beAWARE

Enhancing decision support and management services
in extreme weather climate events

700475

D6.1

Advanced Visualization and Interaction for Enhanced Situational Awareness - State-of-the-Art

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Abstract. This document surveys research of novel and effective visualization of multimodal emergency information to facilitate interaction between operators and first responders. This research is aimed to improve operator focus and efficiency through examination of new presentation concepts in data analysis, temporal data exploration, and anomaly detection that can potentially lead to process improvements and management practices.

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EXECUTIVE SUMMARY

This deliverable reports on the study and application of novel and effective visualization of multimodal emergency information to facilitate interaction between decision makers, operators, and first responders. This research is aimed to improve operator focus and efficiency through examination of new presentation concepts in data analysis, temporal data exploration, and anomaly detection in event sequences that can potentially lead to process improvements and management practices. We focus on strategic and tactical management before and during an emergency. In general, emergency management rooms house senior decision makers, emergency managers, operators, and analysts. Emergency management systems are therefore dedicated to providing functionality and added value for personnel carrying out such roles. The first responders and other field-based roles are not part of the focus of this study, but serve as a reference endpoint in complex end-to-end interactions.

Our findings show that common emergency management systems follow the general line of command and control systems, which are more common in the defense, homeland security, and law enforcement domains. The technological building blocks still include map-based event displays, multimedia integration, information management capabilities, business information analytics, and decision support capabilities. However, additional work has to be done in binding the decision making and command & control procedures with risk analysis and risk-based reasoning.

ABBREVIATIONS AND ACRONYMS

2D	Two-Dimensional
3D	Three-Dimensional
C2	Command & Control
C3	Command & Control Center
CA	City Authority / Administration
DRS	Disaster Resilience
DSS	Decision Support System
DSV	Decision Supporting Visualization
EMS	Emergency Management System
FR	First Responder
IM	Incident Manager
IVISE	Information Visualization and Interaction Services for Emergency
OM	Operations Manager
RBV	Role-Based Visualization
UI	User Interface
UX	User Experience
WP	Work Package

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1 INTRODUCTION

1.1 Scope

This document presents the results of research on advanced visualization and interaction capabilities for enhanced situational-awareness and emergency preparation and response management. The focus of this study and its application is on the central emergency management center control system of the beAWARE project. This document does not discuss visualization and interaction in the context of mobile devices, analytic services, or other services and solutions in the beAWARE platform, as those are out of the scope of the current WP.

This document covers state-of-the-art literature on emergency management systems, command and control systems (in the context of emergency and disaster management), decision support, risk analysis, and information visualization. These are the knowledge areas identified as having significant contribution to the subject matter.

1.2 "beAWARE"

The beAWARE Project is an EU-funded collaboration (#700475) of partners from several countries in Europe to deliver a prototype disaster management system for extreme weather conditions. The Project is focused on Flood, Forest Fire, and Heatwave scenarios, and is intended for deployment and testing of these scenarios in Venice/Vicenza (Italy), Valencia (Spain), and Thessaloniki (Greece), respectively.

The beAWARE system is an end-to-end solution for collecting information from multiple data sources – such as end users, social networks, sensors, and data providers – analyzing it, predicting and assessing emergencies, alerting the public, and managing first responders' activities.

1.3 Outline

This document is structured as follows:

- Section 2 reviews the end-user requirements, technical system requirements, functional implications, and performance criteria related to visualization and interaction at the Emergency Control Center level.

- Section 3 defines the research framework on state-of-the-art visualization and interaction techniques.
- Section 4 provides an illustrative and critical literature review on scientific topics related to advanced visualization and interaction.
- Section 5 concludes and summarizes this document.

2 VISUALIZATION AND INTERACTION REQUIREMENTS

2.1 Scope

In this section we review and analyze the requirements for visualization and interaction that refer to the control center, as part of the beAWARE requirements set. In addition, we derive UI and UX needs and functionalities related to decision-supporting and situational-awareness-augmenting visualization and emergency response management.

2.2 User Requirements for Control Center Visualization and Interaction

Stakeholders of the operational scenarios that beAWARE is required to respond to have defined various operational and functional requirements for the system, in order to support the roles, responsibilities, and activities of human agents during the occurrence of the scenario. The complete list of User Requirements is defined in Deliverable D2.1 [1], which was published in M6.

Several user requirements concern the visualization of decision-supporting information for the authorities, decision makers, control center operators, crisis analysts, and first responders. Additionally, some requirements concern the interaction of the authorities with the public, first responders, and control room operators.

For the purpose of this study, the initial user requirements provided by beAWARE Partners are considered as a general reference for an overall understanding of user needs, expectations, intentions, and constraints. The main user requirements that have possible impact on Control Center-related visualization and interaction have been listed in this document as a reference, and are summarized in Table 2-1. The full list of user requirements can be found in [1].

Table 2-1. Intial User Requirements [1]

UR#	Requirement name	Requirement description
UR_101	Type of visualization	Display information to authorities in a web-gis platform (citizen and first responders reports)
UR_103	Flood warnings	Provide authorities/citizens with warnings on river levels overtopping some predefined alert thresholds, based on forecast results
UR_107	Localize video, audio and images	Provide authorities with the ability to localize videos, audio and images sent by citizens from their mobile phones
UR_108	Localize task status	Provide authorities with the ability to localize first responders reports regarding the status of their assigned tasks
UR_109	Localize tweets	Provide authorities with the ability to localize Twitter messages concerning a flood event
UR_112	Detect element at risk from reports	Provide authorities with the ability to detect the number of element at risk and the degree of emergency from text sent by the mobile app and by social media
UR_117	Manage assignments in case of new emergencies	Provide authorities with the ability to manage first responder assignments
UR_118	River overtopping	Provide authorities/citizens with the ability to know if the river level is overtopping predefined alert thresholds
UR_120	Map of rescue teams and task evaluation	Display to authorities the position of first responder teams in all the municipality and provide the ability to evaluate in real time the execution of the assigned tasks
UR_128	Evaluation of the level of risk	Provide authorities with the ability to evaluate the forecasted level of risks (based on all the available dataset)
UR_131	Traffic warnings	Provide authorities with the ability to send warnings to citizens in order to avoid a certain area that is jammed with traffic
UR_213	Recommendations	Sending recommendations to citizens.
UR_214	Warnings	Sending warnings of pre-emergency alerts to citizens by authorities
UR_215	Evacuation orders	Ordering evacuations of citizens at risk.
UR_302	Automatic warning	beAWARE system to generate and provide the authorities with an automatic warning when an imminent heatwave phenomenon is forecasted
UR_303	Risk assessment for a forest fire	Provide the authorities with a risk assessment regarding the probability of a forest fire to occur during or in the upcoming period after a heatwave. The relevant authorities will have an assessment of a fire risk based on the weather forecast during a heatwave and especially during the following days
UR_306	Number of people affected	Provide the authorities an estimation of the people that might be affected from the phenomenon and in which areas

UR#	Requirement name	Requirement description
UR_309	False Alarms	Provide to the authorities a procedure to confirm necessity of rescue teams so they are not sent needlessly to one place instead of somewhere else where they are needed more urgently, therefore the ability to handle false alarms.
UR_310	City-wide overview of the event	Provide the authorities to have a city-wide overview of the event – allow decision making authorities an overall view of all incidents handled at any point in time/ see where all rescue teams are located in real-time to allow them to make informed decisions regarding who to send where… etc
UR_313	First responders status	Provide to the authorities the current status and location of all first responders when they are performing their tasks
UR_314	Assign tasks to first responders	Allow authorities to assign additional tasks to those first responders who are available or even instruct those who are able to assist other responders
UR_316	Capacity of relief places	Provide to the authorities the current state of the available capacity of all relief places provided to the public
UR_318	Trapped citizens	Allow authorities to know if there are people trapped (e.g. in an elevator) and display where
UR_319	Trapped elders at home	Allow authorities to know if there are elder people trapped in houses without an A/C and display where
UR_320	Hospital availability	Show to the authorities the current availability of the hospitals.
UR_332	Localize tweets	Provide authorities with the ability to localize Twitter messages
UR_334	Manage assignments in case of new emergencies	Provide authorities with the ability to manage first responder assignments
UR_335	Map of rescue teams and task evaluation	Display to authorities the position of first responder teams in all the municipality and provide the ability to evaluate in real time the execution of the assigned tasks with a global visualization of the activities performed
UR_337	Location of vehicles and personnel involved	Allow authorities/first responders to visualize position of vehicles and teams on the incident site

2.3 Visualization and Interaction Modalities

Based on the User Requirements, we have concluded that several functional modalities of visualization and interaction are required, as summarized in Table 2-2. Each modality provides visualization and interaction with one or more types of business entities (namely, Incidents, Units, etc.). In addition, a Menu modality enables navigation within the user interface.

Table 2-2. Control Center Visualization and Interaction Modality

Modality	Definition	Visualized Information
Menu	List of user interface and UI module activation commands	User Interfaces; UI Modules;
Map	Graphical display of object positions with rich symbol semantics on top of a background cartographic base-layer and with information layer visibility control	Incidents; Units;
Dashboard	Graphical display of quantitative information in various analytic view, such as gauge, plot, bar chart, pie chart, etc.	Metrics
Table	List of items with attributes, symbols and item commands	Incidents; Units; Assignments; Alerts
View Tab	Set of readable and modifiable attributes, commands, and extensions for a single item	Incident; Unit; Alert
Media Viewer	Visual display of list of media objects and playback/visualization of media object	Media;

2.4 Roles and Role-Adjusted Displays

We have determined a set of user roles for the Control Center, based on the understanding of user requirements and expectations, especially augmented by discussions and collaboration with end users to crystallize and clarify the requirements, and following the formulation of system requirements and analysis of visualization and interaction modalities. For each role, we analyzed the way each modality can be used to provide functionality to support users in carrying out that role.

2.4.1 Central Authority/ City Administration (CA)

This role is carried out by a senior government or municipal political-echelon person or group who reports to the public, and oversees the preparations and efforts for response to natural disaster emergencies (e.g. mayor, regional disaster resilience committee) and is held accountable for the results.

Table 2-3. CA Role and Utilization of Modalities

Map	Dashboard	Tables	Forms	Media Viewers
Overview of Incidents	• High-Level Metrics; • risk assessment; • crisis classification; • early warning; • incident statistics; • impact statistics (e.g. victims)	• Public Alerts issued to the General Population; • Incidents (overview)	Send Public Alert;	• N/A
Knowledge Domains				
Emergency Management Systems	Decision Support Systems, Risk Management, Information Visualization	Command and Control	Command and Control	Information Visualization

2.4.2 Incidents Manager(s) (IM)

This role is carried out by an Emergency response staff officer who reports to the CA, processes and handles incoming real-time incident reports, investigates them, analyzes them, and prioritizes them.

Table 2-4. IM Role and Utilization of Modalities

Map	Dashboard	Tables	Forms	Media Viewers
Incidents; Localized Metrics	Incident Statistics;	Incidents	Incident	Incident Media
Knowledge Domains				
Emergency Mangement Systems, Decision Support Systems,	Information Visualization	Command and Control	Command and Control	Information Visualization

2.4.3 Operations Manager(s) (OM)

This role is carried out by an Emergency response staff officer who who reports to the CA, oversees first responder team availability, assigns them to incidents, and monitors their progress.

Table 2-5. OM Role and Utilization of Modalities

Map	Dashboard	Tables	Forms	Media Viewers
Assignments; Teams	Operations Statistics;	Assignments; Teams	Assignment; Teams	Task-related Media
Knowledge Domains				
Emergency Mangement Systems	Information Visualization	Command and Control	Command and Control	Information Visualization

2.5 Operational Evaluation Criteria

The operational evaluation criteria in this document are based on the Quality Assurance Plan, issued as deliverable D1.2. The operational criteria were adjusted for Control Center operations.

2.5.1 Flood Disaster (1st pilot)

- Support decision makers in the case study area (Eastern Alps Hydrographic District)
- Monitor flood events
- Monitor crowd dynamics.
- Help decision makers by displaying critical information about events, merged with citizen behavior analysis.
- Support reacting to an ongoing situation
- Support planning for better flood event management.

2.5.2 Fire (2nd pilot)

- Support decision makers in the fire and rescue service in preventing fires.
- Improve fire prevention management

- Improve response to an event of fire.
- Help the fire and rescue service by displaying more accurate forecasts of the weather that can have an influence on the risk of fires.
- Support use of weather forecast information in influencing on public behaviour, to minimise inadvertent fires.
- Demonstrate the use of weather forecast to influence fire risk.
- Demonstrate use of weather forecast information in following and predicting the spreading and development of the fire
- Demonstrate the use of fire prediction analysis in an effective management of the fire and the surroundings.

2.5.3 Heatwave (3rd pilot)

- Increase the efficiency in dealing with a heatwave, by displaying an early warning to decision makers.
- Increase the efficiency in dealing with a heatwave, by dealing with the heatwave phenomenon while it occurs.
- Support decision makers in dealing with the heatwave phenomenon.
- Display an early warning regarding the phenomenon and its duration.
- Issue directions of dealing with the phenomenon to the general public.
- Issue alerts to hospitals for possible relative patients.
- Increase the level of preparedness to Fire Department for possible forest fires due to the heatwave.

2.6 Performance Metrics (Source: Quality Assurance Plan – D1.2)

The KPIs for WP6 are based on the system functional and non-functional requirements derived from the user-requirements document - D2.1 Use cases and initial user requirements (M5) and architectural design document - D7.2 System requirements and architecture document (M10) [2].

The following topics for WP6 related KPIs were identified at the current stage of the Project in the Quality Assurance Plan – D1.2 [3]. The criteria were adjusted to reflect the relevant implications on the Control Center-related visualization and interaction capabilities.

Table 2-6. Evaluation Criteria for Control Center

Performance Indicator	**Usability**
Definition	Clear and user friendly visualisation of different information entities gathered from several data sources
Domain	Visualisation and interaction
Range	5-point Likert scale.
Limitations	Each report should be assessed by multiple UI elements

Performance Indicator	**Uniformity**
Definition	Uniform user interface with regards to different emergency scenarios (flood, fire & heatwave)
Domain	Visualisation and interaction
Range	5-point Likert scale.
Limitations	Each report should be assessed by multiple UI elements

Performance Indicator	**Effectiveness**
Definition	Effective visualisation of the following: • Crisis classification • Early warning display • Real-time emergency alerts
Domain	Visualisation, interaction and decision support
Range	5-point Likert scale.
Limitations	Each report should be assessed by multiple UI elements

Performance Indicator	**Applicability**
Definition	Demonstrated ability to support: • interaction among operators, domain experts, decision makers and first responders • decision making processes.
Domain	Visualisation, interaction and decision support
Range	5-point Likert scale.
Limitations	Each report should be assessed by multiple UI elements

3 Advanced Visualization and Interaction Research

3.1 Scope

The purpose of this chapter is to describe the research framework for addressing the problem and challenges associated with the realization of an intelligent, useful, and robust user experience for emergency decision making, situational awaress, and disaster response management.

3.2 Problem Definition

We define the main problem we wish to address as

> ***Utilize information visualization and interaction technology for decision-support, situational awareness, and operational management, before and during an emergency.***

In short, we label this problem:

> ***Information Visualization and Interaction Services for Emergency (IVISE)***

The solution for IVISE is a determination of necessary and sufficient capabilities, technologies, techniques, services, and means to process, generate, provide, display, analyze, and act upon information for decision-making purposes at the strategic, tactical, and operational levels, in an effective, efficient, reliable, adaptive, and intuitive manner.

The approach to solve the IVISE problem is the definition, design, development, deployment, delivery, and evaluation of an applicative software framework for decision supporting information visualization (DSIV) that will deliver the capabilities and carry out the tasks defined as part of the problem.

3.3 Supporting Knowledge Domains

There are several bodies of knowledge that may support the development of IVISE framework, as listed in Table 2-3, Table 2-4, and Table 2-5.

Figure 3-1 provides an overview of the knowledge domains, namely:

- Emergency Management Systems
- Command and Control Systems
- Information Visualization
- Decision Support Systems
- Risk Analysis and Decision Analysis
- Disaster Resilience

Figure 3-1. Knowledge Domains Supporting IVISE

3.4 Research Method

3.4.1 Research Questions

In order to approach the IVISE problem, we wish to answer several research questions. The research questions are summarized in Table 3-1.

Table 3-1. Research Questions

ID	Research Question	Knowledge Acquisition Method / Sources
Q1	What are the IVISE-related stakeholder requirements and what are the implications on the EMS as a whole?	Deliverable D2.1 Initial Use Cases and User Requirements
Q2	What are the currently known challenges associated with DSIV in general and IVISE in particular?	Literature Review
Q3	What is the current state-of-the-art in DSIV, as the scientific research from the last 5-10 years suggests?	Literature Review
Q4	What are the current best practices in DSIV and IVISE, as the scientific research and commercial practice from the last 5 years suggest?	Literature Review

3.4.2 Research Hypotheses

We have two basic hypotheses that we intend to prove or disprove as part of this research. They are summarized in Table 3-2.

Table 3-2. Research Hypotheses

ID	Research Hypothesis	Examination Method
H1	The IVISE can be resolved by integrating state-of-the-art, state-of-the-practice, and innovative concepts and solutions, which will form the IVISE.	Framework Formulation
H2	The IVISE improves decision making capabilities and outcomes during an emergency, within the scoping of the beAWARE program.	Qualitative Evaluation

3.4.3 Research Goals and Objectives

This research has two primary goals, which are listed in Table 3-3.

Table 3-3. Research Goals

ID	Goal
G1	To provide a clear definition and deep understanding of the IVISE in the context of beAWARE's operational scenarios.
G2	To define a valid, up-to-date framework for the implementation of an IVISE.

In order to meet these goals, our tasks, objectives/outcomes, and corresponding sections of this document, are defined in Table 3-4.

Table 3-4. Research Objectives

ID	Objective	Outcome/Result	Section
T1	Understanding of the research problem	Problem definition and research proposal	Sections 1,2,3
T2	Critical and utilitarian reading, analysis, and review of the literature in the domains mentioned in section 3.3	Literature Review	Section 4

4 Literature Review

4.1 Emergency Management, Command, and Control Systems

Emergency management (EM) is the iterative and comprehensive handling of emergency-related tasks, including pre-emergency mitigation, near-emergency preparedness, in-emergency response, and post-emergency recovery. A Command & Control Center (C3) is typically in charge of coordinating the activities of various workforces – police, firefighters, medical teams, and crisis response teams (e.g., hazardous material squads, collapsed building rescue and evacuation forces, etc.) [4].

A study of the command and control (C2) architecture in the wake of the Kobe earthquake in Japan, 1995, has argued that the main goal of the C3 (a.k.a. Emergency Room) is to maximize the efficiency of the disaster response field teams [5]. This can be done by: a) real-time map and map-placed object sharing; b) informative image sharing for enhancing situational awareness; c) supporting multi-modal communication including voice (live and recorded), text (typed and handwritten), and map cues; d) monitoring the safety and security of the field team members. The proposed monitoring, collaboration, and control mechanisms call for the implementation of complementary mechanisms on the side of the C3:

- **Dynamic map and real-time map-cue sharing**, to allow control room operators to send immediate cues on the map to specific teams in the field. This capability has to include feedback for field team acquisition of the operators' cues.
- **Real-time map-based information sharing** regarding incidents assigned to responder teams, including incident information, images, and instructions (generic and specific).
- **Dynamic real-time map-cue reception**, visualization, and acknowledgement, to allow control room operators to respond to immediate cues on the map from the teams in the field.

Team member-level tracking of health, safety, and security status, provided as information on top of the team information.On the other end of emergency response system functionality, the strategic purposes and goals of emergency response decision support systems (ERDSS) are in assisting the authorities to enhance their emergency response capabilities mainly through early warning, contingency planning and plan evaluation, coordinating and commanding emergency response activities, and managing critical resources, and provide *knowledge* [6]. In light of these roles, the following processing centers (with corresponding modules) and their capabilities were proposed:

- **Emergency Data Collection and Management Service**: collect emergency information; collect emergency rescue demands; collect emergency response feedback; collect emergency rescue proposals submitted by the public;
- **Emergency Early Warning Service**: collect safety, risk, and asset information; analyze data and predict trends; determine security thresholds; provide continuous risk estimation.
- **Emergency Plan Management Module**: analyze emergency risks and requirements; classify emergency, disaster, and crisis conditions; prepare, model, and simulate emergency plans; test, validate, and analyze emergency plan effectiveness; supervise emergency plan execution and gather improvement and revision requests.
- **Emergency Service Helpdesk**: collect and distribute contact information; process, analyze, and filter emergency data; connect with other organizations (as a sole communication channel); connect and interface with other emergency information modules (as a sole interface);
- **Command and Coordination Center**: identify and confirm the severity of the emergency; monitor the emergency response effort; make emergency response decisions; coordinate multiple organizations to conduct rescue work; assess the level of victims' satisfaction; determine the necessary rescue measures.
- **Emergency Relief Supplies Management Module**: determine relief supplies categories and quantities; provide routing algorithms, modeling and simulation; provide logistics operation and coordination; manage relief supplies distributions; collect relief supplies and victims' satisfaction feedback; provide instructions on how to execute emergency rescues.
- **Emergency Organization and Activity Management**: manage organizations, personnel, rescue, and equipment; manage and monitor emergency rescue activities; support rescue performance evaluation; execute emergency plans; collect emergency scene information.
- **Emergency Knowledge Bank**: store and retrieve emergency management knowledge: procedures, protocols, plans, statistics, historical data and reports, lessons learnt from similar cases, specialist and specialty directory, emergency services directory, population directory.

- **Emergency Finance Budget Management**: provide financial planning, budget allocation, costing, accounting, and overall cost estimates.

A holistic end-to-end command and control system for emergency management, called Command Post, was proposed for integrating and visualizing data from different information sources on a single visualization interface, as well as providing a communication and coordination medium for different First Responder Team members [7]. The proposed architecture relies on a central Real-time Information Merging and Visualization C2 application. The C2 supports the command team in interactions with First Responders, and controlling the reaction to events during an emergency. The main capabilities or functionalities of the C2 are:

- **Receive, parse and process data of various forms** from different information sources, including initiated attempted acquisition of information (pull request) by the C2 from field teams when the system is initialized.
- **Visualize the received data to support instant and correct understanding** of the situation and fast response, by providing selective and burst-based data stream displays (of status updates, sensor data indications, or media uplinks) next to minimal team presence (status and position) displays when the team is passive.
- **Respond optimally to the alerts and data received by FR(s)**, via rich media content creation and transmission. This includes, for instance, three types of response formats: Ready Messages, Text Messages, and Media Messages:
    - **Ready Messages** are predefined text messages, which are associated with specific alert type and a specific FR team, that speed up the C2 operators' reaction and response.
    - **Text Messages** allow the C2 operators to interact via free text when ready messages are not applicable
    - **Media Messages** include media text and media - images, graphics, or video, as well as media annotations. They support rich visual communication with FRs that issued the respective alert as well as with other FRs that might be affected by the indicated emergency and need to be fully aware of the situation.

4.2 Information Visualization

Information Visualization (InfoVis) is a research area that focuses on design and development of new presentation approaches, visual layouts, visual interaction methods, data manipulation and transformation, and insight generation for information search, information exploration, and knowledge acquisition, for the purpose of performing various heterogeneous analysis tasks [8].

Visual Analytics is the study of knowledge generation based on interactive visual reasoning. It combines data analysis with interactive visualizations for an understanding and decision making on the basis of large and complex data [8].

Adaptive Visualization is an interactive, autonomously-evolving, learning, and constantly-improving visualization method and display of variables and conceptual structures, based on user-behavior, data characteristics, and other factors. The purpose of this approach is to amplify cognition and enable efficient information acquisition by the users [8].

InfoVis is strongly linked to human cognition-augmentation [9]. It has the potential to leverage human visual perception capabilities for influencing high-level cognitive processes such as retrieval from long-term memory, reasoning, learning, and understanding. However, few visualization paradigms and techniques rely on perception and cognition theories, and the majority of approaches focus on do's and don'ts in human-computer interaction and information displaying. A framework of human cognition, reasoning, and decision making, which provides the reference model for InfoVis, is shown in Figure 4-1 . This framework explains how certain leverage points can be employed by the information visualization and human-computer interaction designer, to maximize the value in terms of perception, cognition, and decision making effectiveness. The leverage points are summarized in Table 4-1. They include: 1) exogenous attention, 2) endogenous attention, 3) information chunking, and 4) mental models.

Table 4-1. Cognitive Leverage Points for Information Visualization [9]

Leverage Point	Idea	Implementation
Exogenous attention	Capture attention by a triggering stimulus in the visual field, often in the periphery. Provide registrable stimuli as memory cues.	Visualizations change over space or time; color and texture cues; motion towards/away from observer (changed); flow out of display (eliminated); flashing elements (new); unignorable visual patterns;
Endogenous attention	Appeal to the observer's cognitive commitment, processing capacity allocation, active working memory, and goal-focus, for the purpose of executive control, distraction preventing, and task completion.	Appropriate organization of material or interaction options; clear labeling; delegating cue control to the user; extraneous detail hiding; context-based relevant information highlighting;
Information Chunking	Minimize working memory's capacity limitation impact by strong grouping and retrieval cues to activate knowledge in long-term memory.	Common image parameters (color, hue, shape); Gestalt principles (continuity, proximity, closure, common fate); association and clustering; "ThemeRiver";
Mental Models	Aid reasoning – inferencing and occluding – by organizing information in mental models that provide strong retrieval cues for knowledge structures in long-term memory.	Multi-modal visualization of conceptual structures; cognitive task analysis (CTA); discrete step representation;

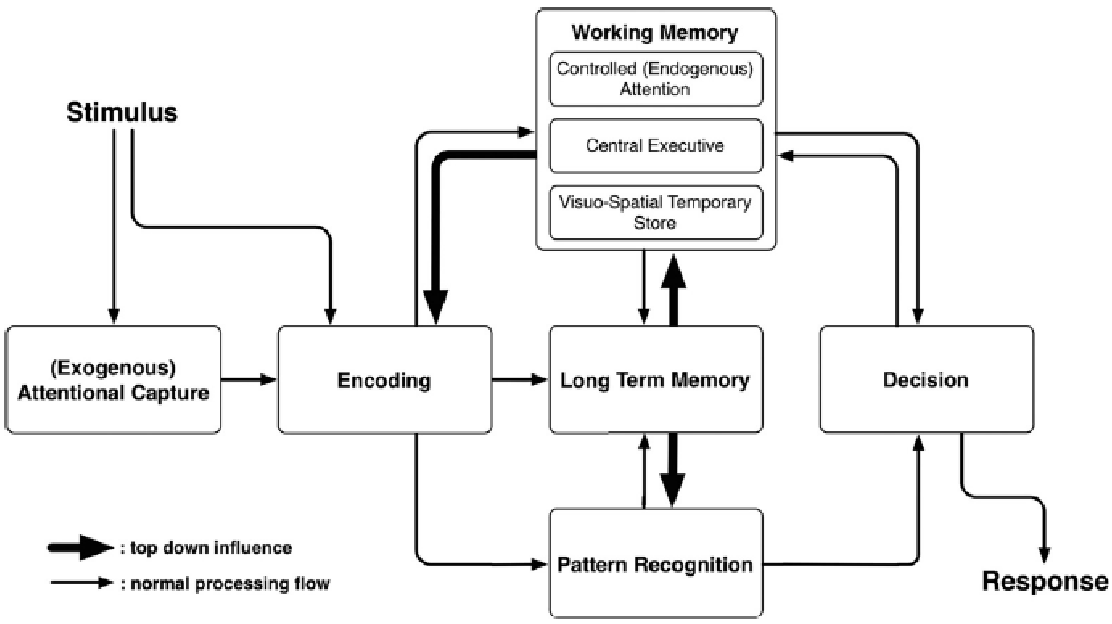

Figure 4-1. Human Cognition, reasoning, and decision making framework for information visualization [9]

A study of InfoVis applications in EM classified and ranked the sources of information, visual paradigms, visualization techniques, and interaction techniques used in studies on EM systems for various tasks and scenarios [4]. We summarized the findings of the study in Table 4-2. The authors did not include clear definitions of the classified techniques; hence it is difficult to understand what exactly is meant by some of the names they used. The classification of cognitive tasks, such as information searching, event management, task assignment, decision making, data analysis, or interaction with other users, is clearly missing in this study. Hence, the findings cannot be attributed to cognitive tasks that are performed during each phase.

Not surprisingly, the interactive 2d-map was found to be the most common interactive visualization technique. However, it did surprise us that visualization of movement was rarely applied, and that objective information sources such as GPS, sensors, and imaging devices were little-used. Another interesting finding is that the common techniques of information visualization can be applied in response to any emergency scenario, as most of the studies were generic and only a small portion of them focused on specific scenarios. In addition, a significant portion of the applications is around pre-emergency mitigation and preparation, and not only around the response to an ongoing emergency situation. However, the applications for the post-emergency recovery phase are the least-addressed.

Effective rescue operation visualization can greatly facilitate emergency response activities such as command and control, system analysis, training, evaluation, and transfer of lessons learned [10]. The authors have shown that the visualization of the following elements can enhance situational awareness and "big picture understanding":

- **Map View** shows the positions of rescue teams, points of interest, and incidents;
- **Image View** shows digital photographs with timestamps and text annotations
- **Casualty View** shows casualty information by location, injury, severity, and treatment status
- **Communication View** shows text-annotated radio and audio tracks.
- **Report view** shows observation reports from observers.

Table 4-2. Common Emergency Management Information Visualization Aspects and Techniques [4]

Aspect	Broadly-Used (60-100%)	Partially-Used (30-60%)	Little-Used (10-30%)	Rarely-Used (0-10%)
Information Sources	Databases	User Input; Social Media	Sensors; Imaging Sources; GPS	XML-Schemas; 3d Hybrid Data
Visual Paradigm	Geo-spatial 2D	Iconographic	Geo-spatial 3D; Pixel-oriented; Geometric Projection	Graph-based Hierarchical
Visual Distinction Technique	Spatial Position; Color; Shape			Movement
Interaction Mechanism	Map Interaction	Details-on-Demand; Filtering	Aggregation; Animation	Sharing; Annotation; Sorting; Brushing; Expanding; Drag-and-Drop; Audio Feedback; Collapse
User Interface		Web; Desktop	Mobile	
EM Phase	Response	Mitigation; Preparadeness	Recovery	
Emergency Scenario	Generic		Flood; Industrial Accident; Earthquake	Hurricane; Terrorism; Epidemic; Fire; Heatwave

4.3 Uncertainty, Risk Analysis and Decision Analysis

4.3.1 Uncertainty

Uncertainty and Risk are critical factors in decision making and management processes, especially before and during emergencies. The combination of statistical data on aspects like weather and climate, in conjunction with anticipated and unforeseen impacts on human lives and community assets, unpredictable individual and social behavior, and possible inability to monitor and control the situation, significantly affect how emergencies are managed, and how they evolve in response.

Defining uncertainty and coping with it has puzzled the most brilliant mathematicians and scientists for ages. Like complexity, uncertainty has been frequently mentioned as the motivation for the proposal of various analysis methods, referred to as a component or variable in the analysis of systems and phenomena, or explored for its nature and intrinsic properties [11]. We restrict our discussion on uncertainty to the *systems* domain on the one hand, and to the *conceptual modeling* domain on the other. Applying a systems thinking approach to the definition of uncertainty, uncertainty can be viewed as the effect of the presence or absence of information on the predictability of the state of a system under given circumstances. Uncertainty can be regarded as a phenomenon—a nature system, a feature – attribute or behavior – of real world systems or situations of these systems, or a perception of a situation by a human being regarding phenomena or systems. Proposed reasons for uncertainty in systems are (i) lack of information or knowledge, (ii) too much information, (iii) conflicting evidence, (iv) ambiguity (uncertainty about uncertainty), (v) measurement error, and (vi) belief [12].

There are two essential types of uncertainty: *aleatory* and *epistemic*. Aleatory uncertainty originates from natural variability and randomness of some phenomenon or event, while epistemic uncertainty originates from lack of sufficient knowledge or information about the system at work [13]. This notion, along with the understanding that both uncertainties may exist concurrently, is part of the challenge in capturing and analyzing uncertainty, based on both the presence and absence of knowledge about the natural behavior of systems . Epistemic uncertainty entails the ability to learn, increase knowledge and reduce uncertainty. It is not unreasonable to believe that there is no aleatory uncertainty, only unexplained epistemic one, but that is a matter of a philosophical debate about universal determinism, which is out of the scope of this research. When epistemic uncertainty is about variability and uncertainty itself, it is referred to as "uncertainty about uncertainty", second-order uncertainty, or *ambiguity* [14]. These empirically evident observations have led to the coining of the common terms: "Known known", "Known unknown", "Unknown known", and "Unknown unknown". These are summarized in Table 4-3.

Table 4-3. Types of Uncertainty as Combinations of Awareness and Variability

Variability / Awareness	Known	Unknown
Known	**"Known known"** a fact or deterministic concept that stakeholders are informed about and aware of ***Strategy: exploit***	**"Known unknown"** aleatory or epistemic variability that stakeholders are informed about and aware of ***Strategy: control***
Unknown	**"Unknown known"** fact or a deterministic concept that stakeholders are not informed about or aware of ***Strategy: manage knowledge***	**"Unknown unknown"** aleatory or epistemic variability that stakeholders are not informed about or aware of ***Strategy: explore and learn***

Traditionally, uncertainty is measured using probabilities. However, in dealing with emergency, when the probabilistic event is already taking place or highly likely to, probabilities are significantly less important than possibilities. In line with Possibility Theory [15], [16], this approach is a traditional departure from the Kolmogorovian probabilistic approach, for two primary reasons: (i) the *subjectivist* paradigm, and (ii) the criticality of *extreme events*.

The subjective uncertainty paradigm has become a matter of fierce debate as an antithesis to the traditional, *frequentist* paradigm. The probability of an uncertain event was traditionally defined as *frequency*—the number of occurrences of the event out of an infinite number of trials, which can be approximated by the frequency after a sufficiently large number of trials. De-Finetti's defying claim – *probability does not* *exist!* – a cornerstone of the *subjectivist* paradigm, means that probability is not real, not part of nature, cannot be unknown, and therefore cannot be discovered using frequentist methods. De-Finetti's Representation Theorem redefined the meaning of a series of observations within a process of learning by experience [17]. The subjectivist paradigm appeals to engineers who deal with complex system events (as opposed to "simple" events such as the roll of a die or the toss of a coin). For complex events, the frequentist approach is impractical, since there is no possible way to generate even a small series of real trials to generate a frequency estimate, nor is it possible to infer this estimate from previous events, as the preconditions of past events are seldom identical to those of a particular case in point.

In his famous book, Nassim Taleb coined the term 'Black Swan' to describe an occurrence which is: i) a very rare event, ii) of severe consequences, and iii) seeming rational after the fact [18]. Extreme events are generally more critical than nominal, expected events, so they require prioritization of attention and analysis [19]. For this reason, probability cannot be used to rank importance of uncertain events or states. This is where the difference between uncertainty and risk, discussed next, becomes apparent. Nevertheless, "it was a 'black swan' or "a 'perfect storm'" is not an excuse to wait until a disaster happens to take safety measures. Although one may not be able to assess the risks of events that have really never been seen before and are *truly* unimaginable, in reality, there are often precursors to such events. The best approach is a mix of alertness, quick detection, and early response [20].

4.3.2 **Risk**

Risk is an expression and a measure of the negative or adverse impact of uncertainty. Uncertainty in itself is neither negative nor positive. Risk exists whenever uncertainty may lead to several results, of which some are negative, or adverse, while others may be neutral or positive. The consequences of uncertainty with respect to subjective interests can have potential positive or negative effects. Risk has therefore been traditionally considered to link uncertainty and utility [21], [22]. The stakeholder's risk perception or risk attitude and preferences dictates the balance between the uncertainty about the possible results and the utility associated with these results. Therefore, the Bayesian-subjective approach underlies risk as a subjective measure, i.e., depending on the observer or decision maker.

In practice, a risk is defined as the answer to four questions: Q1) what can go wrong? Q2) what is the likelihood? Q3) what are the consequences? [23], and Q4) what is the time domain? [24]. The answer for Q1 facilitates a scenario in which, instead of, or in addition to an expected, desired result, an adverse one can arise. Q2, Q3, and Q4 respectively quantify the risk scenario in terms of probability, severity, and timing. Organizations searching for new business opportunities and future profit sources inevitably expose themselves to risk [25].

Risk modeling requires distinguishing between cause and effect. Various entities, reasons, and events constitute risk sources. They are not risky *per se*, but may generate effects that interfere with predetermined or predefined objectives. A physical phenomenon, such as a solar storm, is basically an "innocent" phenomenon, but the occurrence of a solar storm can, for example, render serious damage to a satellite and disrupt the communication it enables. The solar storm is a risk source, while damage to the satellite, or the satellite's failure to function, is the risk effect. Uncertainty is associated with both the risk source and the risk effect, but even if the source is in a risk posing state, it does not necessarily trigger the risk effect. Likewise, even if the risk effect occurs, its result may be harmful (to one or more degrees) or not. Only realization of the risk impact, i.e., the adverse or undesired results or states of the system or stakeholder goals and objectives is the actual realization of the risk itself. Goals and objectives can be cost/profit, duration/time, specification, performance, quality, mission success, reputation, safety, security, business-continuity, health, well-being, etc. It is useful, especially in quantitative models, to consolidate all goals and objectives into a unified measure – utility, or disutility.

4.3.3 Risk Management, Modeling, and Analysis

In both research and practice, there are two main approached to risk: the scientific risk analysis approach and the business-oriented risk management approach. There is a significant difference between these approaches. The former focuses on rigorously modeling, understanding, and analyzing risks with theoretical quantitative foundations. The latter primarily advocates integrating insights derived from the scientific risk analysis into the mainstream business analysis and views risk management as a *bona fide* process within the wider context of enterprise processes.

The scientific approach to risk analysis requires quantitative, probabilistic techniques [13], [26], and dedicated system-oriented methods [27], in addition to classical risk analysis methods, such as fault-tree analysis (FTA), failure mode effect critical analysis

(FMECA) [24], and hazard and operability (HAZOP) [28]. Analytical risk-integrated system modeling attempts to define the system's (multi-)objective function while capturing risk, using mathematical building blocks, such as input, output, state variables, decision (control) variables, and random variables. System vulnerability emerges due to specific inherent undesirable states of that system. State transitions occur within the system in response to inputs and other building blocks [24]. A review of risk management techniques as part of the systems engineering process is provided in [29].

Risk management is a key success factor in emergency operations. It aims at reducing the probability of occurrence of risky events and their adverse impact on stakeholder objectives and assets. Operational risk management is concerned with assuring such system objectives as reliability, safety, security, availability, and business continuity (some of the so-called "*ilities*") in operational settings subject to risk [24], [30]. Several guides and standards with general applicability or relevance to particular domains have been published [31]–[35].

The International Organization for Standardization (ISO) refers to risk management as a "lifecycle process", synonymous with uncertainty management. While risk management includes both positive and negative effects, ISO preserves the term risk, emphasizing the importance of managing and preparing for negative effects [33], [36].

Risk management is a multi-objective, resource-constrained effort aimed at overall risk minimization. It is an application of uncertainty management and management under uncertainty, as part of overall systems thinking, system management, process control, and decision making under uncertainty [37].

Risk management attempts to answer three questions [38]: Q5) what can be done and what options are available? Q6) what are the associated tradeoffs in terms of all costs, benefits, and risks? and Q7) what are the impacts of current management decisions on future options? These questions are aligned with questions Q1, Q2, Q3, and Q4, the answers to which define the risk. Q5 attempts to find a response to the answer for Q1 – what can go wrong? Q6 demands balance between the quantitative measures of probabilities, consequences, and timing, responding to Q2, Q3 and Q4 above. Q7 reminds the decision maker that risk management decisions may result in changed or reduced program scope, and lead to other risks and/or to new opportunities.

4.3.4 The Likelihood Impact Matrix

The most popular risk assessment technique is the famous 5X5 likelihood/severity or probability/impact matrix. The rows and columns indicate certain levels or ranges of severity and likelihood respectively, and often the product of the likelihood and severity is stored in the cells of the matrix as a measure of the risk. Other NxN variations were proposed in tutorials and handbooks. Figure 4-2 displays the common 5X5 benchmark, in which the vertical axis indicates the likelihood of occurrence of some event, the horizontal axis indicates its severity, and each cell holds the product as a measure of the expected impact, classified by impact ranges with a color pattern.

Likelihood						
	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5
		Severity				

Figure 4-2. Risk Impact Matrix

The likelihood level may be relative to the maximum or mean of a corresponding range (each n represents up to, say, 20n%: 1=20%, 2=40% etc.), logarithmic (each n represents, say 10^{-5+n}: 1=0.0001, 2=0.001, 3=0.01, 4=0.1, 5=1), or ranged/categorical (1=0-10%, 2=10-30%, 3=30-60%, 4=60-90%, 5=90-100%). Note that ranges may not be equal in size. Qualitative rankings, like {"Negligible", "Low", "Medium", "High", "Unacceptable"} are also common but are prone to strong bias due to misinterpretation gaps. The severity level may refer to absolute values, which should correspond to relevant values of the assessed magnitude. Alternatively, the severity level may correspond to the relative deviation from target value, which should then take into consideration the initial target value, since the probability of deviation may vary accordingly, due to the level of certainty. Additional impact level is illustrated by color – green indicates light impact, in this example a product of likelihood and severity less than or equal to 4, yellow indicate intermediate impact, product between 5 and 10, red indicates significant impact, 12 to 19, and black indicates very heavy/unacceptable impact, 20-25. The ranges defined for each level and color may change according to organizational policy or management's risk attitude.

Such discrete matrices often display only one pair of likelihood and severity, which means that events are modeled either as Bernoulli events or by a representative estimate. Bernoulli modeling is often used, but may be quite flawed since it considers the result over a binary space, rather than over a continuous or even discrete space. Instead of asking, Bernoulli-wise, *whether* project completion is going to be delayed, with the possible answers "Yes" or "No", it is preferable to ask *by how much* is the project likely to delay, with possible answers ranging from 0 to anything, when the result indicates either the absolute deviation in time units (days, months etc.) or the relative deviation in percentage from the original duration of the project.

On the other hand, an estimate of a continuous answer is also flawed. The estimate being used is usually not defined explicitly, so all common estimates are allowed: mean, median, mode, maximum or any arbitrary estimate. Hence, the documented estimate is biased, and it only represents part of the answer, and does not allow Utility calculations. For the evaluation of delay, for instance, the matrix usually displays only the likeliest delay, say (3,3), which means, for example, 50% probability for a 50% delay, which provides very little information. With the rest of the distribution ignored, a lot of information is lost, and the estimation does not allow further inquiry of the entire stochastic behavior of the event or risk source. When several assessors are involved, the estimate used may vary from person to person, due to cognitive, perceptional factors which cannot be traced easily. Moreover, people asked to provide point estimates will tend to think in terms of point estimates rather than assess the entire distribution and then provide an estimate based on this distribution. It may even be possible that assessors will not be able to tell what type of estimate they chose. Eliciting the full probability distribution may be time- and effort-consuming and may not be easily displayable using a two-dimensional matrix (unless some more graphical techniques, like bubble radiuses, are used).

It has been shown that multiplying values from grids is mathematically wrong to begin with, since these numbers do not represent aligned ordinal values and therefore standard algebraic operators do not apply to them straightforwardly [39]. Formally, if a set of values $V=\{1,2,..,N\}$ indicating probability or impact estimates has no single bijection function $y=f(n)$ to a set or subset of Real Numbers {R} or Natural Numbers {N} such that for all n in V there is a matching y in $Y, Y \subset \mathbb{R}$ such that $|V|=|Y|$, then the operations of addition and multiplication do not apply to the set members. The multiplication of the measures is incorrect and misleading and both properties should be considered together, not their product, even when probability is defined in [0,1] and impact is defined in [0,1] or R [40].

4.3.5 The Risk Management (RM) Process

The RM process modeling and management literature comes mostly from the risk management domain, as well as from domains in which RM is a primary and critical activity, e.g., project management, systems engineering, and information technology. Various associations and large-scale organizations have developed RM frameworks, both as part of general management frameworks and as dedicated risk-centered approaches. Leading standard providers are the Project Management Institute (PMI), International Organization for Standardization (ISO), National Association of Space and Aviation (NASA), National Institute of Standards and Technology (NIST) and International Council on Systems Engineering (INCOSE).

The ISO 31000 Risk Management Standard defines a framework for risk management, which includes an iterative risk analysis process, and concurrently, ongoing communication and monitoring [41]–[43]. An illustration of the ISO 31000 framework is shown in Figure 4-3.

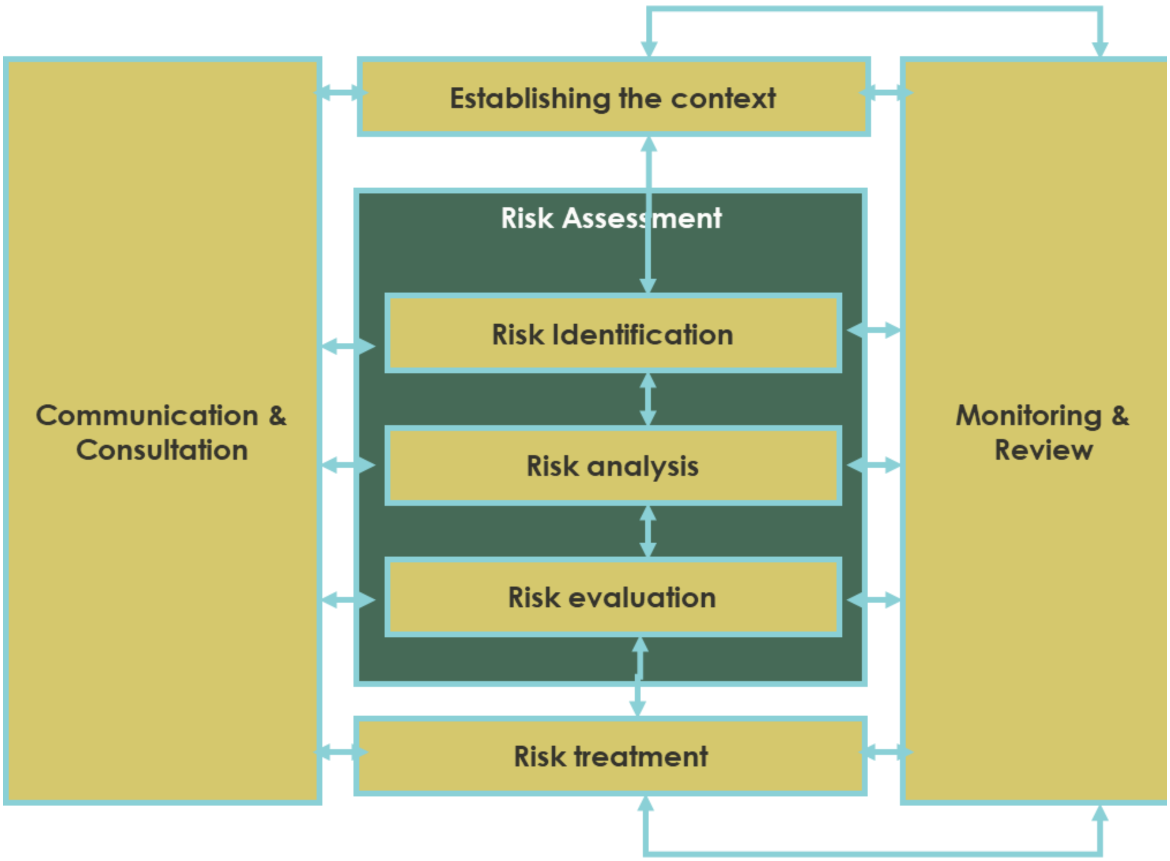

Figure 4-3. The ISO-31000 Risk Management Process

4.3.6 Uncertainty and Risk Management During Emergencies

One of the primary purposes of EMS is to reduce epistemic uncertainty, i.e. uncertainty related to knowledge gaps. Studies have shown that bombarding the user with information is not necessarily helpful in closing knowledge gaps, and may even generate stress and discomfort among the users due to their inability to cope with the flow of information [44] . Strategies for information visualization to improve clarity and reduce uncertainty include clustering, partitioning, 2D-binning, and abstraction – usually in 3-4 layers [45].

In addition, another purpose of EMS is to assist in risk management by promoting decision making for risk probability and impact reduction. **Therefore, each object that generates risk and each object that could be impacted by risk should be clearly visualized to the user, in order to promote prioritized treatment. That said, sources of risk should be clearly distinguished from objects at risk, including persons, assets, and processes.**

At present, the body of knowledge binding the emergency decision making and command & control procedures with risk analysis and risk-based reasoning is underdeveloped, and additional research has to be conducted in this direction.

5 CONCLUSION

This document has presented the results of research on advanced visualization and interaction capabilities for enhanced situational-awareness and emergency preparation and response management. The purpose of this research was to introduce state-of-the-art approaches to underlie the user experience design for the Control Center: the primary front-end interface for the operational management before and during the emergency, as part of the beAWARE platform for natural disaster management.

We have begun this research by clarifying and crystallizing the user requirements and operational evaluation criteria for the beAWARE project, and derived the ad-hoc visualization and interaction requirements for the Control Center.

We have then presented relevant work on topics such as emergency management, decision and risk analysis, and information visualization. The conclusions and insights generated from the research assisted in defining and verifying visualization and interaction functionalities for the Control Center.

Based on these results, we have defined a flexible, robust, and extendable user experience (UX) framework, which accommodates the use of multiple operational roles (e.g., City Authority, Incident Manager, and Operations Manager) based on role-based compositions of various UI building blocks.

The UX framework will be used as the reference and basis for the detailed UI and supporting business logic design and development. The way incidents, teams, tasks, and metrics are shown, managed, and controlled, will be clearly affected by the state-of-the-art concepts and approaches discussed, especially in the area of or in association with emergency management, and the UX design inspired by the user requirements, system requirements, and state of the art.

Further work is needed in the areas of field team interaction with mobile devices, as well as analysts with modeling and analysis tools, in order to cover the entire visualization and interaction of the beAWARE system. However this work is beyond the scope of the current WP, and is intended to take place in the corresponding WPs.

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