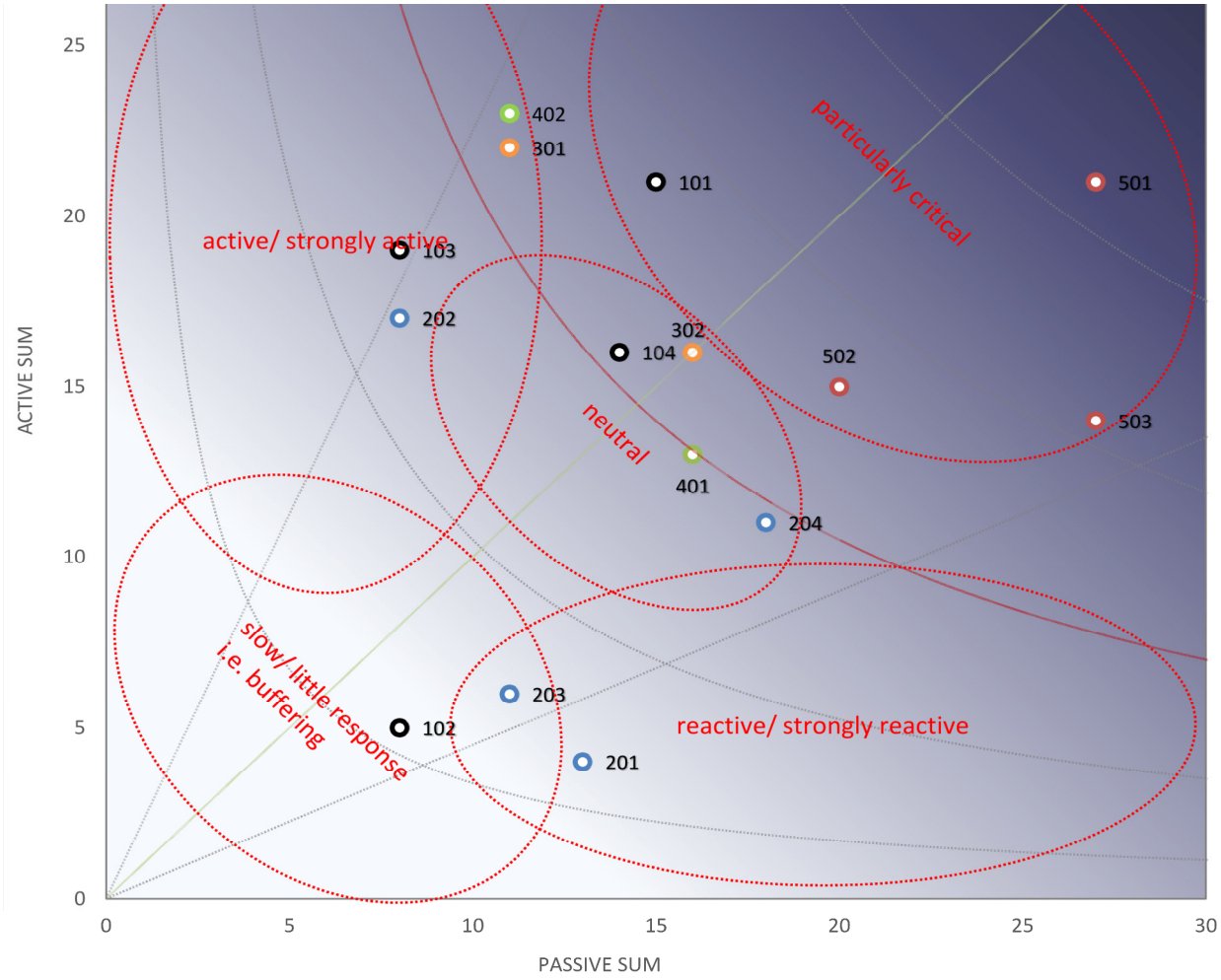
Assessment scale:
0 = no or very low impact/ no relation,
1 = impact underproportionate to/ lower than disturbance,
2 = proportionate impact,
3 = impact overproportionate/ higher than disturbance.

Direction of Impact		101 Electricity Distribution	102 Grid Control and Monitoring	103 Grid Recovery after Blackout	104 Repair Management, Crisis Management, Crisis Communication	201 Water Extraction and Purification	202 Water Distribution (Network)	203 Distribution Network Control and Monitoring	204 Repair Management, Crisis Management, Crisis Communication	301 Public ICT	302 Transportation Network/ Traffic	401 Communal Wastewater Disposal	402 Flood Control	501 Operative-Tactical Crisis Management/ Emergency	502 Administrative-Organisational Crisis Management	503 Demands and Commitment of End Users	
		Passive Side															
101 Electricity Distribution	Active Side	x	1	1	0	2	2	2	1	2	2	1	1	2	2	2	101
102 Grid Control and Monitoring		2	x	2	1	0	0	0	0	0	0	0	0	0	0	0	102
103 Grid Recovery after Blackout		2	1	x	0	1	1	1	1	2	2	1	0	2	2	3	103
104 Repair Management, Crisis Management, Crisis Communication		3	1	1	x	0	0	1	2	0	0	0	1	2	2	3	104
201 Water Extraction and Purification		0	0	0	0	x	2	2	0	0	0	0	0	0	0	0	201
202 Water Distribution (Network)		1	1	1	1	1	x	1	0	1	2	2	0	2	1	3	202
203 Distribution Network Control and Monitoring		0	0	0	0	2	1	x	2	0	0	0	0	1	0	0	203
204 Repair Management, Crisis Management, Crisis Communication		0	0	0	1	0	2	2	x	0	0	0	0	2	2	2	204
301 Public ICT		1	2	0	2	0	0	0	2	x	1	2	3	3	3	3	301
302 Transportation Network/ Traffic		0	1	1	2	0	0	1	2	0	x	0	3	3	1	2	302
401 Communal Wastewater Disposal		1	0	0	1	1	0	0	1	1	1	x	0	3	2	2	401
402 Flood Control		1	1	1	2	3	0	0	3	1	3	2	x	2	2	2	402
501 Operative-Tactical Crisis Management/ Emergency Responders		2	0	0	2	2	0	1	2	2	1	3	1	x	2	3	501
502 Administrative-Organisational Crisis Management		1	0	0	1	1	0	0	1	1	1	3	1	3	x	2	502
503 Demands and Commitment of End Users		1	0	1	1	0	0	0	1	1	3	2	1	2	1	x	503
		101	102	103	104	201	202	203	204	301	302	401	402	501	502	503	

Source: inter 3 GmbH

Criticality Assessment

Criticality Graph



Particularly critical impact factors:

- Electricity Distribution
- Operative-Tactical Crisis Management/ Emergency Responders
- Administrative-Organizational Crisis Management
- Demands and Commitment of End Users

Rather buffering impact factors:

- Grid Control and Monitoring
- Water Distribution Network Control and Monitoring

Source: inter 3 GmbH

GIS Analysis

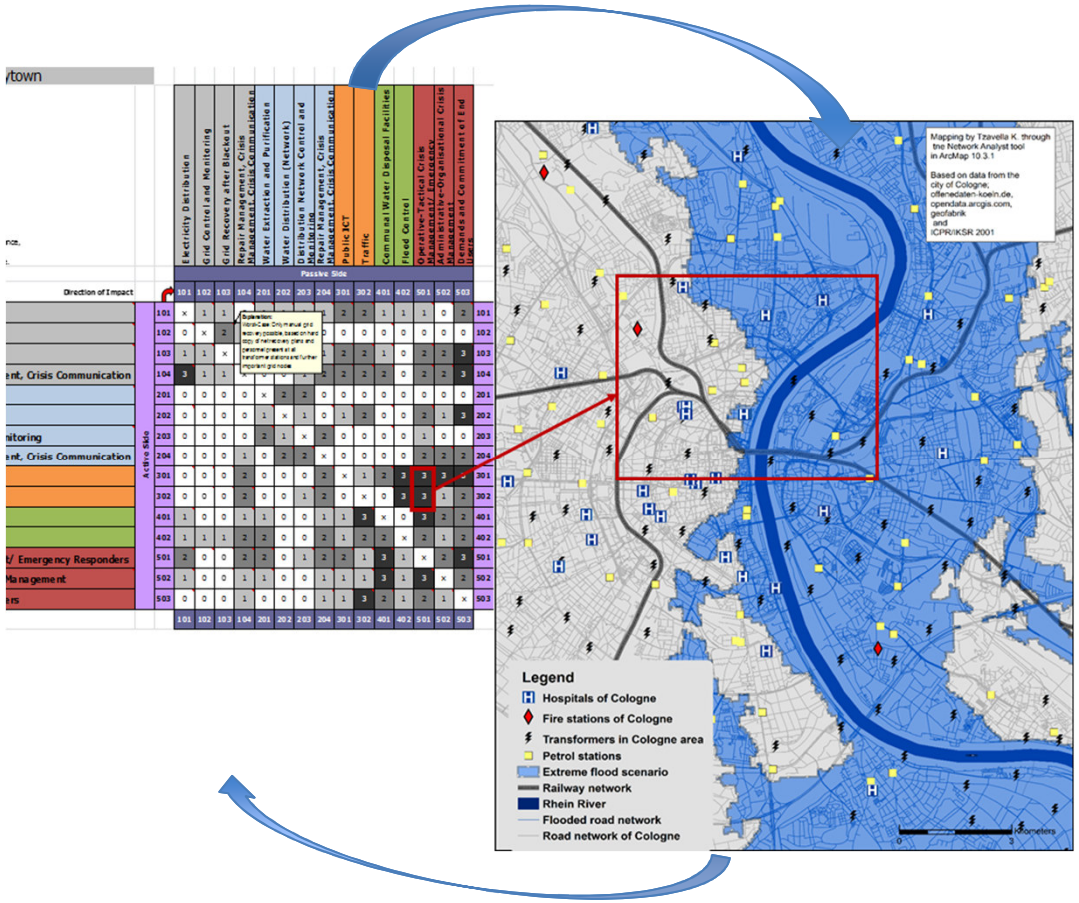
Why GIS Analyses?

GIS enables faster decision-making in times of crisis through fast integration of different kinds of spatial information

- GIS can also play a key role for the **identification of several types of interdependencies** as well as for the **visualization** of such information.
- **Visual results** in forms of maps **assist the decision makers** - and specifically the emergency managers –
  - to **quickly locate the occurring emergencies** in their network service area and
  - to **understand near real-time possibilities** during an event – optimization of emergency services' delivery.

GIS Analysis

Results of GIS Analysis



- Geographic interdependencies, e.g. repairing activities and actions of fire brigades that depend on the transportation network, fuel supply, and electricity supply
- Optimization of the emergency response time through GIS applications, and specifically by:

  1. **Identifying the CI at risk**: spatial assessments with a given scenario (e.g. extreme flood) add value to the situational awareness phase of the emergency management.

  2. **Suggesting optimization approaches** for routing and response time analysis (e.g. before and during a flood)

Source: Katerina Tzavella, TH Köln, with citation of inter 3 GmbH

Iterative Analysis between Qualitative and Quantitative

Verification and update of the Cross-Impact Matrix

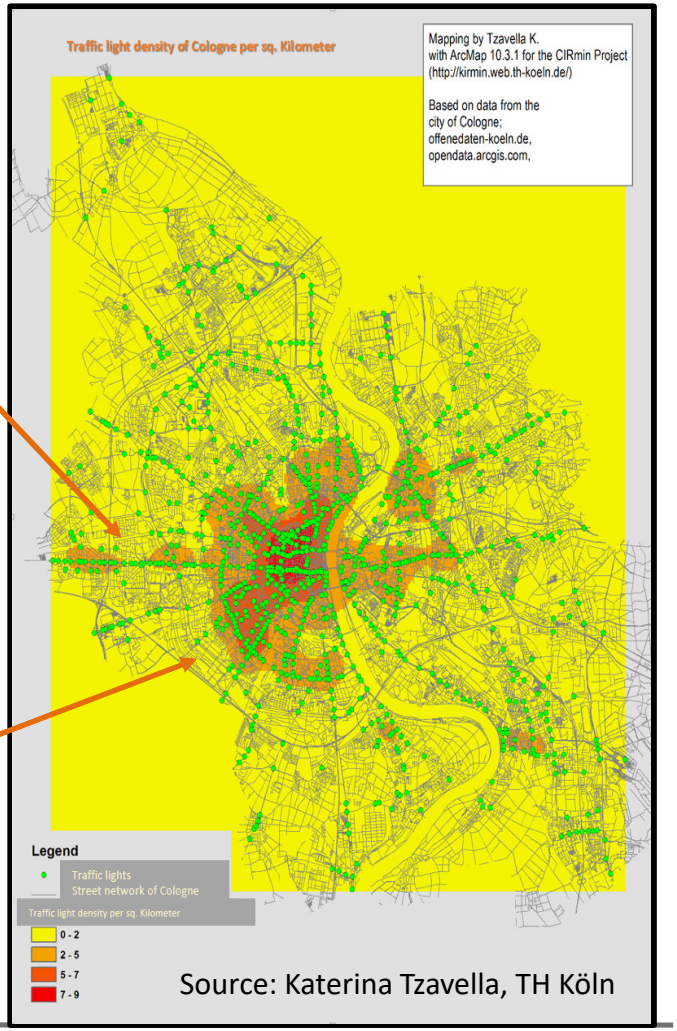
Cross-Impact-Matrix for Anytown

Assessment scale:
0 = no or very low impact/ no relation,
1 = impact underproportionate to/ lower than disturbance,
2 = proportionate impact,
3 = impact overproportionate/ higher than disturbance.

Direction of Impact		101 Electricity Distribution	102 Grid Control and Monitoring	103 Grid Recovery after Blackout	104 Repair Management, Crisis Management, Crisis Communication	201 Water Extraction and Purification	202 Water Distribution (Network)	203 Distribution Network Control and Monitoring	204 Repair Management, Crisis Management, Crisis Communication	301 Public ICT	302 Traffic	401 Communal Water Disposal Facilities	402 Flood Control	501 Operative-Tactical Crisis Management/ Emergency	502 Administrative-Organisational Crisis Management	503 Demands and Commitment of End Users	
		Passive Side															
Electricity Distribution	Active Side	101	x	1	1					2	2	1	1	1	0	2	101
Grid Control and Monitoring	Active Side	102	0	x	2					0	0	0	0	0	0	0	102
Grid Recovery after Blackout	Active Side	103	1	1	x					2	2	1	0	2	2	3	103
Repair Management, Crisis Management, Crisis Communication	Active Side	104	3	1	1	x	0	0	1	2	2	2	0	2	2	3	104
Water Extraction and Purification	Active Side	201	0	0	0	0	x	2	2	0	0	0	0	0	0	0	201
Water Distribution (Network)	Active Side	202	0	0	0	0	1	x	1	0	1	2	0	0	2	1	3	202
Distribution Network Control and Monitoring	Active Side	203	0	0	0	0	2	1	x	2	0	0	0	0	1	0	0	203
Repair Management, Crisis Management, Crisis Communication	Active Side	204	0	0	0	1	0	2	2	x	0	0	0	0	2	2	2	204
Public ICT	Active Side	301	0	0	0	2	0	0	0	2	x	1	2	3	3	3	3	301
Traffic	Active Side	302	0	0	0	2	0	0	1	2	0	x	0	3	3	1	2	302
Communal Water Disposal Facilities	Active Side	401	1	0	0	1	1	0	0	1	1	3	x	0	3	2	2	401
Flood Control	Active Side	402	1	1	1	2	2	0	0	2	1	2	2	x	2	1	2	402
Operative-Tactical Crisis Management/ Emergency Responders	Active Side	501	2	0	0	2	2	0	1	2	2	1	3	1	x	2	3	501
Administrative-Organisational Crisis Management	Active Side	502	1	0	0	1	1	0	0	1	1	1	3	1	3	x	2	502
Demands and Commitment of End Users	Active Side	503	0	0	0	1	0	0	0	1	1	3	2	1	2	1	x	503
			101	102	103	104	201	202	203	204	301	302	401	402	501	502	503	

Explanation:
Worst-Case: Only manual grid recovery possible, based on hard copy of net recovery plans and personnel present at all transformer stations and further important grid nodes

Source: inter 3 GmbH



Source: Katerina Tzavella, TH Köln

Iterative Analysis between Qualitative and Quantitative

Cascading effects

- **Presentation of cascading effects through GIS analysis → Risk maps**

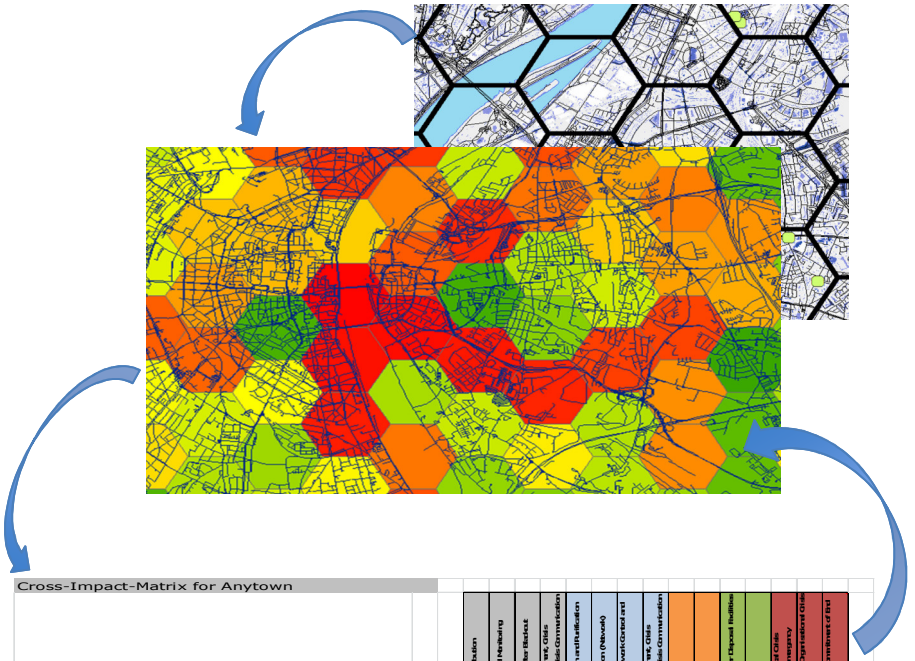
Visualizations of the **affected elements** and their **risk level of failure**.

These processes are results of several spatial analyses and assessments which can include, indicatively, classifications, weighting according to criticality level etc. Could then be categorized according to geographical relations (neighbouring elements) and finally provide an aggregated result of the criticality of the different elements per area.

- **Transformation of GIS analyses into the Matrix of Qualitative Analysis**

Classification of the elements (and in our case of cascading scenarios, the affected elements of a domino effect) according to their criticality level, extracted from the qualitative analysis and weighting within a scale from 1-5 for example.

Iteration: When in GIS assessments more elements are observed to be affected then these would be inserted into the matrix under the specified categories.



Cross-Impact-Matrix for Anytown

Assessment scale:
0 = no or very low impact/ no relation,
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2 = proportionate impact,
3 = impact overproportionate/ higher than disturbance.

Direction of Impact		Passive Side														
		101	102	103	104	201	202	203	204	301	302	401	402	501	502	503
Electricity Distribution	101	×	1	1	2	2	2	2	2	2	2	1	1	1	0	2	101
Grid Control and Monitoring	102	0	×	2	0	0	0	0	0	0	0	0	0	0	0	0	102
Grid Recovery after Blackout	103	1	1	×	2	2	2	2	2	2	2	1	0	2	2	3	103
Repair Management, Crisis Management, Crisis Communication	104	3	1	1	×	0	0	1	2	2	2	2	0	2	2	3	104
Water Extraction and Purification	201	0	0	0	0	×	2	2	0	0	0	0	0	0	0	0	201
Water Distribution (Network)	202	0	0	0	0	1	×	1	0	1	2	0	0	2	1	2	202
Distribution Network Control and Monitoring	203	0	0	0	0	2	1	×	2	0	0	0	0	1	0	0	203
Repair Management, Crisis Management, Crisis Communication	204	0	0	0	1	0	2	2	×	0	0	0	0	2	2	2	204
Public ICT	301	0	0	0	2	0	0	0	2	×	1	2	3	3	3	3	301
Traffic	302	0	0	0	2	0	0	1	2	0	×	0	3	3	1	2	302
Communal Water Disposal Facilities	401	1	0	0	1	1	0	0	1	1	3	×	0	3	2	2	401
Flood Control	402	1	1	1	2	2	0	0	2	1	2	2	×	2	1	2	402
Operative-Tactical Crisis Management/ Emergency Responders	501	2	0	0	2	2	0	1	2	2	1	3	1	×	2	3	501
Administrative-Organisational Crisis Management	502	1	0	0	1	1	0	0	1	1	1	3	1	3	×	2	502
Demands and Commitment of End Users	503	0	0	0	1	0	0	0	1	1	2	2	1	2	1	×	503
		101	102	103	104	201	202	203	204	301	302	401	402	501	502	503

Source: Katerina Tzavella, TH Köln
with citation of inter 3 GmbH

Conclusions

Why and how the QQ approach helps interdependency analysis

Two major advantages:

- The approach **does not demand precise data sets from the participants**, thus avoiding the often-insurmountable obstacle of sensitive data sharing or even costly data collection, and yet
- **it provides relevant information both in specific detail** (combined qualitative description of key elements, analysis of their nodes and quantitative GIS-based analysis), **as well as on a more abstract** but all-embracing **level** (cross-impact-analysis using aggregated impact factors), thus drawing the big picture.

Conclusions

Advantages of Involving Practitioners and Exchanging Information

Interviews and Workshop Discussions…

- … helped prioritizing information in direct dialogue with the experts
- … allowed for plausibility checks of GIS open source data through the experts
- … allowed for exchange of information about mutual dependencies and weaknesses outside of specific exercises or formal frameworks
- … supported understanding of service availability on the side of the other CIs in crisis situations

Conclusions

Advantages of quantitative analysis through GIS applications

Spatial Assessments can…

- …reveal emerging risks through identification of different types of interdependencies of the CIs raising awareness towards integration of additional critical elements in the emergency/crisis management cycle.
- …trigger further exchange of information between various actors gaining valuable information.
- …identify potential hot-spots for evacuation processes.
- …verify the results of the interdependency analysis (impact factors) – iterative approach to improve / refine results.
- …result from analyses of low quality open source data (Tzavella et al., 2018), which can be crucial in times of crisis where exchange of information could be hindered.

Conclusions

Added Value of the approach

Stakeholders confirmed usefulness of the results, in terms of

i) justification of their work on security and emergency management,

ii) intensifying the CIRMin-triggered knowledge exchange parallel and even after the end of the project (in bilateral collaborations) and

iii) applying GIS planning tools for emergency back-ups and resource planning.

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