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 [1]

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. The outcomes of this research are expected 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 the visualization aspects related to 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 in complex end-to-end interactions with the first responders, volunteers, citizens and other field-based agents participating in preparedness and overcoming of the extreme weather conditions and natural disasters.

Part A, which is open to the public, and constitutes the bulk of beAWARE Deliverable 6.1 focuses on understanding of the operational view, including the current state as experienced by beAWARE Partners representing organizations dealing with Heatwave, Flood, and Fire natural disasters, their operational requirements and expectations, we study the state-of-the-art literature on emergency management systems, decision making, risk analysis, and information visualization – knowledge areas with high relevance to the problem at hand. The purpose is to rely on the state-of-the-art and promote it further by: a) incorporating these technologies into the emergency management domain, and b) advancing emergency management with additional capabilities such as end-to-end connectivity and interoperability.

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.

[1] Modified in V2.0

ABBREVIATIONS AND ACRONYMS[2]

Acronym	Full Term
2D	Two-Dimensional
3D	Three-Dimensional
C2	Command & Control
C3	Command & Control Center
CA	City Authority / Administration
DOMS	Dispatch and Operations Management
DRS	Disaster Resilience
DSS	Decision Support System
DSV	Decision Supporting Visualization
EMAP	Event Map
EMC	Emergency Management Centre
EMS	Emergency Management System
FR	First Responder
IM	Incident Manager
INCM	Incident Management
IVISE	Information Visualization and Interaction Services for Emergency
OM	Operations Manager
PA	Public Alert
PALM	Public Alert Management
PSAP	Public Safety Answering Point
RBV	Role-Based Visualization
UI	User Interface
UX	User Experience
WP	Work Package

[2] Modified in V2.0

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PART A: OVERVIEW AND ANALYSIS OF THE OPERATIONAL VIEW AND THE STATE OF THE ART IN EMERGENCY MANAGEMENT (PUBLIC)

This section concludes the study of the operational view of the beAWARE end users regarding emergency management in general and the emergency operations centre in particular. This includes a description of the current situation in emergency management (state of the practice), as well as the end users' expectations and operational requirements, evaluation criteria, etc.

This section also provides an in-depth review of the state of the art as reported in scientific and professional literature.

This section of the document is open to the public and constitutes the bulk of deliverable D6.1 – the public derivative of D6.5 (both of which are the outcomes of task T2.1).

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 emergency management center (EMC) control system of beAWARE, further referred in the Project as "Public Safety Answering Point" (PSAP).

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.

This document does not discuss visualization and interaction in the context of mobile devices, analytics services, or other components and services of the beAWARE platform, which are out of the scope of the WP6.

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 Methodology [3]

The methodology implemented in T6.1 and summarized in this deliverable consists of the following main phases:

a. Learning from studies on state-of-the-art techniques for visualization and interaction techniques for command and control centres in general and for emergency management centres and situations in particular.

b. Understanding of the current state of situation at beAWARE operational partners as representatives of Public organizations dealing with preparedness, management and consequences of Heatwave, Flood, and Fire natural disasters.

c. Gathering user requirements and expectations related to visualization and interaction capabilities for the EMC operators.

d. Specifying a framework for the user interface, which accounts for the operational, visual, and functional aspects of the EMC operator's user experience while interacting with the system.

e. Adopting the Motorola Solutions design system as the basis for the UX Design of the PSAP application.

f. Validation through continuous reviews and discussions of the UX framework by the AAWA, FBBR, HRT, and PLV partners as representatives of Public organizations dealing with preparedness, management and consequences of Heatwave, Flood, and Fire natural disasters.

g. Evaluation of the UI in the Project integration sessions and demonstrations.

1.4 Outline

This document is structured as follows:

Part A comprises sections 2 through 5, and is open for public access.

- Section 2 reviews the state of the practice as experienced by the end users, end-user expectations and requirements, technical system requirements, functional implications, and performance criteria related to visualization and interaction at the Emergency Control Center level.

[3] Added in V2.0

- 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 the public section of this document, which contains the operational view and the literature review.

Part B, comprising sections **Error! Reference source not found.** to **Error! Reference source not found.**, which is restricted to the EC officers and consortium partners, includes a specification of the visualization and interaction functionality in the PSAP UI.

- Section **Error! Reference source not found.** provides an overview of the PSAP environment and system, including system requirements derived from the operational requirements.
- Section **Error! Reference source not found.** introduces the conceptual framework for the User Experience and User Interface design.
- Section **Error! Reference source not found.** introduces the designated PSAP actor roles and their required functionality and integrated displays.
- Section **Error! Reference source not found.** introduces the building blocks and visual/interactive components of the UI, which compose the role-based integrated displays.
- Section **Error! Reference source not found.** provides a report on the end users' feedback, evaluation, and validation of the specification provided in this document.

This document uses the IEEE citation convention.

As this document constitutes a major revision, we added an appendix which includes a list of comments from the first project review and the response that we have integrated into this revised version, including references to the sections in which the responses were integrated. In addition, each modified or newly-added section is marked with a footnote relating to the specific comment(s) that its revision or addition address.

2 The Operational View [4]

2.1 Scope

In this section we review and analyze the operational perspective and viewpoint of AAWA, FBBR, HRT, and PLV partners as representatives of Public organizations dealing with preparedness, management and consequences of the Heatwave, Flood, and Fire natural disasters. This includes an understanding of the current state of the practice, requirements for visualization and interaction that refer to the control center, and evaluation criteria that the operational stakeholders will use to evaluate the outcome. 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 State of the Practice [5]

In this section we describe the current state that the beAWARE operational partners (AAWA, FBBR, HRT, and PLV) face nowadays.

2.2.1 Flood Emergency Management – AAWA

The Alto Adriatico Water Authority (AAWA) is responsible for the management of the rivers flowing into the Northern Adriatic Sea, namely Isonzo, Tagliamento, Livenza, Piave, and Brenta. AAWA is responsible for the development and implementation of river basin management plans that lay down policies and measures for optimization of water use, hydrogeological and flood defence, protection of water bodies, and regulation of water rights in the basin as a whole.

AAWA has a technical staff highly qualified in software applications to planning hydrology and hydraulic issues. AAWA offers a range of programs along with several thematic areas including but not limited to Disaster risk management systems, Early warning system for flood defense, Fluvial and Coast Hazard Evaluator and Risk mapping. AAWA performs a key role in the pre-emergency phase.

[4] Modified in V2.0.

[5] Added in V2.0

AAWA has developed the Flood Forecasting Model AMICO to predict river water levels for the Bacchiglione River. This model is running continuously in AAWA servers and in parallel in the Civil Protection Veneto Region Office, moreover AAWA can decide to execute AMICO on request. If the results of AMICO, together with the meteorological scenario at regional scale, show a possible dangerous situation for the next days, the Veneto civil protection authority emit a hydraulic bulletin which shows an alert for the basin of Bacchiglione river. The bulletin comes by email, fax, or sms; It is also available on the website of the Veneto Region.

Delegates of AAWA join the decision makers in the control room during the occurrence of the emergency itself, to provide support and knowledge about flood risk management according to the river basin management plan and flood risk maps.

The Civil Protection chain in Italy is a complex and dynamic System specifically settled during emergency, which involves not only the Civil Protection Agency itself, but also several public authorities such as:

- Fire brigades (VVF)
- Armies (Carabineers, Police, Navy, the Army, Air Force...)
- Italian red cross (CRI)
- Sanitary agency (ULSS)
- Various associations of volunteers (based on the specific emergency that occurs)
- Various public societies and agency (such as AAWA itself, based on the specific emergency that occurs)

Based on the geospatial extent and the severity level of the crisis, these authorities are involved at different level (local, regional, national...).

In Italy, the lowest possible administrative level owns the responsibility for implementing civil protection measures. For this reason the mayors are the primary civil protection authorities within their municipalities and are thus responsible for preparedness and rescue operations.

In case of concrete emergencies, coordination and operational activities are carried out through a multi-level hierarchical organization:

- **Municipal**: City Operational Centres (COC) and local crisis units (UCL).
- **Provincial**: Mixed Operational Centres (COM) and Rescue Coordination Centres (CCS).

- **Regional**: Regional Operations Centres (COR)
- **National**: the Direction of Command and Control (DICOMAC)

A hierarchical command and control structure is established at the higher levels (e.g. for the DICOMAC). However, municipal emergency management structures are less rigid, with no fixed definition of roles and hierarchy. Rather, response to the local emergency is more flexible, adaptive, and dependent on the involvement of different people carrying out roles as needed. Municipal emergency management protocols are also general and not very strict.

In the Vicenza test case, for example, the Mayor, as the head of the Civil protection chain at the municipal level, receives bulletins from the early warnings and forecasting systems (e.g., meteorological National or Regional Weather forecasting services, AMICO flood bulletins, etc.). In addition, the mayor receives measurements from sensors that cover the Veneto Region. If these data show a possible incoming flood, the mayor can decide to officially establish the COC (crisis operative center) and summon the local civil protection volunteer group to safeguard the city center from the passage of the flood wave and thus to.

The COC members (AAWA, Municipal technicians, Fire fighters, Province of Vicenza, Municipal Police, Italian Red Cross, Vicenza Company for multi-utility services , Civil Protection Volunteers…) are informed by mobile phones communication.

After the activation of the COC a set of pre-emergency procedures are performed, such as sending volunteers to monitor the water level. Other teams of civil protection volunteers are usually posted in the municipality's warehouse to prepare flood prevention equipment (aquadike, sandbags). Sandbag distribution stations are listed in the Municipality's website). Sanitary provides also a PMA (medical post) to rescue the population in case of flood.

All communications are conducted over radio communications using personal mobile radio devices (PMR), leading to the loss and lack of suitable logging and tracking of information and reports. Many volunteers have no smartphone or internet reception.

During the emergency phase (e.g. during the occurrence of the flood), the Mayor and the COC decide on the actions that have to be taken to cope with the evolving crisis. Decisions include deployment of first responders, task assignment to first responders and rescue teams, determination of the level of alarm in the city, closure or evacuation of areas of the city, and declaring the end of the emergency.

Most of the communication is performed over Land Mobile Radio. Volunteers provide reports of the flood damage observed and of their actions during emergency to municipality technicians.

When the emergency ends, the Mayor adjourns the COC and convenes a press conference to inform about the emergency status.

The Regional government may request the municipality to provide impact maps and data (flood damage estimation, flood expansion, etc…).

2.2.2 Forest Fire Scenario – PLV, FBBR

PLV is the local police force of the Valencia Municipality and metropolitan area. One of the major hazards in the Valencia area is the La Devesa forest reserve, which is vulnerable to fires and may jeopardize nearby population as well as visitors to the forest. As the local police force, PLV oversees the emergency management efforts before and during forest fire emergencies.

The system used for the emergency management is called SIRE (Integral System of Emergency Response), based on Oracle RAC (Real application Cluster). With this system, PLV officers are able to geolocalize resources through their personal mobile radio devices (EADS THR880i portable radio), which are connected to a land mobile radio (LMR) TETRA network. (European standard. 380-400Hz). The capability to engage the organic emergency response teams seem to be adequate as well. PLV's PSAP staff pleased with the conditions and communications of the center. PLV's modus-operandi is relies on daily fax reports from the 112 center (emergency call centre), in containing climatological emergencies for the coming day (if existent). A real time index of climatological risk would be more accurate and useful than our current way. Currently, PLV's PSAP does not provide a real-time updated view of risk levels.

The PSAP is commanded by the highest-ranking police officer on duty, who keeps direct communication and coordination with local authorities and with the fire and rescue services. When an emergency situation begins, a Command Advanced Post is established close to the incident, including representatives of every organisation involved in the emergency management or response (First responders, Security, Health services, logistical support, social action). The Command Advanced Post manages the emergency, in ongoing communication with PSAP. The organizational structure for each emergency level is illustrated in the three consecutive figures below.

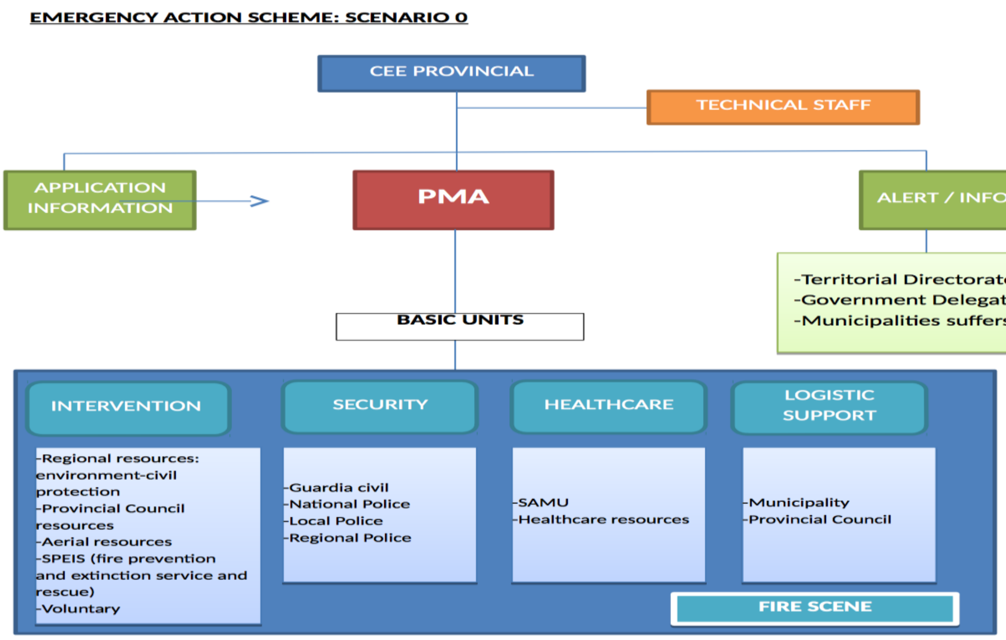

Figure 2-1. PLV's Organization Structure for Emergency Level 0

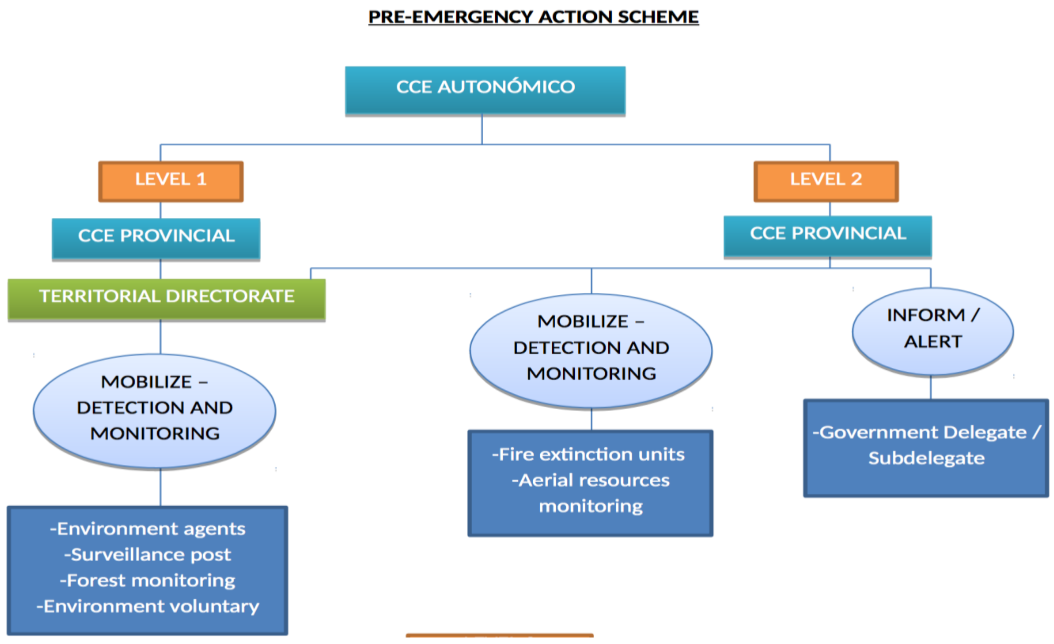

Figure 2-2. PLV's Organization Structure for Pre-Emergency

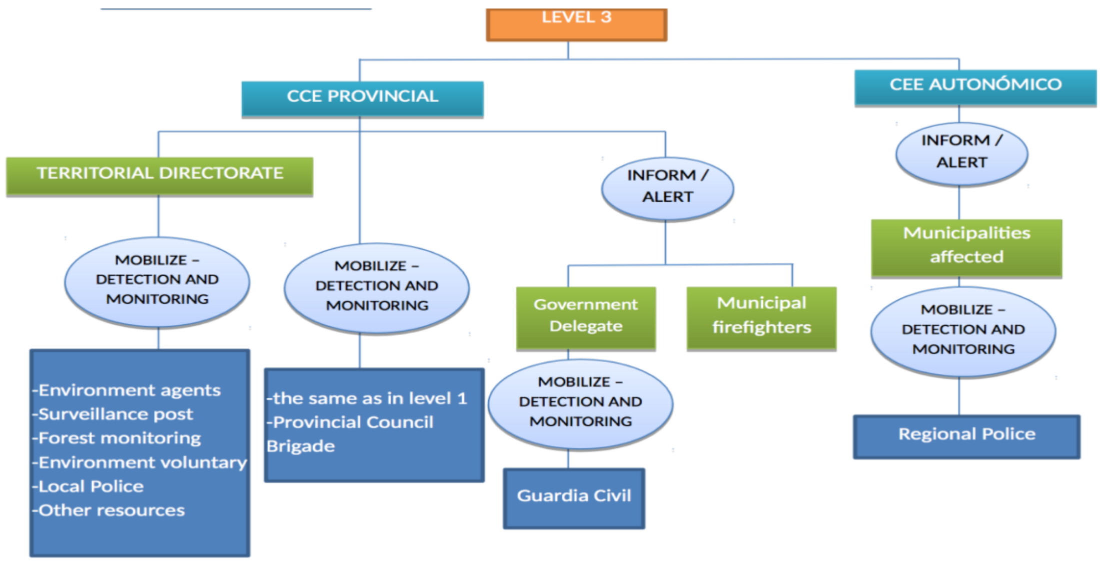

Figure 2-3. PLV's Organization Structure for Emergency Level 3

FBBR provides fire and rescue services to the six municipalities of Frederikssund, Halsnaes, Hilleroed, Gribskov, Egedal and Furesoe in the center of the island of Zealand, in Denmark. The area, 1058 square miles, houses approximately 250.000 inhabitants. FBBR works according to the Danish Emergency Management Act, issued by the Danish Emergency Management Agency (DEMA).

FBBR's mission is to provide rapid response services in emergency situations. This includes the following:

- Prevention of and responding to fires, road accidents, flooding, fires at sea, hazardous material and chemical incidents, major incidents including terrorist attacks, boat preparedness and providing other humanitarian services such as rescuing casualties from a variety of emergency scenarios.
- preventative work and includes fire and safety inspections, fire safety building design, fire hydrant maintenance, basic firefighting courses, etc.

Following DEMA's recommendation, FBBR follows a Comprehensive Preparedness Planning (CPP), which is composed of seven pillars: (1) programme management, (2) planning, (3) prevention, (4) crisis management, (5) training, (6) exercises, and (7) evaluations. The concepts and models applied include Risk-Based Dimensioning and Vulnerability Analysis.

The crisis management unit (CMU) has been structured and organized following standard/best practices, which includes continuous implementation of lessons learned based on the evaluation of past disasters. Crisis Management activities handled by the CMU include:

- **Activation and operation of a crisis management organization**, a fixed organizational setting with well-known and tried procedures. This happens as soon as it is realized that an extraordinary incident has occurred, which requires crisis management.
- **Combined Situation picture and Information management**, collect, analyse and distribute relevant information about the crisis in all of its phases; Provide information to decision makers in critical timing; sensible management of the information flow; recording and writing down critical information,
- **Coordination of activities and resources**, generating a collective overview of ongoing actions and resource allocation at the central level and in decentralised units; instructions for how employees and other resources can be transferred between different units during a crisis; principles for decision-making competence, including how such competence is delegated from the strategic to the operational level; procedures for authorising executives to obtain and dispose of extraordinary large sums, so that crisis managers are not forced to act on an uncertain or insufficient financial basis.
- **Crisis Communication**, set up a dedicated crisis communication team, that can ensure a timely, reliable, and open crisis communication through the organization's internal and external channels - media, citizens, partner organisations and other stakeholders.
- **Operative response**: deploying personnel and equipment in the field or performing tactical/operational crisis management, while addressing key operational factors: Who?, How?, When?, Why?, What?. Preparing and executing response plans at national level in a relation to the national risk profile and at the municipal level.

Primary roles within the CMU include (core roles are marked in bold)

- Crisis Management Chief of Staff
- Crisis Information & Communication Team/ Officer
- Resource Coordination Team (including HR and Legal)

- Response and operations Team
- IT Support and Logistics Team
- Secretariat and Administrative Team

Additional services and activities include:

- Operate emergency call out centres,
- Inspect fuse cabinets and shelters, technical arms, equipment, and gear
- Arrange accommodation and provisioning during natural disasters and catastrophes.
- Participate in emergency service provision,
- Provide support to pensioner organizations,
- Provide Emergency pre-hospital fires response services.
- Conduct courses and training to school children and the general public.

All emergency calls are managed by emergency call centre (ECC) at 112 for ambulance, police and fire services. The ECC asks callers for their name, address, and phone number. The call centre makes sure that appropriate help is sent immediately. The ECC transfers calls regarding fire and rescue to FBBR.

FBBR is using the Online Data Registration and Reporting System (ODIN/ODIN-GIS), developed and operated by DEMA. This system supports the municipalities carrying out tasks in relation to the municipal rescue preparedness. The system must provide a reliable data base that can be used in connection with municipal plans for risk-based dimensioning, prevention, supervision, counseling, research, trend analysis, etc. ODIN provides data to support a) the capabilities of the emergency rescue team, and b) emergency and assistance activities.

FBBR publishes emergency information on its website (fbbr.dk), Facebook and Twitter.

FBBR plans and executes prevention plans and measures following a risk-based dimensioning approach, with respect to risk scenarios (wildfire, flood, etc.). These include the following aspects:

- **Systems** for physical protection, information systems, secondary sites,
- **Procedures** for e.g., alert from authorities, early warning, monitoring, internal alarm, emergency plans, evacuation plans, crisis management organization (CMO),

- **Behavior** e.g. crisis communication, education and exercises, information on safety and preparedness etc.)

Similarly, operative response is also planned per risk profiles in representative scenarios. This includes the utilization of FBBR staff, organic workforce, and volunteers, as well as potential support by DEMA within 2 hours from contact and from neighboring municipalities.

Existing visualization and interaction mechanisms in support of FBBR's CMU include:

- **UMS.** SMS service for handling a given emergency situation immediately and effectively. Allows the user to alert large groups of people in established distribution lists. See Figure 2-4.

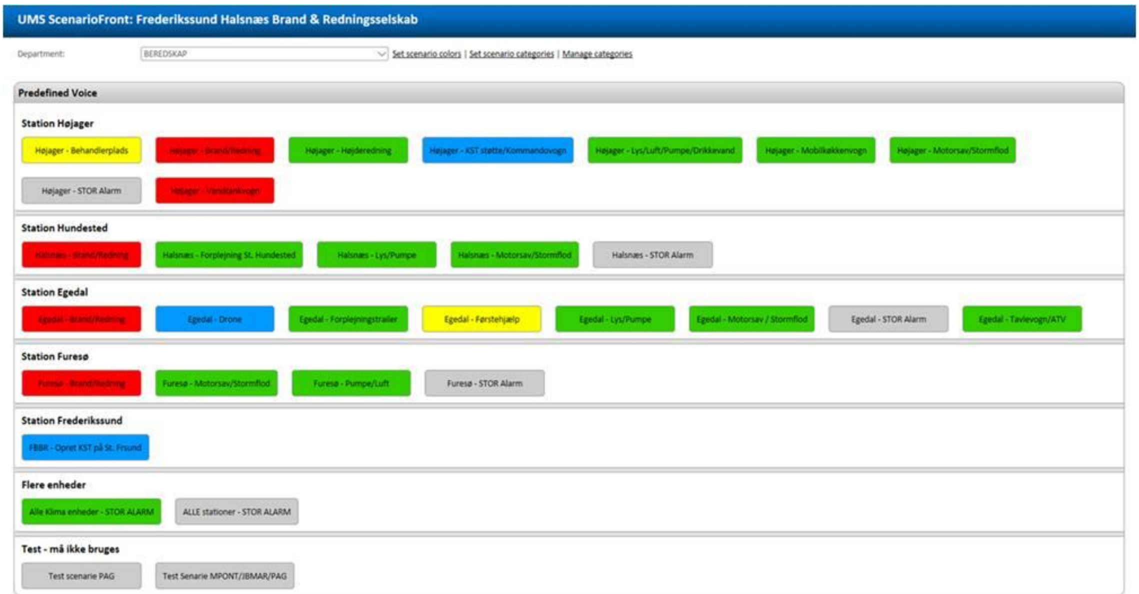

Figure 2-4. FBBR's UMS Module for Alerting Volunteers

- Weather Forecast Services – DMI (Danish meteorological Institute) – 4hr update frequency.

30/10/2017 | Frederikssund S | Tabel

Frederikssund S 30. oktober 2017 Målinger Prognose DMI

00:00	+130	04:00	+127	08:00	+116	12:00	+ 91	16:00	+ 70	20:00	+ 67
00:10	+130	04:10	+127	08:10	+115	12:10	+ 90	16:10	+ 70	20:10	+ 66
00:20	+129	04:20	+126	08:20	+114	12:20	+ 89	16:20	+ 70	20:20	+ 66
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00:50	+129	04:50	+126	08:50	+112	12:50	+ 86	16:50	+ 69	20:50	+ 64
01:00	+128	05:00	+125	09:00	+111	13:00	+ 85	17:00	+ 69	21:00	+ 64
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01:30	+128	05:30	+125	09:30	+108	13:30	+ 82	17:30	+ 68	21:30	+ 62
01:40	+128	05:40	+124	09:40	+107	13:40	+ 80	17:40	+ 68	21:40	+ 62
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03:30	+129	07:30	+116	11:30	+ 94	15:30	+ 72	19:30	+ 68	23:30	+ 55
03:40	+128	07:40	+116	11:40	+ 92	15:40	+ 71	19:40	+ 68	23:40	+ 55
03:50	+128	07:50	+116	11:50	+ 91	15:50	+ 70	19:50	+ 68	23:50	+ 54

Hent målinger som CSV

Den gyldne linje angiver en beregnet værdi for en 20 års hændelse. Se Kystdirektoratet Højvandsstatistik

Alle klokkeslæt er i dansk tid, dvs. henholdsvis normal- og sommertid.
Vandstanden måles i forhold til det danske højdesystem, Dansk Vertikal Reference 1990 (DVR90).

Målingerne præsenteres i samarbejde med Kystdirektoratet og en række kommuner og havnemyndigheder.

Se data-leverandørerne

Figure 2-5. FBBR's Interface to DMI's weather forecast services

- ODIN/ODIN – GIS
- Mapping
- **GIS.** Map visualization service.
- Maps from Response and action plans
- **Municipal and regional maps** (forests, flood planes, urban infrastructure etc.)

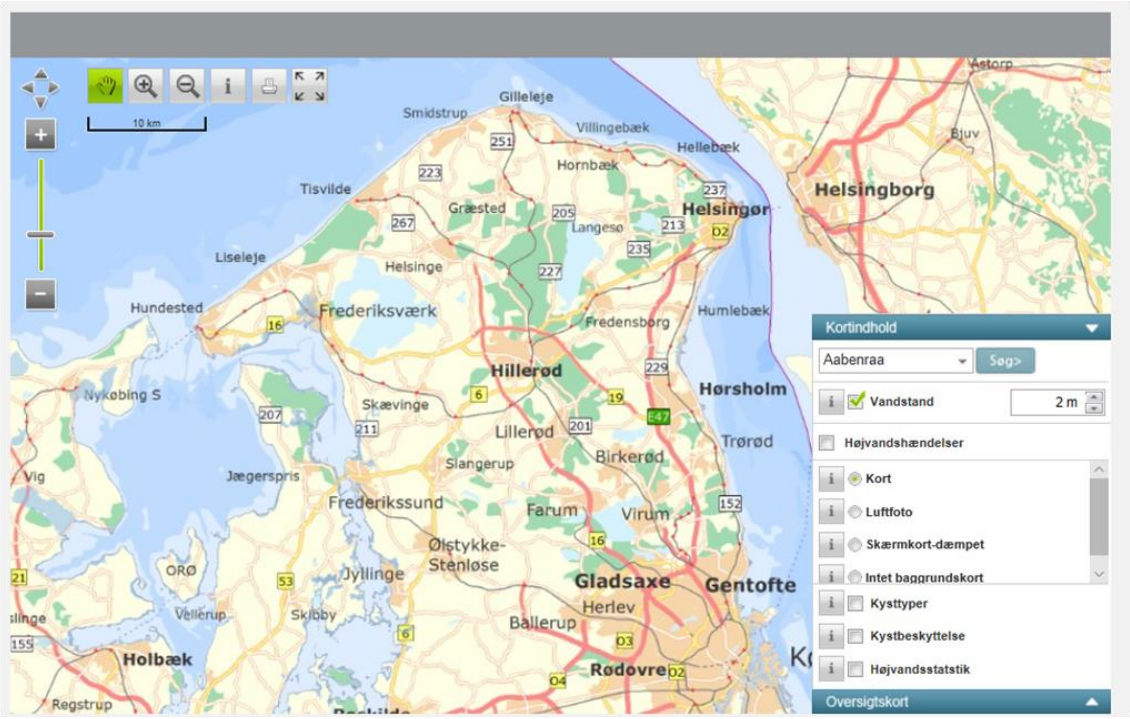

Figure 2-6. Flooding Forecast Map

- **TETRA.** Mission-Critical Land Mobile Radio (LMR) Communication System.
- **Personal communication systems:** mobile phones (GSM), pager, landline phones
- **Public media: FM-Radio, national TVl**
- **Siren – public warning.** See Figure 2-7.

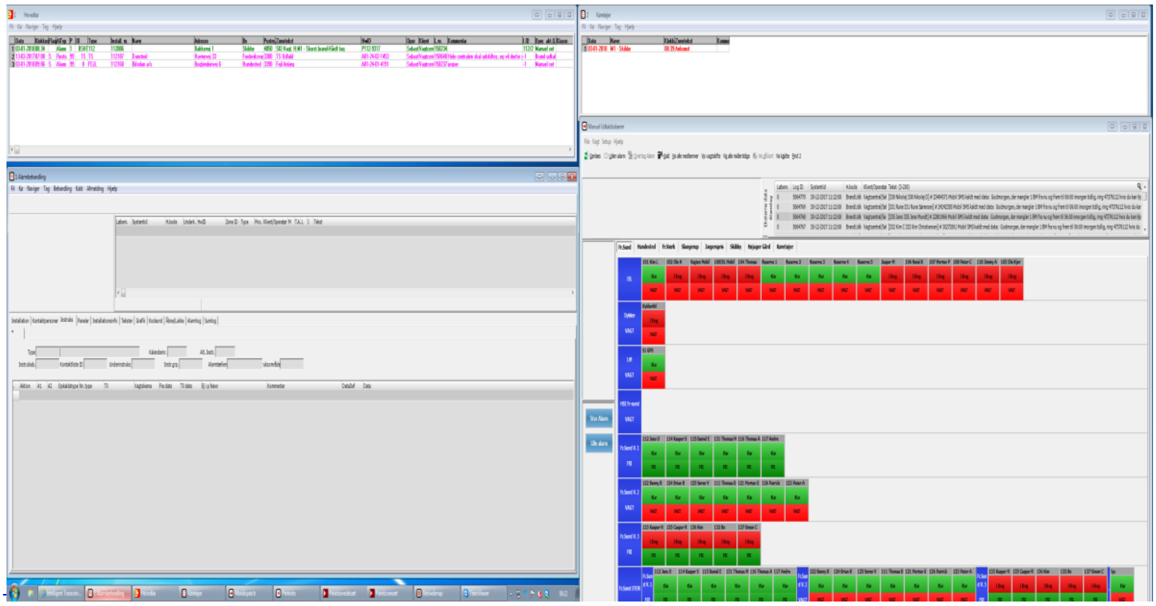

Figure 2-7. FBBR's Public Alarm Module

2.2.3 Heatwave Scenario – HRT

Hellenic Rescue Team (HRT) is one of the largest volunteer organization in Greece with more than 30 branches. It supports the Hellenic Civil Protection Authorities in national, regional and local level, the Hellenic Fire Brigade, the Hellenic Coast Guard and other national or local organizations and entities.

HRT strategic goal is to provide help and support, in rescue operations, in mountains, sea, earthquakes, fires, search & rescue (SAR) missions and generally first aid support wherever we are able to provide it. Moreover, HRT continuously educates and informs citizens with first aid, sea, mountain, earthquake and fire safety lessons.

Currently, HRT has no central information system. Information from public authorities is provided by phone, e-mails, VHF radio communication, or social media (Facebook, twitter). HRT's Head of Operations notifies relevant heads of departments, depending on the incident. All available department members are notified and informed about the situation or the incident based on the information provided downstream.

Moreover, Currently HRT has no early warning system. HRT asks the national early warning service from the General Secretariat of Civil Protection in Greece to relay alerts to institutions and authorities, and acquires requested data depending on the situation.

HRT faces various organizational and operational challenges, especially during a mountain, sea, or forest-fire operation. A platform that will support the emergency management, before, during and after the operation is one of the most important needs of HRT.

HRT currently organizational structure has a multilevel command and control structure. Since HRT is one of the largest volunteer organization with experience and participation in many SAR operations, it closely cooperates with national and local authorities and their PSAPs. The operations division acts as the operational link between HRT and other agencies (GSCP, Fire Service, Air Force, UN, EU, etc.). Before an emergency, HRT's operations division cooperates and communicates with international, national and local authorities, and participates in meetings and trainings in simulated and tabletop scenarios. During an actual operation this team communicates with the national (or local) authorities and directly with HRT rescuers in the field. The rescuers in the field communicate with the On-Scene Coordinator (OSC) and the command and control operation team via VHF or mobile.

In order to achieve its aims, the Operations Division uses modern electronic and telecommunications equipment, as well as special IT applications. It has four mobile telecommunications centres with the code name “HERMES”, which are equipped with various kinds of telecommunications devices and other equipment. The Operations Division is also responsible for running the HRT’s radio network. The equipment that HRT uses is: VHF/UHF and HF radios, mobile phones, GIS and other online and offline maps, Hellenic Meteorological Institute data, national and local maps, etc.

The main roles in HRT's operation centre are:

- Head of the operation division at HRT HQ / Director of Mission
- Operation Division board at HRT HQ
- Head of the operation division at HRT local branch
- Head of the responsible Department
- On-Scene Head of the operation

2.3 User Requirements for EMC Visualization and Interaction [6]

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.

2.3.1 User and Stakeholder Expectations [7]

The Stakeholders of the operational scenarios listed expectations for a system that will be able to provide added value in several ways.

[6] Revised in V2.0

[7] Added in V2.0

HRT indicated that beAWARE can fulfill HRT's expectations and requirements in a very significant way. More specifically, the beAWARE platform can contribute to improve HRT's preparedness, planning, and most of all emergency management. FBBR indicated that the platform can significantly support its comprehensive preparedness planning program.

Following is a list of expectations collected and summarized from the beAWARE operational partners as representatives of Public organizations dealing with preparedness, management and consequences of Heatwave, Flood, and Fire natural disasters.

- Improving scenario building and scenario simulation/prediction through dimensioning of the operative and preventive response in case of disasters such as wild-fire, floods, and heatwaves.
- Improving emergency training and preparedness of staff, volunteers, and citizens.
- Improving crisis communication among authorities, HQ personnel, operators, first responders, and citizens
- Improving support for decision-makers at local and regional level, and improving decision making among the municipality authorities (including fire and rescue service)
- Estimation of impact on the affected people, infrastructure etc.
- Creation of the situational picture in real time including the positioning and monitoring of incidents, teams, and resources.
- Better Coordination of resources
- Early warning to citizens in case of fire and flood (e.g. by using an App)
- Better Weather prognosis/prediction/simulation (e.g. updating every 2-3 hours)
- Friendly user interface and visualization
- Training and increasing awareness of citizens through the beAWARE app
- Demonstration of visualization of critical information such as the positions of relief places, power outages, traffic jams, etc.

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].

2.3.2 Derivation of Visualization/Interaction Modalities from User Requirements[8]

For each user requirement, we determined the visualization/interaction modality needed to satisfy the requirement. There was no intention to create a dedicated user interface to comply with each requirement. Rather, we determined a minimal set of interfaces that covers as many requirements as possible while offering a holistic experience which supports the operational processes. Therefore, we tried to identify similar or complementary patterns in the requirements and focus on a set of modalities that will underpin the conceptual definition of UI building blocks.

Table 2-1. Initial Operational User Requirements [1]

UR#	Requirement name	Requirement description	Implied/Expected Interaction Modality[9]
UR_101	Type of visualization	Display information to authorities in a web-gis platform (citizen and first responders reports)	Event Map
UR_103	Flood warnings	Provide authorities/citizens with warnings on river levels overtopping some predefined alert thresholds, based on forecast results	Alert/Warning Display
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	Event Map integrated with media viewer
UR_108	Localize task status	Provide authorities with the ability to localize first responders reports regarding the status of their assigned tasks	Event map integrated with Task management
UR_109	Localize tweets	Provide authorities with the ability to localize Twitter messages concerning a flood event	Event map integrated with social media reports
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	Risk assessment metrics
UR_117	Manage assignments in case of new emergencies	Provide authorities with the ability to manage first responder assignments	Task management interface

[8] Added in V2.0

[9] Added in V2.0

UR#	Requirement name	Requirement description	Implied/Expected Interaction Modality[9]
UR_118	River overtopping	Provide authorities/citizens with the ability to know if the river level is overtopping predefined alert thresholds	Alert/Warning Display
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 status of the assigned tasks	Event map with informative icon semantics
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)	Risk prediction metrics
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	Public Alert/Warning Editor-Generator
UR_213	Recommendations	Sending recommendations to citizens.	Public Information Editor-Generator
UR_214	Warnings	Sending warnings of pre-emergency alerts to citizens by authorities	Public Alert/Warning Editor-Generator
UR_215	Evacuation orders	Ordering evacuations of citizens at risk.	Public Instruction Editor-Generator
UR_302	Automatic warning	beAWARE system to generate and provide the authorities with an automatic warning when an imminent heatwave phenomenon is forecasted	Event Map Emergency metrics
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	Risk prediction metrics
UR_306	Number of people affected	Provide the authorities an estimation of the people that might be affected from the [heatwave] phenomenon and in which areas	Emergency metrics
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.	Task management
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	Informative Summary/ emergency overview display

UR#	Requirement name	Requirement description	Implied/Expected Interaction Modality[9]
UR_313	First responders status	Provide to the authorities the current status and location of all first responders when they are performing their tasks	Workforce monitoring interface
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	Workforce monitoring interface integrated with task management interface
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	Emergency Statistical metrics
UR_318	Trapped citizens	Allow authorities to know if there are people trapped and display where	Map-based Incident display
UR_320	Hospital availability	Show to the authorities the current availability of the hospitals.	Emergency Statistical metrics
UR_332	Localize tweets	Provide authorities with the ability to localize Twitter messages	Event map
UR_334	Manage assignments in case of new emergencies	Provide authorities with the ability to manage first responder assignments	Task management interface
UR_335	Map of rescue teams and task evaluation	Display to authorities the position of first responder teams and provide the status of the assigned tasks	Workforce monitoring interface
UR_337	Location of vehicles and personnel involved	Allow authorities/first responders to visualize position of vehicles and teams on the incident site	Map-based Workforce monitoring

2.4 Operational Evaluation Criteria [10]

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.

As part of the revision of this section we have consolidated and applied a holistic view to all the operational scenarios, in order to ensure a unified experience and generic approach to natural disaster management. This was done without discriminating system objectives in the context of specific scenarios. Each criterion was elaborated with a set of measures and assessment factors that reflect the added value the users

[10] Modified in V2.0

will expect to see, and in some cases specific capabilities. In some cases the same aspect can support multiple evaluation criteria. For instance, different icons on a map can support several evaluation criteria as it can help decision making, planning, preparation, and emergency operations.

The main goal for the flood pilot is to support decision makers in the case study area (City of Vicenza). A set of qualitative criteria to evaluate the platform from the end-user point of view were devised and proposed, in order to assure that beAWARE is aligned to this purpose.

The main goal for the fire scenario is to support comprehensive preparedness planning for wildfires (e.g. planning of preventive measures and operative response) as well as during the incident-phase, including support for decision makers in the fire and rescue service and in preventing fires. FBBR's implementation of the above aspects during the CPP includes (1) programme management, (2) planning assumptions, (3) prevention, (4) crisis management and crisis management plans, (5) training, (6) exercises, and (7) evaluations. The concepts and models such as Risk Based Dimensioning, Risk and Vulnerability Analysis, Risk matrix and estimation of impact, Crisis Management (activation and operation of crisis management organization, coordination of activities and resources, communication, information management, situation picture, and operative response).

For HRT, the main goals for coping with a heatwave crisis are to support and inform decision-makers before, during and after the crisis, to improve alert to citizens, authorities and rescue teams, to maximize response to heatwave-related incidents, to manage and monitor relief places and their capacity, to monitor infrastructure incidents (power outage, traffic blockings), and to allow the operations team to oversee the activities and whereabouts of field rescuers positions and tasks.

Expected utilization:	**Support planning for better disaster resilience and preparedness**
Operational Evaluation Criteria	Verify that the beAWARE platform provides valuable information for planning a better flood/fire/heatwave management even when no crisis is imminent; verify that it provides the user with reference information (e.g. measure, hazard maps, etc.) coming from external sources.
Qualitative metrics/ Monitored element	• Presence of GIS layers (e.g. specific critical assets, etc); • Displaying more accurate forecasts of the weather that can have an influence on the risk of fires • Supporting decision makers in the fire and rescue service in preventing fires

Expected utilization:	Monitor the development of natural disaster events
Operational Evaluation Criteria	Verify that there is a clear and intuitive visualization of all the available data and measure regarding the development of flood. This include the visualization of flood and weather forecasts, visualization of the network of sensors.
Qualitative metrics/ Monitored element	• Simple and intuitive icons: the presence of different icons for every different type of data (measure of water level, measure of rain, forecast…). This include also colors of icons which evoke the level of hazard or risk associated to the forecasts and/or to the measures, based on the Crisis Classification results. • Access to raw data: show on request for the forecasts and the physical sensors, a graph with the whole time series or a specific time interval of recordings defined by the user [11] • Contents comprehensibility to the operator: in order to achieve this, the contents displayed should be in the end-user's language; moreover the contents have to be shown in a simple and clear way • Demonstrate the use of forecasted weather influence on hazard evolution in the relevant scenarios, as well as the use of weather forecast information in predicting and following and the spreading and development of the fire

Expected utilization:	Support the authorities during pre-emergency phase
Operational Evaluation Criteria	Verify that the Platform allows the visualization of the results of the available early warnings and forecasting systems (flood, weather) before the occurrence of the flood itself, when fixed predefined thresholds are exceeded, and that it allows the sending of specific alerts.

[11] Out of scope for PSAP, possibly supported by the SensorThings Server

Expected utilization:	Support the authorities during pre-emergency phase
Qualitative metrics/ Monitored element	• Presence of features that allow displaying - in every time and under users' request - the results of the available forecasts; • Simple and intuitive visualization of the forecast results, for example using a color scale of the icons which immediately highlights if a dangerous scenario has been forecasted ; • Displaying an early warning to decision makers. • Presence of features that allow for sending alerts to Citizen related to the specific forecasted scenario.

Expected utilization:	Visualize Event dynamics
Operational Evaluation Criteria	Verify if the platform is able to provide features that allow to monitor the specific dynamics that occur during the flood, in order to avoid possible situation of overcrowding and panic which can be an obstacle for the first responders.
Qualitative metrics/ Monitored element	• Presence of features that allow the spread of both general alerts to the whole public and specific ones only for certain areas of the city (e.g. send specific alert to avoid certain area) • Presence of features that allow the real-time monitoring of the status of filling of the safe places;

Expected utilization:	Support reacting to an ongoing situation
Operational Evaluation Criteria	Verify platform capability to show in a clear way information about the available resources (i.e. sand-packs, water reservoirs), the position of the safe places and their level of filling, the position of the rescue teams and the level of accomplishment of their assigned tasks;
Qualitative metrics/ Monitored element	• Simple and clear visualization on the Event Map of the distribution of resources, rescue teams, safe places etc. • Demonstrate hazard impact prediction through visualization of emergency data • Issue alerts to predefined stakeholders (e.g. citizens, first responders, volunteers, public bodies).

Expected utilization:	Provide a real-time updated situation picture
Operational Evaluation Criteria	Verify that - in every moment - the visualization is updated and providing the latest available information
Qualitative metrics/ Monitored element	• Continuous updates of the map in order to show in every moment the latest available data. • Filtering data from on the display (e.g. accomplished tasks resolved incident, etc.) • Display forecasts and data indicating the risk of fires. • Display the expected duration of and remaining time to the heatwave phenomenon.

Expected utilization:	Assist decision makers by displaying critical information about events, merged with citizens' reports
Operational Evaluation Criteria	Verify that there is a clear and intuitive way of visualize all the information provided by both first responders and Citizen by the Mobile app (incident reports) or by the social media.
Qualitative metrics/ Monitored element	• Simple and intuitive icons: different icons for different type of data. This include also colors of icons which evoke the level of hazard or risk associated to the forecasts and/or to the measures, based on the Crisis Classification results. • Contents comprehensibility to the operator: The contents of the messages should be displayed in the end-user's language; moreover the contents have to be shown in a simple and clear way. • Rapid accessibility to all the available data: the feature to show on request the text of the incident reports or of the tweets, together with the potential multi-media attached; • Increase the level of preparedness to multiple parallel crises by visualizing indicate metrics and incidents, e.g. heatwave+fire.

Expected utilization:	Support the communication between the Authorities and the Citizens
Operational Evaluation Criteria	Verify that the system allows to compose and spread rapid alerts to the whole Citizen (or a part of it)
Qualitative metrics/ Monitored element	• Support use of weather forecast information in to reduce inadvertent fires caused by the public; • Pre-defined alert template in local language; • Letting the end-user compose text in the alert; • Send alerts to citizens when detected approaching a hazard. • Allow the authority to send recommendations for dealing with the phenomenon to the general public.

Expected utilization:	Support the communication between the Authorities and the First responders
Operational Evaluation Criteria	Verify that the system allows communication with the first responders even in difficult condition and that it allows rescue teams' management and task assignation:
Qualitative metrics/ Monitored element	• Simple and clear visualization of information about the status and position of the rescue teams • Simply and clear visualization of the level of accomplishment of the assigned tasks • Help the firefighters and rescue teams by providing them with information about the disaster (fire area, flood area, etc.). • Improve response times of first responders to an emergency (e.g. fire event, rescue, etc.) – compared to response times of past services with similar characteristics

2.5 Performance Metrics (Source: Quality Assurance Plan – D1.2) [12]

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 2-2. Evaluation Criteria for Control Center

Performance Indicator	Usability
Definition	Clear and user friendly visualisation of different information entities gathered from several data sources. The interface will display information in a way that allows that user to make sense of it, to handle it, to navigate across it easily, etc.
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) The interface shall be one and the same for all scenarios. The data structures for incidents, teams, and metrics (etc.) will be identical, with adjustments of content – including text messages, icons according to incident/team/metric categories, metric displays according to relevance to the authority, etc.
Domain	Visualisation and interaction
Range	5-point Likert scale.
Limitations	Each report should be assessed by multiple UI elements

[12] Revised in V2.0

Performance Indicator	Effectiveness
Definition	Effective visualisation of the following: • Crisis classification • Early warning display • Real-time emergency alerts • Critical capabilities for preparedness and timely response should be visualized clearly and accessible to the users whose role in the EOC is to notify the decision makers, the public, etc.
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. • Support interactions of authority personnel with external entities including the public, first responders, and decision makers.
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 awareness, 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 [13]

The inputs to the specification and design process includes the following resources:

- Operational expectations and requirements as defined by the beAWARE end-users w.r.t. the operational scenarios defined for the platform – flood, fire, and heatwave. The knowledge acquired from the end-users has been summarized in section 2.
- The state of the art in the scientific and professional literature concerning advances in technology for emergency management. This knowledge will be introduced in section 4.
- Best practices in user experience design and system architecting to support the specification of a robust and usable solution. This knowledge will be introduced in section **Error! Reference source not found.**.

There are several bodies of knowledge that may support the development of IVISE framework. Figure 3-1 provides an overview of the knowledge domains, namely:

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

[13] Revised in V2.0

Figure 3-1. Knowledge Domains Supporting IVISE

3.4 Research Method [14]

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.

[14] Modified in V2.0

Table 3-1. Research Questions

ID	Research Question (RQ)	Knowledge Acquisition Method / Sources
Q1	What are the IVISE-related stakeholder requirements and what are the implications on the EMS as a whole? *The purpose of this RQ is to ensure that the concrete, present-day stakeholder requirements associated with the beAWARE scenarios and use cases are addressed as part of the problem analysis, as the basis for this study, and that it does not rely solely on theory or past reports as found in the literature*	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? *The purpose of this RQ is to ensure that the scientific, technological, and practical challenges associated with the formulation and implementation of an emergency management system are identified, understood, and accounted for, thus ensuring that the stakeholder requirements are feasible on the one hand and in-line with the emerging challenges on the other hand.*	Literature Review
Q3	What is the current state-of-the-art and best-practice in DSIV, as the scientific research from the last 10 years suggests? *The purpose of this RQ is to ensure that the most important, prominent, and broadly-accepted concepts, approaches, conventions, insights, and findings are identified, studied, synthesized, and utilized for the definition of a management and decision support framework for emergency management centres.*	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 (RH)	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. *This RH captures the basic idea underlying this study, which is that only a combination of operationally-driven requirements, state-of-the-art approaches, and best practices – fused together and considered jointly – can provide a sufficiently-broad basis for the definition of a valid, useful, and robust framework for emergency management. Ignoring or minimizing the necessary balance of the three aspects may cause the result to be insufficient.*	Framework Formulation
H2	The IVISE improves decision making capabilities and outcomes during an emergency, within the scoping of the beAWARE program. *This RH captures the notion that a holistic framework relying on the foundations depicted above does in fact support and enhance the performance of emergency management agencies. With this RH we set out to evaluate the framework in action, assuming it will eventually generate significant added value for its users and stakeholders.*	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	Provide a clear definition and deep understanding of the IVISE in the context of beAWARE's operational scenarios. *With this goal in mind, we set out to study the current state of the practice, state of the art, and best practices, that would facilitate a holisitic IVISE framework based on those three aspects.*
G2	Define a valid, up-to-date framework for the implementation of an IVISE. *With this goal in mind, we set out to define a holistic IVISE framework that would provide significant added value to its users and stakeholders*.

In order to meet these goals, our 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 [15]

4.1 Emergency Management, Command, and Control Systems

In many countries, disaster response is handled by military, homeland security, or civil protection agencies, which draw operational concepts from military chains of command. Risk reduction strategies thus focus on command-and-control measures such as engineering structures, technology-based warning systems, hazard-based land-use planning and hazard-based risk awareness campaigns [4].

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. The fundamental mission of emergency management is to propose an operable, accurate, and cost-effective plan to cope with different unforeseen events [5].

The four stages of emergency management are commonly defined as: a) Mitigation b) Preparedness; c) Response; and d) Recovery. Mitigation focuses on prevention and reduction of the impact of imminent and potential crises. Preparedness focuses on pre-crisis measures to develop and improve crisis response and operation capability. Response focuses on crisis-time actions to rescue people and prevent the loss of property and casualties. Recovery focuses on measures to reinstate normal life, resume economic growth, and recover or rebuild the infrastructure. [5].

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.) [6]. 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 [7]. 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:

[15] Extended in V2.0

- **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.

In light of these roles, the following processing centers (with corresponding modules) and their capabilities were proposed:

a. **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;

b. **Emergency Early Warning Service**: collect safety, risk, and asset information; analyze data and predict trends; determine security thresholds; provide continuous risk estimation.

c. **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.

d. **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);

e. **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.

f. **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.

g. **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.

h. **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.

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

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* [8].

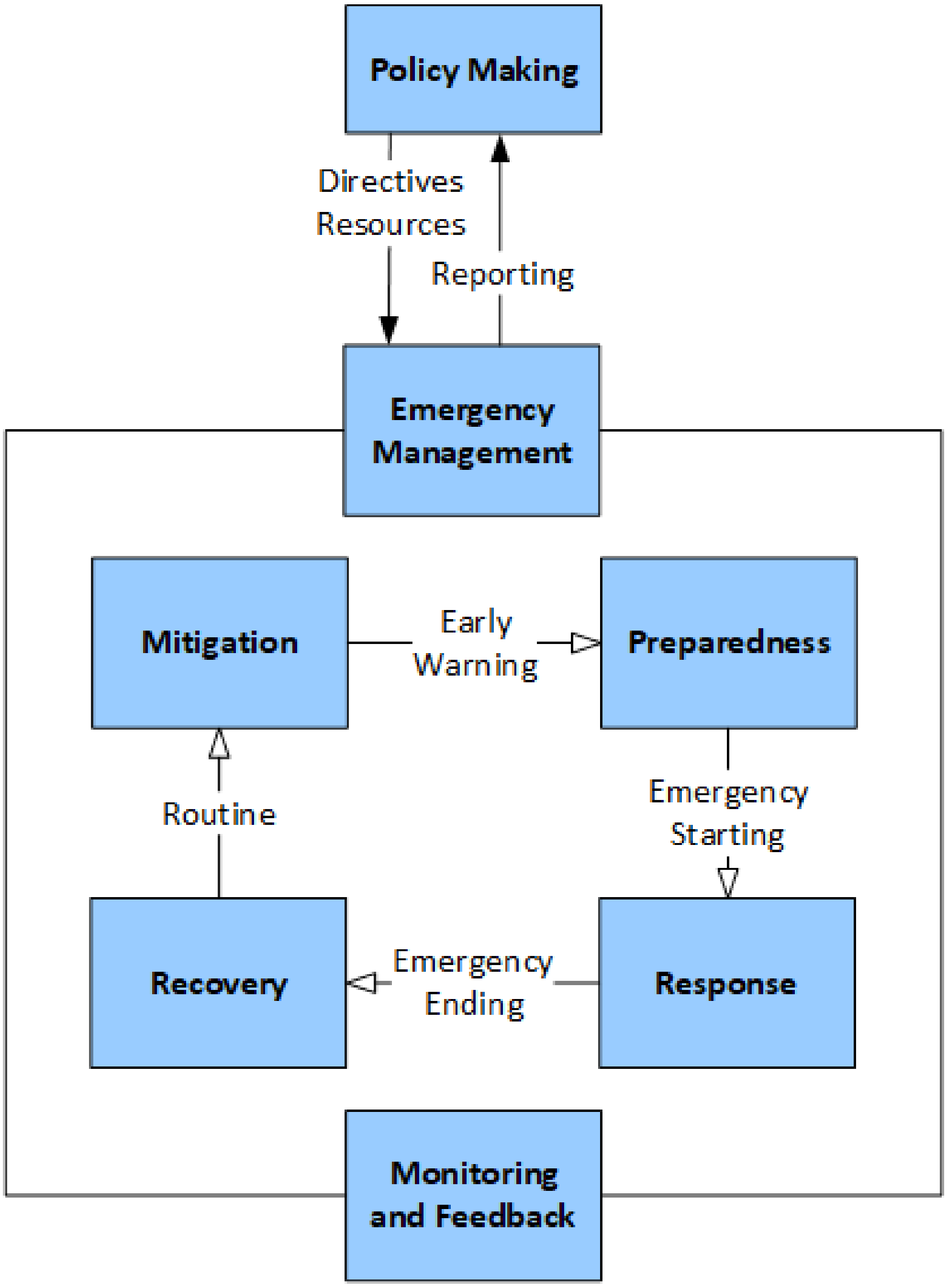

Figure 4-1. Emergency Management Model – Adapted from [5].

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 [9]. 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:

a. **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.

b. **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.

c. **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:

d. **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.

e. **Text Messages** allow the C2 operators to interact via free text when ready messages are not applicable

f. **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.

Comparative analysis of four command & control models by [10] – Lawon's process model, Hollnagel's control model, Rasmussen-Vicente's decision model, and Smalley's functional model – found strengths and weaknesses in all of them, but some more comprehensive perspectives in Smalley's functional model. Still, the authors conclude that the modeling of a generic comprehensive C2 framework remains challenging. Such challenges include the need to face a chaotic behavior of the controlled environment (moreso in cases of emergencies and crises), emergent behavior and phenomena in complex scenarios in which C2 systems need to act, the flexibility and dynamicity of goals and objectives in response to quickly-varying conditions, and the inability to provide all the critical information for decision-making based on existing capabilities (and therefore the need for evolvability of information channels). An adapted visualization of the functional command & control model is depicted in Figure 4-2. This model clearly separates the command functions from the control functions, and emphasizes the important role of command functions in planning, decision making, and directing (or navigating) – based on the situation picture and available policies. The control functions focus on communicating and distrubting information, monitoring operations and resources, and coordination with internal and external entities.

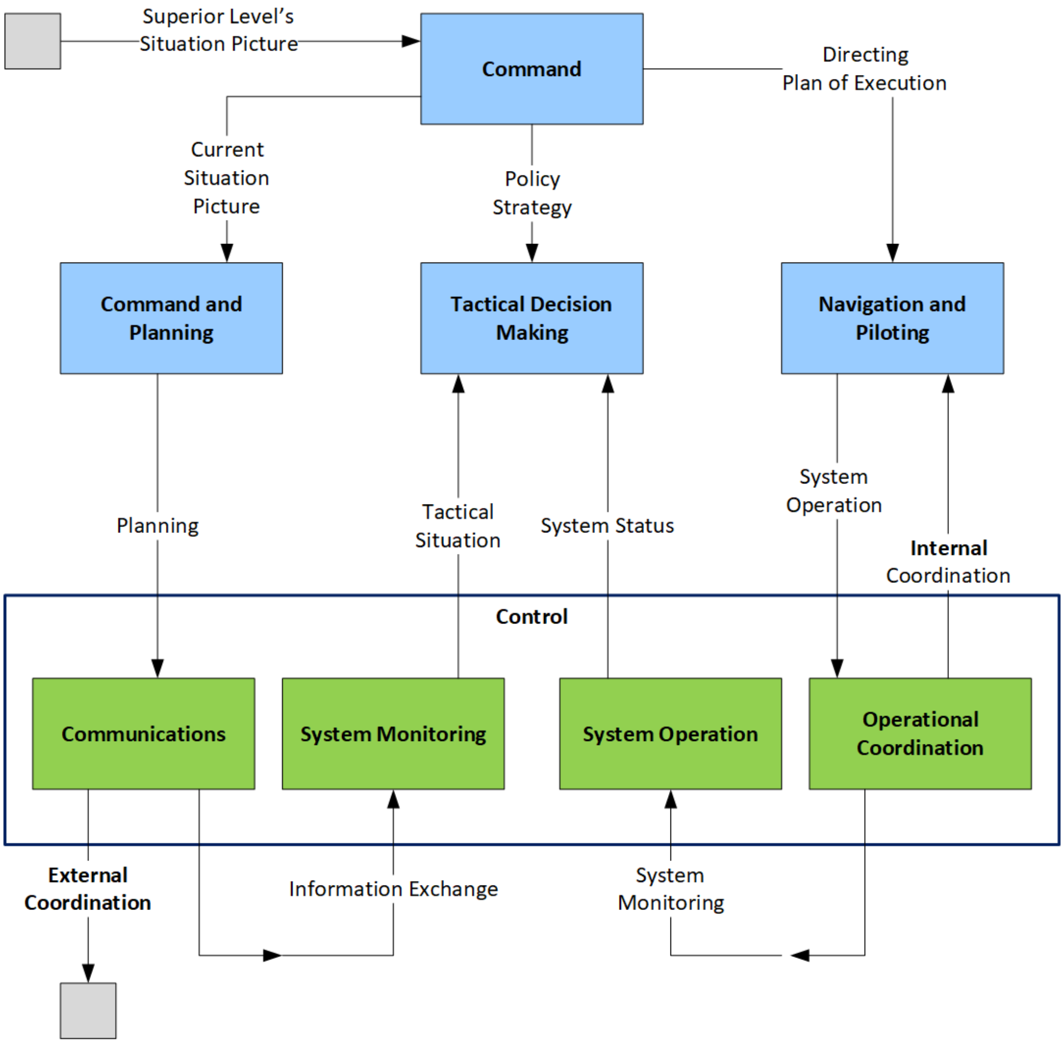

Figure 4-2. Command and Control Functional Model – Adapted from [10]

4.1.1 The Incident Command System (ICS)

In the United States, many local and regional authorities use the Incident Command System (ICS), which has been under development and improvement for over 40 years. Originally, it was meant to facilitate coordination of multiple units from several jurisdictions working in parallel on massive-scale disasters such as California Wildfires [11]. The ICS is a component of the US Homeland Security Department's National Incident Management System (NIMS). NIMS is a set of doctrines, concepts, principles, terminology, and organizational processes for effective, efficient, and collaborative incident management [12]. ICS increases organizational effectiveness through 14 features: (1) common terminology, (2) modular organization, (3) management by objectives, (4) reliance on an Incident Action Plan, (5) chain of command and unity of command, (6) unified command, (7) manageable span of control, (8) pre-designated incident locations and facilities, (9) resource management, (10) information and intelligence management, (11) integrated commu- nications, (12) transfer of command, (13) accountability, and (14) deployment.

A study on the utilization of the ICS by American emergency authorities during the Hurricane Rita disaster in 2005 sought to examine the extent to which different EOCs utilized and benefited from ICS, what were the main tasks performed by EOCs using the system, and how did previous experience affect their interaction with the system [11]. The researchers found significant differences among local authorties' EOCs in the extent to which they experienced their degree of utilization of and added value from the use of ICS. Another interesting finding was that the mode and scope of activity and operations in different EOCs was quite similar, in spite of differences in the extent of impact, damage by the hurricane, and mission orientation (e.g. evacuation, rescue, relief, logistics, etc.). Based on this finding, the authors concluded that **the same organization structure can be applied to EOCs regardless of the extent of activity they experience during the emergency.** At the same time, authorities should strive to maximize their added value for users and EOCs by correct usage and adoption of the ICS functionality.

FEMA recommends the organization structure depicted in Figure 4-3 for EOCs working with the ICS. This org. structure consists of an Incident Commander who supervises the operations, planning, logistics, and finance/administration functions. The Incident Commander is also in contact with safety, liaison, and public information personnel.

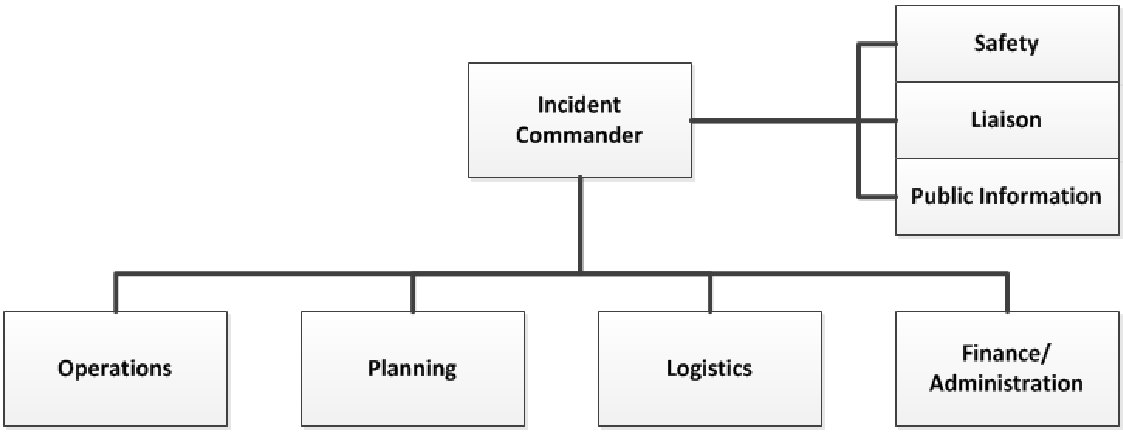

Figure 4-3. Recommended Organization Structure for EOCs working with ICS [13]

The importance of planning and preparation in emergency management and operations centers is discusses and emphasized in [14]. Key recommendations following observations in EOCs and evaluation of technological challenges and opportunities for EOCs include:

a. Automated systems for constant monitoring of situational awareness and ensuring that EOC leadership is kept up to date with the most current and valid information during a disaster. Designation of specific personnel for generating and ensuring continuous updates.

b. Procedures and solutions for ensuring a common operational picture within the EOC, such that everyone is informed of what is taking place at any given moment, understand what is planned in the future, and aligned to work within the same mindset and priorities.

c. Operator aids for personnel – checklists, guidebooks, visual aids and live key performance indicators – to ensure team-members' understanding of what is required from them during an emergency (which may differ from what is needed during routine operations) and prevent confusion of roles and responsibilities.

d. Planning and tracking tools to support knowledge and information management, work scheduling and prioritization, issue management, etc.

e. Means for continuous coordination, collaboration, and communication, to ensure and encourage an atmosphere in which individuals in a collaborative setting know "who knows what" and further use that knowledge to coordinate work and reach more efficient and effective individual and collective performance.

f. Frequent training sessions for personnel within the EOC, ensuring personnel familiarity with the place and setting, rehearsing procedures, and practicing interaction under stress.

According to [14], it is **not recommended** for the EOC to attempt to manage field operations. Rather, the EOC must maintain a global perspective, focus on planning and coordination and provide the operational field teams with informational and material support.

A study on the acceptance and adoption of information systems for emergency management [15] looked into factors such as social influence, personal intention and commitment, performance and usefulness perception, effort perception, information quality perception, and facilitating organizational and technical conditions. The study found that social influence and collective acceptance greatly affect willingness to adopt and use systems by individuals. In addition, perception of usefulness and ability to achieve better personal performance is a major driver of acceptance and adoption. The authors recommended to consider behavioral implications and personal needs during the implementation phase, and to ensure and enhance the end-users' performance expectancy and perception, for example by highlighting the advantages of the technology for the personal benefit of the users, Public works

According to FEMA [16] The Emergency Manager (EM) is a person who owns the responsibility for coordinating all components of the emergency management system for the community - civil defense, police dept. fire dept., emergency medical services, volunteers, and other groups involved in emergency activities. The EM must be involved and proactive before, during, and after the emergencies he or she is responsible for, and across all emergency management phases: mitigation, preparedness, response, and recovery. Therefore, this role should be defined by law, based on national and international directives. This role demands a broad-minded, holistic approach, and foresight. FEMA includes the following activities and responsibilities under the Emergency Manager’s role:

a. Ensure that all components of the system know of threats to the community,

b. Participate in hazards and vulnerability analysis, mitigation, and prevention activities, as an Emergency Operations Planning (EOP) committee member,

c. Coordinate planning activities for emergencies using an all- hazards approach,

d. Coordinate operations during emergency situations, and

e. Coordinate and assist in recovery operations after disasters.

In order to ensure that effective coordination takes place during any phase of operation, the emergency manager and others responsible for EOC management and operations must work closely in a team environment with other EOC personnel, elected officials, and other private-sector groups.

An interesting practical implementation as published by the Charlotte-Mecklenburg County Emergency Services [17] clearly defines separate responsibilities for key EOC stakeholders and personnel. The Incident Commander (IC), for instance, is responsible for establishing a command post and arranging for its facilities and provisions; establishing perimeters for disaster area; staging areas, etc.; directing field operations; arranging critical resources for personnel (accommodations, food, safety measures, clothing, etc.). There is a clear separation between the professional emergency management echelon, the administrative echelon (elected officials, legal services, regional managers, public/media relations), and supporting public services (law enforcement, hospitals, firefighting, medical teams, etc.). The emergency management office responsibilities include:

a. Developing action and coordination plans with law enforcements, federal and local authorities, etc.;
b. Coordinating multi-agency response at the EOC, command post, or incident location;
c. Ensuring that adequate resources are available to respond to major disasters / emergencies;
d. Ensuring the continuity of command and control
e. Activating national resources and mutual aid to assist local government in disaster operations;
f. Providing information and recommendations to elected officials and local government executives.
g. Training of staff personnel and Education of the public

Continuous communication and common understanding of the situation across stakeholders and actors during a disaster or emergency are critical for enabling disaster resilience throughout the emergency management lifecycle – comprising prevention, preparation, response, and recovery. Failure to ensure communication and information alignment may actually intensify the severity of the situation [18]. This notion has been validated by dozens of experts in emergency management in both government and indudsry. Specifically, interactions among authorities and industry/business liaisons are critical. For instance, rescue and evacuation of employees from a factory that caught fire. This raises the importance of mechanisms for facilitating communication and information sharing with the public, including industry contacts.

A comprehensive set of design requirements for multi-incident emergency management systems was provided in [19], based on Concrete scenario-related issues, theoretical foundations (e.g. Coordination Theory, Decision Structure Theory), and methodical systems analysis. The requirements include, for instance:

a. Effective collecting and analyzing of information;
b. Managing a directory of response resources;
c. Managing a knowledge base to support task execution;
d. Facilitating and supporting communication;
e. Information sharing, exchange, and access management;
f. Supporting decision making;
g. Tracking the response in the field;
h. Enabling multi-media and geographic information aids;
i. Security, survivability, modularity, and scalability

For multi-incident emergencies and scenarios, an additional layer is needed for coordination, including:

j. Iteratively coordinating and optimizing resource allocation and deployment;
k. Iteratively coordinating task assignments and responsibilities
l. Monitoring resource inventories
m. Shortening response time and idle times between emergency-related activities.

The roles and responsibilities of the members of an emergency command center in China are divided among the departments of the ECC as follows [5]:

a. Decision-Making Department – responsible for overall management and decision-making
b. Operations Department – responsible for emergency response
c. Planning and Information Department – responsible for acquisition and analysis of information to support planning and operations

d. Logistic Department – responsible for logistic support – equipment, materials, services for emergency response, administrative services, etc.

e. Financial Department – responsible for financial support and control of expenditures for emergency management activities

f. Communication Department – responsible for releasing and communicating information and alarms to the public, media, social media, etc.

g. This structure and distribution of responsibilities reflects the principles of flat organization, comprehensive end-to-end control, process-orientation, and expertise.

Figure 4-4. Emergency Management Centre in Brazil [20]

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 [21].

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 [21].

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 [21].

InfoVis is strongly linked to human cognition-augmentation [22]. 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 4-5 . 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 [22]

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;

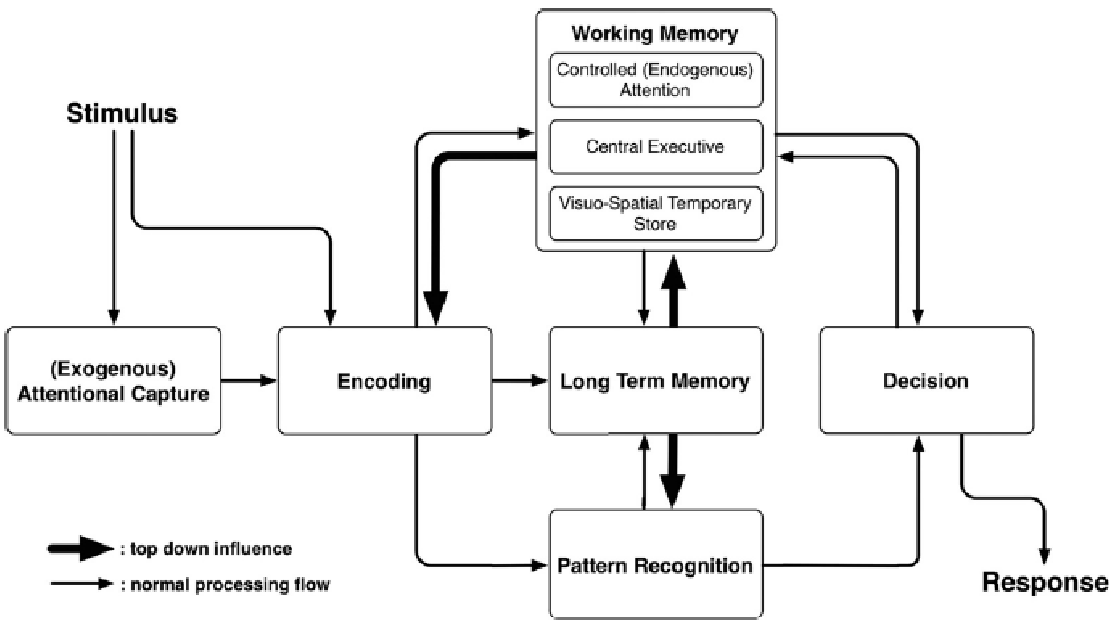

Figure 4-5. Human Cognition, reasoning, and decision making framework for information visualization [22]

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 [6]. 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 [23]. 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 [6]

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; Preparedness	Recovery	
Emergency Scenario	Generic		Flood; Industrial Accident; Earthquake	Hurricane; Terrorism; Epidemic; Fire; Heatwave

An observational study on the flow and management of information in EOCs during natural and man-made disaster management operations [24] found three challenges related to information visualization for emergency management: a) asymmetric knowledge and experience, b) barriers to maintaining mutual awareness, and c) uneven workload distribution and disrupted communication. A table summarizing the observations related to each challenge and recommended action to improve information flow, coordination, and collaboration within the EOC are summarized in Table 4-3.

Table 4-3. Observed Challenges in Information Flow in EOCs and Recommended Action [24]

Disruption to Information Flow and Management	Recommended Action
Asymmetric knowledge and experience: significant differences in operational understanding, procedure understanding, access to information technology and visual tools, familiarity with the functions and features they provide, and focus on narrow areas of expertise – all mandate the use of simple tools that provide clarity, intuitive activation, and immediate interaction.	In some cases, manual tools such as whiteboards, wallmaps, notebooks and phonebooks come in handier than complicated information systems. Nowadays, smart mobile devices could also be considered as highly-intuitive and highly-personalized tools that could help individuals with the right functionality to bridge the knowledge gaps.
Barriers to maintaining mutual awareness: most of the information is coming in through voice channels – telephone and radio communications – leading to significant issues with information logging, understanding, and sharing – especially during emergency situations with disrupted or overloaded voice communications. This includes communication both with the external world, for coordination with other agencies, and even within the EOC.	As much as possible, shared displays and information log forms should be used for information sharing and workload distribution. However, adding new forms and features should be done cautiously and with suitable training, since during an emergency, there are chances that operators will not be familiar and will not have time and attention to familiarize themselves with such enhancements. In addition, it is recommended to use fault-tolerant communication systems like text and digital voice recording and playback solutions; as well as layout of the facility to maximize oral immediate communication and visibility of shared information. Finally, updating shared displays should be assigned as personal responsibility to someone in the EOC.
Uneven workload distribution and disrupted communication: Information that reaches outward-interfacing personnel and critical response facilitators (EOC director, firefighting liasison, etc.) does not systematically reach EOC-internal personnel, resulting in overloading some users with information and work, while starving others of the same. There is no systematic sharing and feeding of information to other users.	Designing information flow toward the core operations team (EOC director, Police Liasison, Firefighters liaison, etc.) could be useful for tunneling information to the right places and at the right timing. This also includes appointing specific persons for handling information requests from and frequent updates to the core team.

4.2.1 Visual Modeling and Simulation for Emergency Operations

The adoption of simulation tools for disaster risk assessment and analysis has been gradually moving from the research laboratories to the operation centres, adding significant analysis and decision support capabilities for emergency preparations, response, and recovery.

In [25], a visual modeling and simulation framework for disaster risk assessment is described. The model receives input from an external phenomenon simulation model (e.g. flood model, earthquake model, etc.) with hazard intensity measures. Hazards affect the network nodes according to their degree of vulnerability. The visualization was added to support operational decision makers. As such, the visualization tool includes several modalities: map display, parallel coordinates plot, state dependency graph, and time-series graphs. The tool has been applied to the assessment of multi-hazard risks in a Swiss town. Figure 4-6 illustrates some of the results.

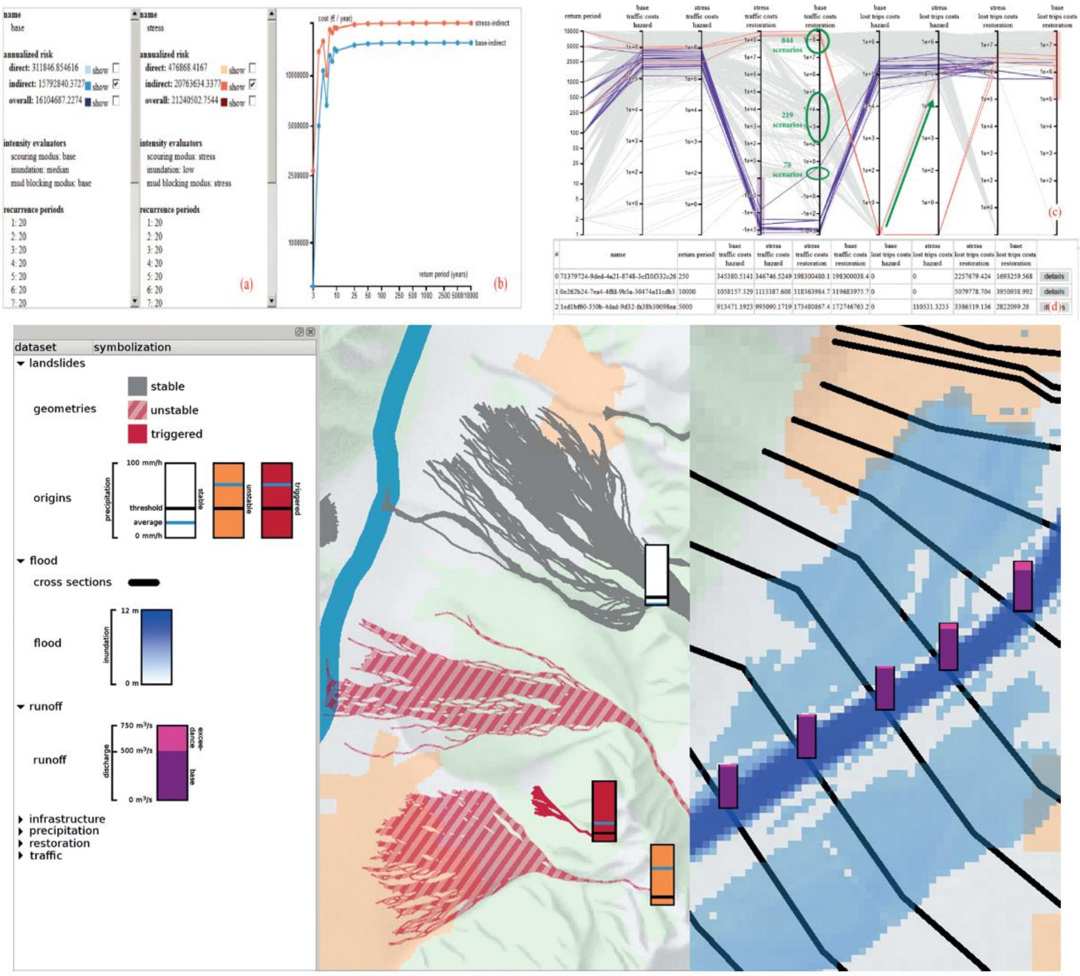

Figure 4-6. Visualization of Simulated Multi-Hazard Risk Assessment [25]

In [26], a conceptual modeling and simulation framework is used for building a system model of a nuclear reactor, and extending the model in order to capture possible disruptions and faults, including gaps in operator's perception and situational awareness. The paper analyzes the famous case of the 1979 Three Mile Island partial nuclear meltdown – which was the most severe nuclear accident in the US. Integrating the simulation into the emergency operations centre can assist analysts and decision makers in simulating and understanding causality relations, failure modes and chains, and potential vulnerabilities to critical infrastructure and facilities, which could be critical during an emergency. The capability to modify the model also provides for working in changing conditions and responding to evolving situations.

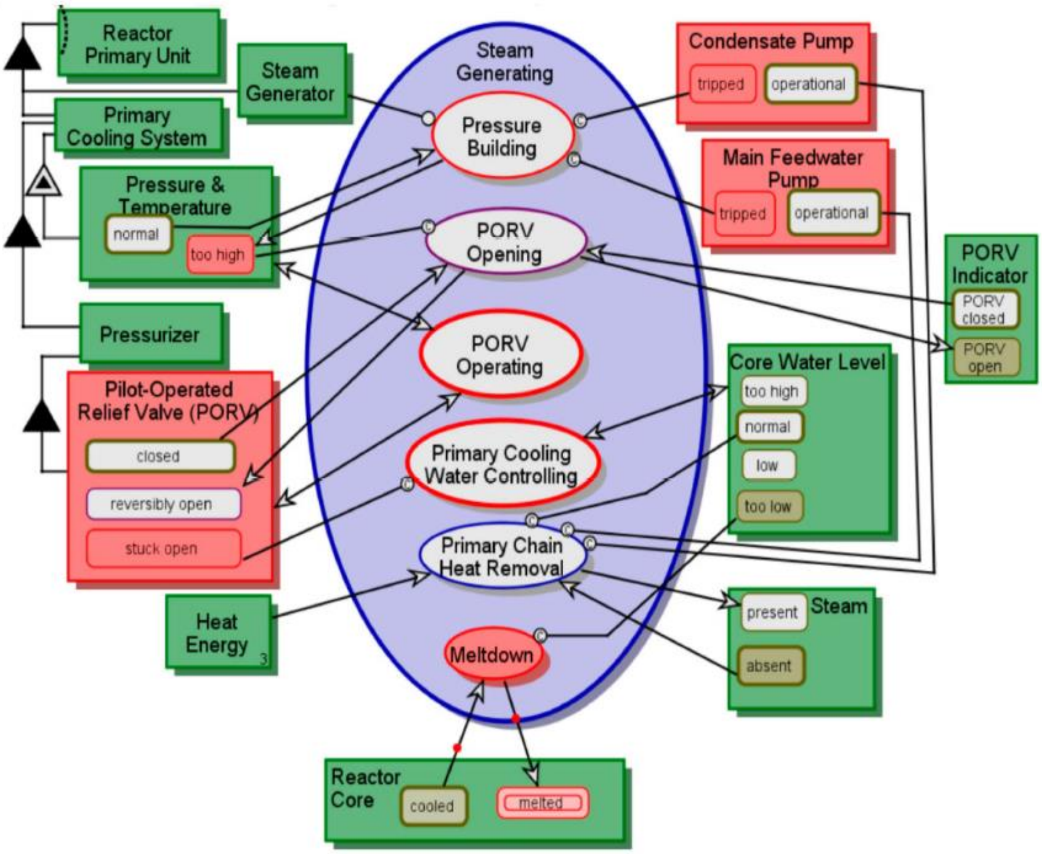

Figure 4-7. Visualization of Functional Failure Simulation of the Three Mile Island Nuclear Reactor Accident [26]

4.3 Uncertainty, Risk Analysis and Decision Analysis

4.3.1 Introduction [16]

Due to the unending amount of research done in the fields of uncertainty and risk, no one ultimate literature review on these topics can even be complete. This literature review is focused on the main characteristic of emergency management, which is decision making under risk and uncertainty. In this review we focus on understanding, assessing, and managing risk and uncertainty during emergencies and disasters, which is the main focus of the beAWARE project. The purpose of this review is therefore not

[16] Added in V2.0

to constitute a comprehensive reference on risk and uncertainty but an introductory overview to allow PSAP users, designers, and developers to understand the concepts underlying the decisions and operations made during emergency operations.

While different views on risk and uncertainty are possible, when focusing on disaster risk, it is defined as 'the potential loss of life, injury, destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity. The emerging approach to disaster risk is focused on three aspects: hazard, exposure, and vulnerability (with capacity being an element of the vulnerability) – as opposed to traditional likelihood-impact analysis [27].

Thus it is becoming more prevalent to define risk in terms of hazard (*H*), exposure (*E*), and vulnerability (*V*). The formula $R = f(H,E,V)$ reflects this approach. One adaptation of this formula for risk is $R = H \cdot E \cdot V$. Vulnerability can be defined as $V = V_0 - C$, where V_0 is the initial vulnerability, and *C* is the asset's Capacity to respond to *H*.

The risk analysis and management paradigm has gradually shifted over the years from focus on the scientific analysis of the hazard (e.g. the expansion of flooded areas or the propagation of earthquake shockwaves) towards focus on the exposure (e.g. identification and analysis of human population, critical infrastructure, and ecological systems at risk). It has been argued that a proactive approach must further shift towards focus on the vulnerability of exposed entities, and explore opportunities for vulnerability reduction, e.g. planning and prioritization of vulnerability reduction, technological and social factors of vulnerability reduction and resilience enhancement, etc. This assertion is based on studies showing that the population's vulnerability is extremely significant in risk and loss reduction [28].

4.3.2 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 [29]. 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 [30].

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 [31]. 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* [32]. 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 4-4.

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 [33], [34], 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*.

Table 4-4. 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***

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 [35]. 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 past events, as their preconditions are seldom identical to those of a particular case.

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 [36]. Extreme events are generally more critical than nominal, expected events, so they require prioritization of attention and analysis [37]. 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 [38].

4.3.3 **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 [39], [40]. 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.

Traditionally, risk was defined as the answer to four questions: Q1) what can go wrong? Q2) what is the likelihood? Q3) what are the consequences? [41], and Q4) what is the time domain? [42]. 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 [43].

Risk modeling requires distinguishing between cause and effect. The emerging approach to disaster risk consists of a clear definition of hazard, exposure, vulnerability, and capacity [27]. *Hazard*s are adverse events causing potential or actual loss or damage. *Exposure* is the presence of entities that may experience possible or actual harm (people, property, environment, resources, etc.). *Vulnerability* is the degree and mode of impact by the hazards on the exposure. *Capacity* is the ability to respond to an adverse event and reduce the exposed entity's vulnerability [44].

Various entities, reasons, and events constitute risk sources, or Hazards. They are not risky *per se*, but may generate effects that interfere with predetermined or predefined Exposed entities. 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 hazard, while damage to the satellite, or the satellite's failure to function, is the *exposure*.

Uncertainty is associated with both the hazard and the exposure, but even if the hazard is in a risk-posing state, it does not necessarily generate an impact. This is where the extent of vulnerability of the exposed entities, or their resilience and capacity to respond or adapt are crucial. Only realization of the exposure, is the actual realization of the risk itself.

4.3.4 **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 [31], [45], and dedicated system-oriented methods [46], in addition to classical risk analysis methods, such as fault-tree analysis (FTA), failure mode effect critical analysis (FMECA) [42], and hazard and operability (HAZOP) [47]. 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 [42]. A review of risk management techniques as part of the systems engineering process is provided in [48].Operational risk management is concerned with assuring such system objectives as safety, security, availability, and business continuity (some of the so-called "*ilities*") in operational settings subject to risk [42], [49].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 [50], [51].

Risk management is a multi-objective, resource-constrained effort aimed at attaining a reasonable level of residual risk that stakeholders can live with. 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 [52]. Risk management attempts to answer three questions [53]: 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.

4.3.5 The Likelihood Impact Matrix

The famous 5X5 likelihood/severity or probability/impact matrix is a very popular risk assessment technique. 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 4-8 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 4-8. 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 [54]. 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 $\{\mathbb{R}\}$ or Natural Numbers $\{\mathbb{N}\}$ 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 $\mathbb{R}$ [55].

For these flaws, the risk impact matrix is gradually phased out especially in emergency operations, and the mapping of hazard impacts on assets and exposed entities is becoming a more constructive approach for disaster risk prevention, mitigation, and response.

4.3.6 The Risk Management (RM) Process

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 [56]–[58]. An illustration of the ISO 31000 framework is shown in Figure 4-9.

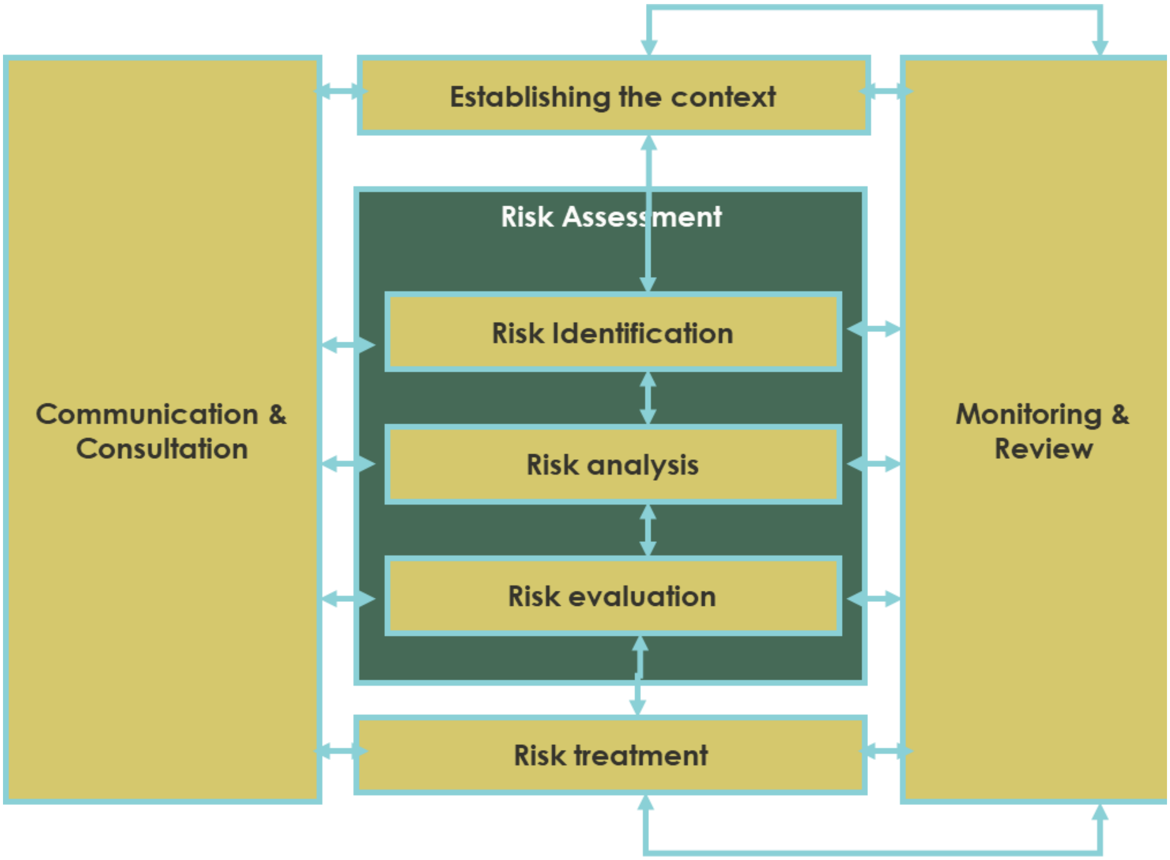

Figure 4-9. The ISO-31000 Risk Management Process

4.3.7 Uncertainty and Risk Management During Emergencies and Disasters

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 the exposure. Operational risk management is concerned with assuring such system objectives as reliability, safety, security, availability, and business continuity in operational settings subject to risk [42], [49]. Several guides and standards with general applicability or relevance to particular domains have been published [51], [59]–[62].

FEMA proposes a simple table for assessing and managing risk before and during an emergency (see Figure 4-10) [63]. The FEMA approach emphasizes the importance of starting off with a list of assets (people, facilities, machinery, equipment, raw materials, finished goods, information technology, etc.), thus focusing on the exposure rather than on the hazard. Then, for each asset, there is a list of relevant hazards. This makes the hazard description more concrete and relevant to the assets, rather than settling for generic, vague hazard descriptions. Multiple hazards could impact each asset and multiple assets may suffer from the same hazard. For each hazard it is advised to consider high probability/low impact scenarios and low probability/high impact scenario. This demonstrates the departure from the probabilistic approach and adoption of criticality analysis. It is then critical to identify and assess the asset's vulnerabilities or weaknesses that would make it susceptible to loss. These could entail or become prevention and mitigation opportunities. The potential impact of the hazard scenario should be analyzed with respect to each exposed asset people, (property, operations, environment, and entity). Finally, the “Overall Hazard Rating” is a two-letter combination of the rating for “probability of occurrence” and the highest exposure. It is then expected to make decisions regarding prevention, mitigation, absorption or diversion of each risk.

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 [64] . Strategies for information visualization to improve clarity and reduce uncertainty include clustering, partitioning, 2D-binning, and abstraction – usually in 3-4 layers [65].

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Risk Assessment Table

(1) Asset or Operation at Risk	(2) Hazard	(3) Senario (Location, Timing, Magitude)	(4) Oportunities for Prevention or Mitigation	(5) Probability (L, M, H)	Impacts with Existing Mitigation (L, M, H)					(11) Overall Hazard Rating
					(6) People	(7) Property	(8) Operations	(9) Environment	(10) Entity	

Figure 4-10. FEMA Risk Assessment Table for Emergency Response Planning and Management [63]

4.4 Risk-Based Decision Making in Disasters and Emergencies

An important purpose of EMS is to assist in risk management by promoting decision making for risk probability and impact reduction. Decision-making in crisis events is different from conventional decision-making. Emergency and crisis response are time-sensitive, constrained by unforeseen conditions, based on partial information, and subject to moral and ethical issues. In addition, there are always insufficient resources and time to account for every possible incident [5].

Various analytic approaches for Multi-Criteria Decision Making (MCDM), such as the Analytic Hierarchy Process (AHP) and Multi-Attribute Utility Theory (MAUT) were proposed for decision making in disaster management, for instance in flood risk management, for decisions on flood mitigation options, reservoir management, susceptibility and vulnerability assessment, coping capacity assessment, and emergency management policies [66]. Probabilistic benefit-cost analysis has also been proposed for decision making for flood scenarios [67].

Recently, multi-hazard scenarios (including the potential for more than one type of disaster – e.g. earthquake and flood) have become interesting, since many cities and regions face the threat of multiple hazards [68]. Multi-hazard and multi-risk decision making has not been in broad usage and adoption in the past, due to issues like the lack of suitable tools, tool usability issues, and methodological validity [69]. A framework for the consideration of expert opinion in conjunction with geo-spatial modeling and visualization of hazard, exposure, and vulnerability data in multi-hazard risk estimation has been proposed for balancing the preparation and response for various hazards in the Eastern Italian Alps [70].

Due to the unique aspects in the context of the potential for degradation of utility from the efforts during an emergency (e.g. the need to act fast to save the lives of survivors in a disaster area), the adoption Prospect Theory (Tversky & Kahneman), Group Decision Making, and ordered assessment schemes (as opposed to scalar continuums), were integrated into a unified decision analysis framework that is meant to facilitate a reliable decision scheme that decision-makers can utilize for informed decision making (as opposed to intuition-based) [71], [72].

A study of decision making processes in a disaster risk management centre in Brazil found that operators tend to prefer past experience and personal knowledge for making decisions. However, when the required data sources are clearly defined, the required data and information are specified, and the decision logic is well-defined and rationalized to operators, decision-making becomes a significantly more structured and coherent process, especially when facing the uncertainty and dynamicity of emergency and disaster occurrence and response [20].

A proposed paradigm shift proposed in [73] to better incorporate scientific impact in the administrative and operational processes includes the following aspects: a) holistic, interdisciplinary hazard analysis based on a broad variety of scientific fields that complement and enrich each other; b) focus on the analysis of exposure and vulnerability – rather than the physical properties of the hazard – as a means to prevent and reduce disaster risk and loss; c) mental transition from viewing disasters as natural phenomena to viewing them as social phenomena, and d) incorporation of disaster risk knowledge deep into the practice and operation, e.g. performing hazard mitigation while accounting for all known characteristics of the hazard and the best practices for handling it.

The importance and role of knowledge in disaster risk reduction and disaster response has been also discussed the Sendai Framework for Disaster Risk Reduction (SFDRR) [74]. SFDRR specifically asserts that: "*Disaster risk reduction requires a multi-hazard approach and inclusive risk-informed decision-making based on the open exchange and dissemination of disaggregated data, including by sex, age and disability, as well as on the easily accessible, up-to-date, comprehensible, science-based, non-sensitive risk information, complemented by traditional knowledge*". While this is a step in the right direction, the focus should shift from information to knowledge in the sense that learning, understanding, and reasoning facilitate transformation of raw and factual information regarding the risk at hand into actionable insight and wisdom regarding the mitigation, prevention, and recovery from impact [75].

Further in the context of focusing on the analysis and reduction of vulnerability, visual maps of social vulnerability can significantly improve decision-making especially in the mitigation and preparedness phases. Such high-resolution maps based on demographic clustering and the definition of a social vulnerability index have been proposed in [76]. An illustration of such a social vulnerability map is shown in Figure 4-11. The map shows the vulnerability index of areas of Nashville, Tennessee, USA and the Cumberland River, relative to a 100-year flood hazard.

Another example of a vulnerability map which accounts for social **and** physical properties of the exposure in the context of the earthquake and fire hazards has been proposed in [77]. Additional properties taken into consideration include, for example, the number of floors per building, function (residence, business, commerce, etc.), and construction quality. An example of such a map is illustrated in Figure 4-12.

An adaptation of such vulnerability maps for real-time estimation of the exposure, in conjunction with the actual population's vulnerability, relative to an actual imminent natural disaster, can also support decision makers during the response and recovery phases.

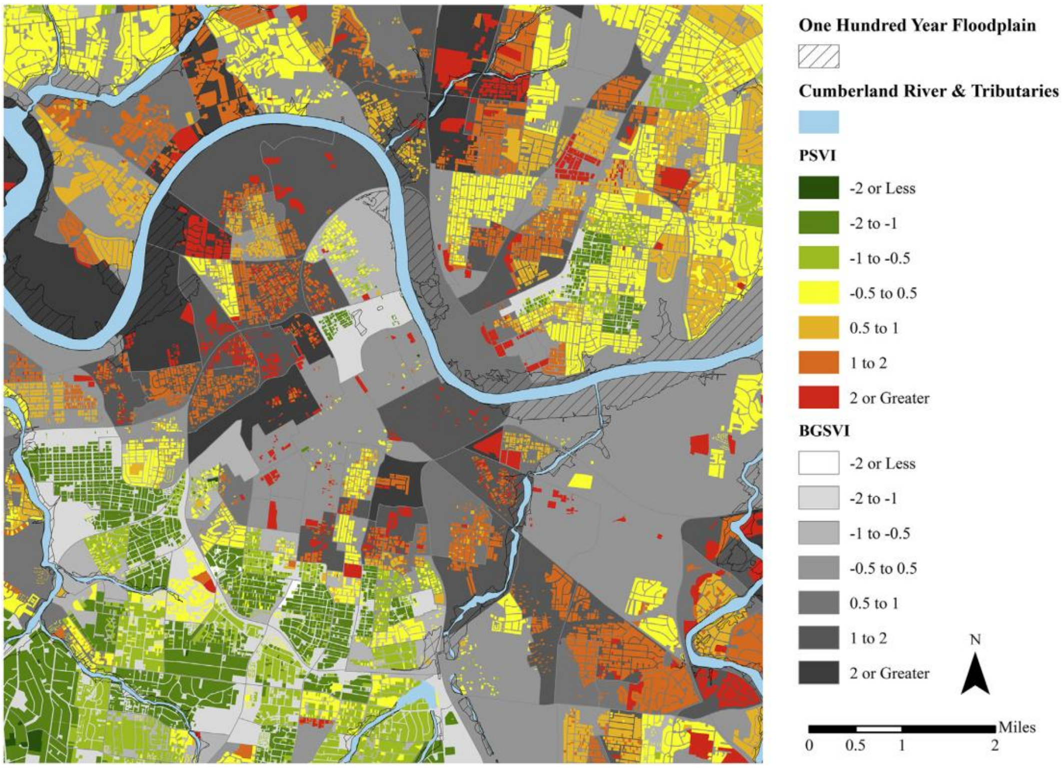

Figure 4-11. Social Vulnerability Map [76]

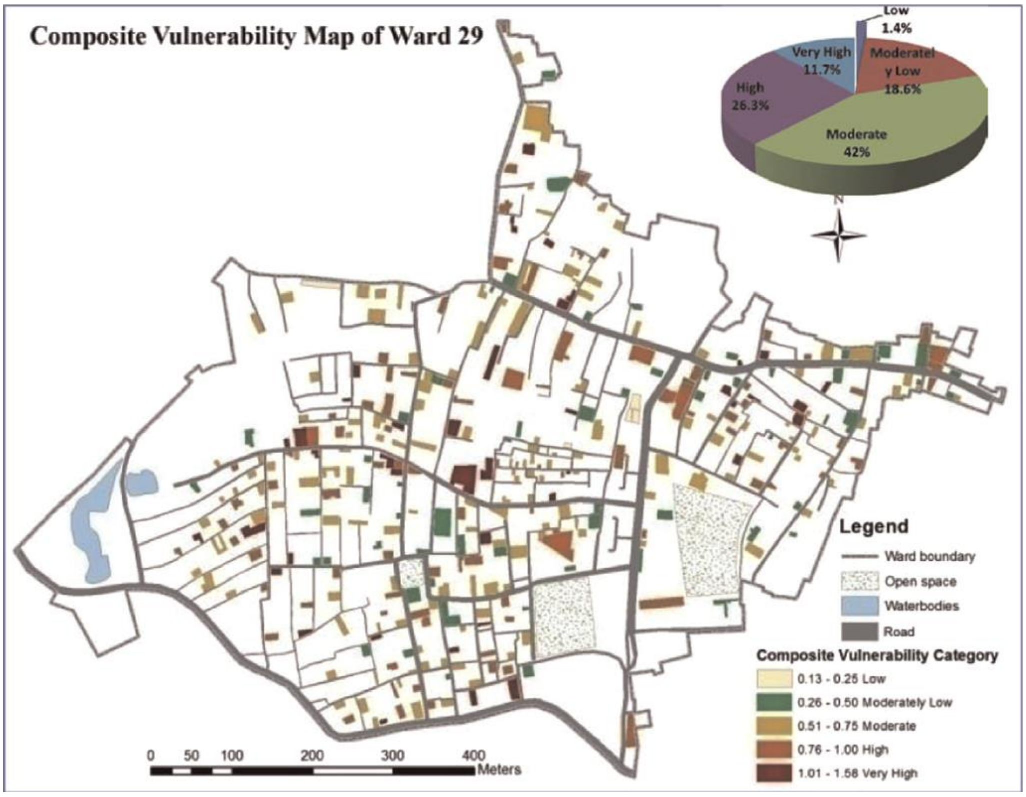

Figure 4-12. Socio-Physical Vulnerability Map [77]

4.5 Literature Summary and Uptake [17]

This section summarizes the main outcomes of the literature review and the primary uptake that would be useful for the definition and specification of a UX framework. We have tried to draw usable conclusions that will contribute to the specification, design, development, and deployment of the PSAP as part of and in conjunction with the beAWARE platform, and for the benefit of the operational users. While the operational view clarifies the current state of the practice and expectations of the operational stakeholders based on their existing domain perception, the literature review meaningfully improve the added value that the platform will be able to provide to its current and potential users.

The uptake has been organized into the three following categories:

- The Conceptual Emergency Management Environment
- The Emergency Management Organization
- The Emergency Management Process

[17] Added in V2.0

- The Emergency Management System

The conclusions and insights from the literature review allows to design an Emergency Management System that would provide significant added value to the Emergency Management Organization, working in a consistent conceptual environment, by facilitating and executing the Emergency Management Processes. A conceptual framework binding these aspects together in order to support the specification and implementation of an EMS is illustrated in Figure 4-13.

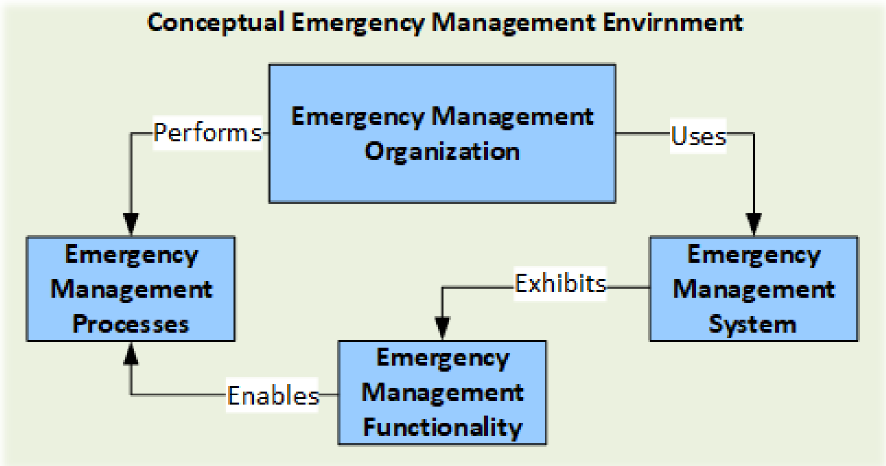

Figure 4-13. A Conceptual Framework for the literature uptake to support Emergency Management System Design

4.5.1 Uptake Referring to the Conceptual Emergency Management Framework

In this context we have studied the fundamental concepts, patterns, and drivers of emergency management that would standardize and conventionalize the entire emergency management effort. This includes the understanding of the role of the Emergency Operations Centre (EOC) as the primary facilitator of emergency management; concepts related to the command and control processes and terminology; concepts related to the definitions of risk, hazards, assets, exposures, and vulnerabilities, and the need to address them all within a unified consistent framework; concepts related to the knowledge, information, and data collected, distribute and shared in the system; and concepts related to decision making under risk and uncertainty.

4.5.2 Uptake Referring to the Emergency Management Organization

In this context we have studied the various organizational configurations, roles and responsibilities that will be dealt to EOC personnel. Specifically, the role of the Emergency Manager is fundamental to the understanding of the various roles in the

EOC, as delegates acting for and on behalf of the EOC to accomplish the EOC's missions and fulfill the expectations of the public from the authorities. It would be useful to structure the solution for actors such as decision makers, planners and analysts, and response managers. The focus would be on the operational staff, enabling and performing operational processes.

4.5.3 Uptake Referring to the Emergency Management Process

In this context we have studied the various processes, procedures, and activities that the EMC would need to perform and execute. The scope of the platform is restricted to preparedness and response. The platform is less oriented towards mitigation and recovery. Hence, it would be important to focus on operational pre-emergency and in-emergency phases and activities, such as early warning generation, alerting the public, situation picture building and analysis, risk assessment before and during the emergency, risk-informed decision-making regarding response management and resource allocation, etc.

Each hazard and each exposed asset should be clearly visualized to the user, taking its vulnerability into consideration, in order to promote prioritized treatment. Hazards should be clearly distinguished from exposed objects, including persons, assets, and environmental entities. Due to the need for flexibility and quick response to dynamic needs and concerns, a robust framework for emergency events and metrics visualization has already been introduced [78]. This framework is one of the valuable outcomes of this research and a potential fundamental and reusable asset for future informed decision support applications.

4.5.4 Uptake Referring to the Emergency Management System

In this context we have studied the various typical and conventional visualization and interaction modalities, common information system structures and services, and typical workflow management capabilities that should be applied. In addition to the highlighting of the importance of modalities like semantically-rich event maps and robust analytic displays of critical decision-supporting information that support evolving information needs, it is also important to identify typical modules that would be deployed in EOCs and used by personnel to execute the operational processes mentioned above.

5 CONCLUSION [18]

This deliverable 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 beAWARE operational partners (as representatives of Public organizations dealing with preparedness, management and consequences of Heatwave, Flood, and Fire natural disasters) description of the current situation, their expectations and requirements, and operational evaluation criteria for the beAWARE project. We 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 results of the review provide insight into several aspects that are critical for designing the UX framework:

- Responsibilities and goals of the emergency management centres (EMCs),
- Activities and tasks performed by the EMC staff,
- Information required for the EMC to carry out its work, as well as suitable visualization modalities,
- Interfaces and interactions of the EMC with external entities – organizations, agencies, citizens, etc.
- Required technological capabilities and functionalities to support the EMC.

The conclusions and insights generated from the literature in conjunction with the end users' input regarding the state of the practice, assisted in defining and validating 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

[18] Modified in V2.0

Administration / Emergency Manager, Incident Manager, and Operations Manager/ Dispatcher) 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.

Our research hypotheses were that a) integrating state-of-the-art, state-of-the-practice, and innovative concepts and solutions, will form the IVISE; and b) IVISE improves decision making capabilities and outcomes during an emergency.

We have seen that the state of the practice and the state of the art complement each other in a harmonious way. The SotA moves ever closer to practice-oriented approaches and towards the harnessing of scientific research to the prevention and reduction of disaster risk. At the same time, practicing organizations continuously absorb and implement methodologies and concepts from the scientific and professional literature and consolidate the terminology, procedures, and interoperability potential. Cutting edge advances in UX design, information management and visualization support the implementation of SotA techniques and guidelines and provide higher-than-ever experiential and functional value to end-users, with real-time support, personalization, ergonomics, and workflow support. Therefore our first hypothesis is validated.

Our focus in the specification on providing decision-supporting visualization capabilities to operators, including map-based and analytic displays with rich indicative semantics, multi-media integration, and decision making aids (e.g., monitoring of team status and availability, tracking public alert distribution, etc.), These features greatly enhance the operators' ability to act, make decisions, and execute them in real time using the PSAP application in conjunction with the services provided by the entire beAWARE platform. Thus, we asset that the second hypothesis is also validated.

Future research might be considered 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. Specifically, automated decision-support features would greatly reduce workload and improve efficiency. For instance, information reliability assurance (e.g. automated verification of observations' severity levels) and monitoring the status of data availability from sensors, teams, etc.) [19].

[19] Added in V2.0

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