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Using Web GIS for Designing Added-Value Training Systems for Crisis Managers

MASTERARBEIT

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Preface

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Abstract

Critical infrastructure systems constitute a major importance for modern societies. The increasing dependence on functioning infrastructures has increased the need for effective and coordinated decision-making by crisis managers. Technologies like Geographical Information Systems (GIS) play a crucial role in Critical Infrastructure Protection (CIP) with regard to decision-support by providing spatial data describing statuses of CIs, available resources, damaged areas, etc. 'What if' analysis (WIA) is a method that enables operators to simulate and examine behaviors of sophisticated systems by incorporating crisis management scenarios. This thesis is based on the ongoing research project 'Critical Infrastructure Preparedness and Resilience Research Network' (CIPRNet) and aims at identifying and applying best practices for the application of web-based GIS in complex crisis scenarios as well as developing a prototype application with WIA support, which enables operators to enhance their decision-making process for future crises. The system architecture, features and specifications of the application will be developed and illustrated on the basis of a crisis scenario. A usability evaluation is performed, which examines possible weak points in the human-machine-interaction and measures the satisfaction of using the system.

Kurzfassung

Kritische Infrastruktursysteme stellen eine große Bedeutung für die modernen Gesellschaften dar. Die wachsende Abhängigkeit von intakten Infrastrukturen erhöht zugleich die Notwendigkeit wirksamer und koordinierter Entscheidungskompetenzen der Krisenmanager. Technologien wie Geographische Informationssysteme (GIS) können eine entscheidende Rolle beim Schutz kritischer Infrastrukturen (CIP) in Bezug auf Entscheidungsunterstützung unter Verwendung von raumbezogene Daten spielen. Diese Informationen können akute Zustände von kritischen Infrastrukturen, verfügbare Ressourcen, Schadstellen beschreiben. "What if" Analyse (WIA) ist eine Methode, die es Betreibern ermöglicht, Verhalten komplexer Systeme durch den Einsatz von Szenarien zu untersuchen und zu simulieren. Diese Arbeit basiert auf das laufende Forschungsprojekt "Critical Infrastructure Preparedness and Resilience Research Network" (CIPRNet) und zielt auf die Identifizierung und Anwendung von Best Practices für die Anwendung von web-basierten GIS in komplexen Krisenszenarien sowie die Entwicklung eines Prototyps mit WIA-Unterstützung ab, die es Betreibern ermöglicht Entscheidungsprozesse für zukünftige Krisen zu verbessern. Dies beinhaltet die Aufstellung der Systemarchitektur, Merkmale und Spezifikationen der Anwendung und wird anhand eines Krisenszenarios illustriert. Eine Usability-Evaluierung wurde durchgeführt, die mögliche Schwachstellen in der Mensch-Maschine-Interaktion prüft und die die Zufriedenheit der Benutzer beim Verwenden der Software misst.

Acknowledgment

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Chapter 1

Introduction

1.1 Motivation

Crisis management has become more complicated, since large-scale crises seem to be more prevalent and new threats arise due to the increasing dependence on a functioning infrastructure for society. This increasing dependency has evolved due to factors such as urbanization, population increase and climatic changes [10, 11]. Hence, a comprehensive improvement in the efficiency and effectiveness of crisis management and Critical Infrastructure Protection (CIP), the "programs, activities and interactions used by governments, owners, operators and stakeholders to protect their critical infrastructure," [36] has become paramount. Infrastructures are growing faster than ever and form a sophisticated system. A loss of an infrastructure, for instance a nationwide power outage, can cause economical and societal damages [37].

The Critical Infrastructure Preparedness and Resilience Research Network (CIPRNet), a project funded by the European Union, aims at conducting research and development and providing a "Network of Excellence" for CIP [36]. Two major capabilities of the CIP are the advanced decision support system (DSS) and the 'what if' analysis (WIA). WIA is a method that enables the user to check the impacts and consequences of different lines of action by utilizing integrated or federated simulation [33]. This method can be useful for crisis managers since they are capable of exploring different actions and their consequences, thus enhancing their decision-making.

Geographical Information Systems (GIS) are capable of giving an overview of all important infrastructures of a country as well as storing and analyzing a wide variety of information ranging from social to natural environmental data [17]. Combining GIS with the WIA method can provide a better situational awareness for crisis managers by incorporating and centralizing data onto one display [16].

1.2 Objective

This thesis aims at identifying and applying best practices for the application of web-based GIS in complex crisis management scenarios and developing a prototype application called *CIPRTrainer* with WIA support in order to enable operators to enhance their decision-making process for future crises. The system architecture, features and specifications of the application will be developed and illustrated on the basis of a predefined crisis scenario.

1.3 Project Context

This section gives a brief description about the CIPRNet project including the area of research, which is relevant for perusing the objective of this thesis.

1.3.1 CIPRNet‘s Goal

The goal of CIPRNet is to build a ‘Network of Excellence’ in CIP for public administrations, critical infrastructure operators and crisis managers to enhance mitigation, preparedness and resilience processes of critical infrastructures [9]. This includes establishing a “European Infrastructures Simulation and Analysis Center” (EISAC) that provide an enhancement of responses by authorities or critical infrastructure owners towards complex crises, which affect critical infrastructures (CIs) [9]. CIs are defined as those organizations and facilities that have a major importance to society [38]. The failure of a CI would cause dramatic consequences such as sustained shortages of supplies, significant disruptions to safety and security or other dramatic consequences [38]. The area of research of CIPRNet includes capabilities like ‘advanced decision support’ (DSS), ‘what if’ analysis (WIA) and ‘ask the expert’ capability. This thesis focuses on the WIA capability that incorporates Federated Modeling, Simulation and Analysis (MS&A).

1.3.2 Federated Modeling, Simulation and Analysis

The main idea of federated MS&A is to evaluate the behavior of complex systems of any kind by applying simulation [33], which requires a realistic system model. In the context of CIPRNet , MS&A can be applied to investigate certain disruptions of CIs and their effects on further CIs [33]. The result reveals interdependencies of CIs. A CI forms a closed, complex system, e.g. power grid systems. Another interacting system can be a railway network. The set of subsystems builds a global system. Modeling a global system can be implemented in two ways: *Integrated Modeling* or *Federated Modeling* [28].

Integrated Modeling

Integrated modeling uses one large, complete model that describes the whole system. Only one simulator is necessary to perform analysis. Moreover, fewer analytical methods are required due to the usage of a single simulator. Integrated Modeling has advantages and disadvantages. The advantages are:

- Accuracy of the model can be chosen as needed
- Model for the entire set of subsystems is consistent
- Model can be outlined on a desired level of detail
- Simplified communication infrastructure between model and simulator [33]

On the other side, an integrated model can also bring disadvantages with it:

- Building the model can be very complex, especially by heterogeneous systems
- Modeling requires numerous resources for verification and validation
- Adding new features (e.g. a new CI) may require a new implementation of the entire model [33]

Federated Modeling

Federated modeling follows a different approach by using multiple simulators and connecting them together in order to evaluate the behavior of a system. Each simulator requires a specific system model that can be different to the other models. Hence, a communication layer between the simulators has to be implemented in order to enable an interoperability. Therefore, the simulation behaviors have to be interpreted *semantically*. The advantageous features of federated modeling are:

- Commercial simulators can be adopted
- More accurate results can be achieved since each simulator has an appropriate fitted model
- Level of detail of the models can vary between the simulators
- Multiple simulations perform simultaneously [33]

The disadvantages are:

- Computational effort of the results is much higher
- Communication layer for the simulators has to be implemented
- Simulation behavior has to be interpreted semantically
- Synchronization is needed [33]

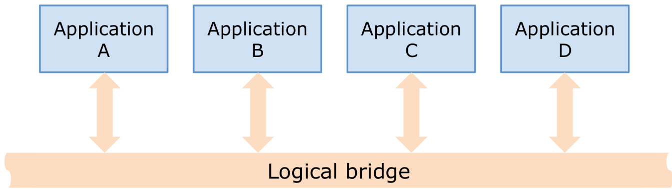


Figure 1.1: One logical bridge provides the communication between the simulators [28].

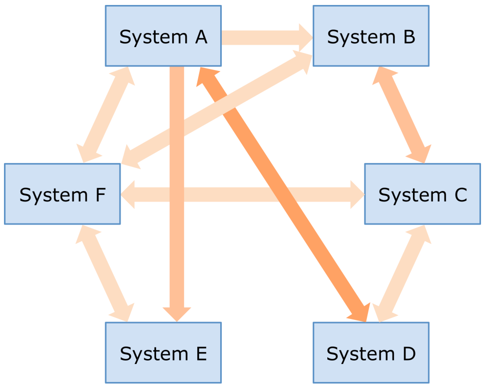


Figure 1.2: Systems communicate to others using one specific communication channel each [28].

Lateral and Central Coupling

Coupling of the simulators can be done in two ways: *Central*- and *Lateral* Coupling. Following the Central coupling approach, there exists one main logical bridge, which handles data- and simulation time-management, messaging and security measures [33]. Figure 1.1 illustrates the system structure using the *Central* topology. Using *Lateral* coupling, the simulators are connected directly to each other by using one communication-specific channel for a simulator pair that provides all necessary interoperability capabilities (see Figure 1.2).

1.3.3 'What if' Analysis

Evaluating a behavior (e.g. with focus on impacts and consequences) of certain events beforehand requires a predictive system [26]. The main idea of WIA is to evaluate the system‘s behavior by initiating certain actions, evaluating the behavior by applying scientific methods and jumping back to certain prior states such that the operator is able to continue the same procedure again, but with different actions. A designed scenarios is required

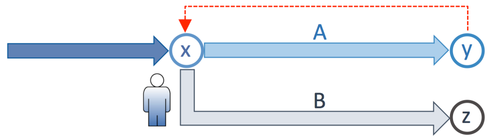


Figure 1.3: 'What if' analysis capability explores different courses of action [33].

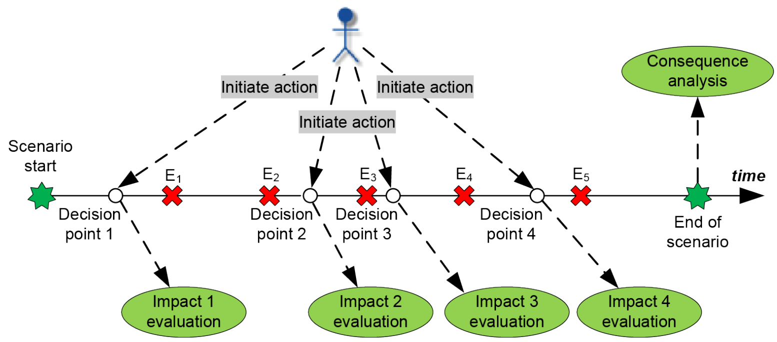


Figure 1.4: 'What if' analysis decision-making process example on a timeline [33].

in order to perform WIA [12]. Figure 1.3 depicts the functioning principle of this method. Given a scenario, user is able to initiate actions at certain decision points (x_t). Each action affects the behavior of the system. Once the user initiates one or more actions and the simulation behavior is computed, he can return to the decision point (x_t) and initiate a different action (e.g. Action B). When the simulation terminates, the user continues with evaluation of the system using scientific methodologies e.g the consequence analysis (CA). Figure 1.4 shows an example of a decision-making process on a timeline. Three types of events are defined: Internal simulation events, produced by the simulator, scenario events, represented as red crosses (E_i); and user events, which are initiated by the user. When a decision is taken, the user can demand an impact evaluation, which is performed by the simulator. The outcome of the simulation leads to a set of consequence analyses of different action chains. The user is able to evaluate the different results and inspect the behavior of a complex crisis scenario [12].

1.3.4 Consequence Analysis

Currently there is no agreed upon definition of Consequence Analysis (CA). To define CA it is necessary to discern between the terms incident, impact and consequence. CIPRNet considers this logical sequence as the basis of the CA:

$$\text{Threat} \rightarrow \text{Incident} \rightarrow \text{Impact} \rightarrow \text{Consequences [27].}$$

An incident is defined as “an event that might be, or could lead to, an operational interruption, disruption, loss, emergency or crisis” (ISO/PAS 22399:2007). Impact is defined as “the direct outcome of an incident” [27], for example the physical damage on a private house due to a flood. This impact has consequences in terms of economic cost for the repair of the damage and the decreased/lost living quality for the inhabitants. A consequence is therefore the evaluated outcomes of an impact [27]. CA is defined as the evaluation of CI- and other-related consequences by applying methods for domain-specific hazards/disaster, CIs and outputs that perform quantitative and qualitative damage measurements. The CA module of the CIPRTrainer considers mainly socio-economic consequences caused by impaired or not functioning CIs or extreme natural phenomena such as flooding. There exists methods for hazardous events like storms, floods and earthquakes that measure consequences by applying domain-specific damage formula.

Chapter 2

State of the Art

2.1 Geographic Information Systems

This section introduces the fundamentals of Geographic Information Systems beginning with a definition of GIS followed by a section about the difference between data and information. Furthermore, brief sections describe the core capabilities of GIS and standards that are applied in modern GIS applications. Lastly, a short section about notable GIS open-source-software is presented.

2.1.1 GIS in a Nutshell

GIS is defined as an information system that enables users to visualize and analyze spatial data in order to gain knowledge about different kinds of features, tendencies and relations [31]. GIS can be categorized into six components: software, hardware, people, knowledge, data and network [31]. Since information systems are applications, **software** is needed to run these programs on **hardware** (e.g. normal computers). **People** are included who want to gain **knowledge** about relations, tendencies, pattern of specific spatial data, for instance the Federal Office of Civil Protection and Disaster Assistance (BBK). The representation of spatial information relies on **data**, which is the most significant component of GIS. The **network** combines all other components together.

2.1.2 Data, Information and Knowledge

It is necessary to distinguish between data, information and knowledge when dealing with GIS: Data is essentially raw facts or symbols that are not processed and for human being meaningless. Information is processed, organized and structured data that provides a context [31]. Knowledge is a "collection of information" with the intention of being useful [3]. GIS itself does not

Figure 2.1: Satellite Imagery: A typical GIS base map.

provide knowledge, since it can only answer “who,” “what,” “where” and “when” questions, which are by definition information [3]. However, GIS processes data and can provide information such that the user is capable of gaining knowledge by understanding patterns and relations and answering “how” questions.

2.1.3 Core Capabilities of GIS

The main capability of GIS is the accumulation of various sets of geographical layers containing data that can be shown onto one display. Two types of layers can be distinguished: *Reference* and *Thematic* layers [31]. Reference layers build the background of GIS and do not deliver any specific message, but gives an orientation to the user. Reference layers are also referred to as *base layers* or *base maps* [31]. A typical base map is a satellite image as depicted in Figure 2.1. The more relevant layers are the thematic layers, of which there are several types: Choropleth Maps, Dot Density Maps, Proportional Symbol Maps and Isarithmic Maps [31]. **Choropleth maps** are used for classifying homogeneous and areal entities using specific colors [34]. Considering a qualitative classification, the colors should be selected carefully depending on the amount of entities. In this case, the colors can be differentiated by the color hue. For quantitative classifications colors should be used in a short hue ranges with different saturation levels that are proportional to the classified entities [31]. Usually the entity with highest quantitative value has the darkest color. “**Proportional symbol maps** use symbols of varying sizes that are proportional to the value or magnitude being shown" [31]. **Dot density maps** illustrate the distribution of behavior patterns or conditions by marking these observations as dots on the map [31]. Examples are the usage of Twitter or the dissemination of a disease across the globe. **Isarithmic maps** are used to show continuous data like elevations, temperature or rainfall commonly illustrated on a contour map [31].

2.1.4 Data and Service Standards for GIS

The Open Geospatial Consortium (**OCG**) is an international organization that provides spatial data- and service standards for various GIS applications [39]. One of these standards is the Web Map Service Interface Standard (**WMS**) that "provides a simple HTTP interface for requesting geo-registered map images from one or more distributed geospatial databases" [40]. Another important standard is the Web Feature Service Interface Standard (**WFS**), which provides an interface specification for requesting spatial features [41].
The Geographic Markup Language (**GML**) is a **XML**-based grammar specification for spatial features and is mostly combined with the OCG services [31]. The following represents a point in **GML**-notation:

```xml
<?xml version="1.0" encoding="UTF-8"?>
<gml:Point gml:id="p21" srsName="http://www.opengis.net/def/crs/EPSG
    /0/4326">
  <gml:pos srsDimension="2">6.238827 51.833094 0</gml:pos>
</gml:Point>
```

A very common feature representation for geographic visualization, including annotation of maps and images, is the Keyhole Markup Language specification 2.2 (**KML**), which is developed by Google [42]. **KML** is also a **XML**-based grammar. The following illustrates a hospital in Emmerich (Germany) using the **KML**-notation:

```xml
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://www.opengis.net/kml/2.2">
  <name>Emmerich Krankenhaus</name>
  <Placemark id="1.3.2">
    <name>St. Willibrord-Spital Emmerich</name>
    <address>Willibrordstraße 9, 46446 Emmerich am Rhein</address>
    <phoneNumber>02822 730</phoneNumber>
    <description>http://willibrord.de</description>
    <Point>
      <coordinates>6.238827,51.833094,0</coordinates>
    </Point>
  </Placemark>
</kml>
```

Shapefile is another standard for spatial feature representation, developed by Environmental Systems Research Institute (ESRI). It consists of three files: a main file (.shp), an index file (.shx) and a dBASE table (.dbf) [8]. The main file stores vector information like points, lines or polygons. The index file contains the indices of each record in the main file. The dBASE table includes feature attributes of each record in the main file. Geometry can also be represented in tabular data source format, for instance in the **Comma Separated Value** format (CSV). The first row contains the list of title describing the data and are delimited by commas. Each further row contains the actual entry record. Many GIS applications allow the import of CSV files. The following illustrates a hospital entry in CSV-notation:

```
ID, Latitude, Longitude, Name, Address
01, 6.238827, 51.833094, "hospital", "St. Willibrord-Spital Emmerich"
02, 6.433381, 51.848910, "hospital", "Augustahospital Anholt"
```

A different format for representing geographical features is **GeoJSON**. It supports geometry types such as `Point`, `LineString`, `Polygon`, `MultiPoint`, `MultiLineString` and `MultiPolygon` [43]. By definition of the **GeoJSON** specification, geometry is a `FeatureCollection`-object that contains a type-attribute and a list of `Feature`-objects. A `Feature`-object includes a type-attribute, the `geometry`-object, containing the type and coordinates, and an additional `properties`-object containing attributes of the geometry. The following illustrates the Emmerich example using the **GeoJSON**-notation:

```
{
  "type": "FeatureCollection",
  "features": [
    {
      "type": "Feature",
      "geometry": {
        "type": "Point",
        "coordinates": [6.238827, 51.833094]
      },
      "properties": {
        "name": "St. Willibrord-Spital Emmerich",
        "address": "Willibrordstraße 9, 46446 Emmerich am Rhein",
        "phoneNumber": 02822730,
        "description": "http://willibrord.de"
      }
    },
    {
      "type": "Feature",
      ...
    }
  ]
}
```

2.1.5 GIS Open Source Software

This section provides a brief overview of the most important GIS open-source-software.

Desktop Applications

There are several open source desktop applications available. A well-known application is **Quantum GIS** (QGIS), which allows users to "create, edit, visualize, analyses and publish geospatial information" [44] and is available on operating systems like Windows, Mac, Linux, BSD and Android. Equivalent applications are **gvSIG** and **grassGIS**.

Map servers

Map servers build the back-end of a GIS application, including map rendering and other services. **Mapnik** is a library written in C++ with Python bindings and provides map rendering [45]. The open source project OpenStreetMap uses Mapnik. An equivalent renderer is **MapServer** [46], which is written in C. **GeoServer** allows users to view and edit geospatial data [47] and is written in Java. QGIS also offers a map server called **QGISServer**. All servers provide the OGC standards WMS and WFS.

Spatial Database Management Systems

Serializing geographical data in conventional databases is not convenient since entries may have different geometrical types that result in problems querying locations. **PostGIS** is a spatial extension for an object-relational **PostgreSQL** database [48] with the ability to query geospatial entries [49]. An equivalent database for geographic entries is **SpatialLite** [50] that extends a **SQLite** database [51].

Web-based Software Development Frameworks and Libraries

LeafletJS is a modern open source JavaScript library for interactive maps [52]. **OpenLayers** is an equivalent JavaScript library for rendering maps on web pages. The 3.5.0 release allows the integration of WebGL, which provides 3D capabilities [53].

2.2 Crisis Management in Germany

Crisis management makes a significant contribution to the protection of life, property and the environment [29]. In the context of CIP, the goal is to achieve "the best possible maintenance of operability and quickest possible recovery of critical processes respectively" [29]. Crisis management incorporates several management concepts, for instance risk management [29]. Measures are developed and established to "ensure the operational and official continuity, and if crises occur to return to the normal state" [29]. The main tasks of crisis management in Germany are "to create the conceptual, organizational and procedural requirements to ensure the best possible coping with an extreme event" and "the establishment of special structures for response to a crisis, in particular the establishment of a crisis management team" [29].

2.2.1 Emergency, Crisis and Disaster Terminology

Terms like emergency, crisis or disaster can have different meanings in different countries. Nevertheless, in this thesis definitions will be chosen that correspond to the definitions of the Federal Ministry of the Interior. An emergency is defined as "a loss-causing event in which processes or resources of an institution do not function as intended" [6]. Moreover, the availability of the corresponding processes or resources can not be provided within the required time. The business establishment is severely impaired and without an interaction of an emergency organization cannot be re-established. The term crisis is defined as a "situation deviating from the normal state with the potential for companies, authorities or states of not being able to proceed procedural- and structural organization" [29]. Crises can degenerate differently: crises with insidious signals that can only be recognized by early warning systems (latent crisis); eruptive or acute crises that cause critical situations without any advance notices; and permanent crises that remain at a critical level for a long period of time [32]. Finally, a disaster is "a major loss event which is temporally and spatially hardly limited and can have a large impact on the environment in which the existence of institution, human life and public life are endangered" [6]. Moreover, a disaster cannot be resolved solely by the institution itself, but requires civil protection and external organizations.

2.2.2 Crisis as a Recurring Process

Every crisis resolution begins with an event that is in most cases unforeseeable. A *cyclic workflow* for the crisis resolution is approved by practical experience in crisis management, which can be categorized into four phases: Preparedness, Response, Recovery and Mitigation (see Figure 2.2) [19]. The following paragraphs describe the four phases.

Figure 2.2: Crisis Management encompasses four phases: Preparedness, Response, Recovery and Mitigation [19].

Preparedness

The preparedness phase includes those activities that prepare for actual emergencies or crises, which can be emergency maneuver and training, establishing warning systems or other programs [11]. Potential crises will be identified and preventive measures developed. It also incorporates a risk analysis which is part of the risk management. It includes establishing early warning systems or defining processes in the case of a crisis [19].

Response

In latent crises, early warning systems are used to report crisis-potential deviations in companies, agencies or other organizations. In this case, measures and precautions will be taken in order to avoid further degeneracy of the crisis into an acute crisis. In acute crises, the status report needs to be communicated even though the information is not complete [19]. Emergency services like rescue teams, fire brigades, police, THW, logistical support and public safety need to be informed and mobilized [19]. A coordination and exchange of information between local authorities, companies, public media, experts and the public is vital in the beginning of the crisis in order to protect life, property and the environment.

Recovery

Recovery activities usually begin when the emergency or crisis is over. This can be categorized by two phases: short-term and long-term recovery. During short-term recovery, vital services and systems are restored (e.g. temporary food, water, shelter to citizens). Long-term recovery can last several years depending on the extent of the emergency or crisis. It restores all services (e.g. replacement of homes, water systems, streets, school and hospitals) [16].

Mitigation

The mitigation phase attempts to reduce damages and losses for future crises. Based on the knowledge gained of the past crises, the existing strategies and concepts need to be re-analyzed and, if necessary, improved in efficiency and effectiveness [19].

2.2.3 The Federal Office of Civil Protection and Disaster Response

Germany established the Federal Office of Civil Protection and Disaster Response (BBK) in 2004 [2]. It is in charge of:

- Cooperation with government and federal states in hazardous situations
- Critical infrastructure and civil protection
- Warning and informing the people
- Performing risk analysis
- Developing standards and concepts for civil protection
- Establishing warning systems
- Supporting community in terms of self-protection
- Conducting technological and scientific research
- Training for Civil Protection
- Protection of cultural assets according to Haager conventions
- Other services like personnel matters [2]

The organizational chart (see Figure 2.3) illustrates the structural organization of the BBK. It consists of five major departments: *Crisis Management*, *Risk Management*, *Science and Technology*, *Training* and *Central Services*, which are conducted by the BBK president and vice president. The use of IT supporting systems is a characteristic of a modern and effective civil protection. They are vital for coping with crises and enable support in many cases, for instance providing status reports, planning and controlling of help services [5]. Moreover, they are an advantageous tool to visualize information consistently and to make it accessible for participants. The 9/11 incident in New York in 2001 led to an enhancement of the BBK [5]. It now enjoys

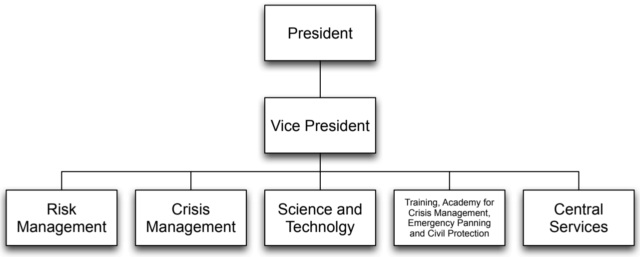


Figure 2.3: The organizational chart of BBK [54].

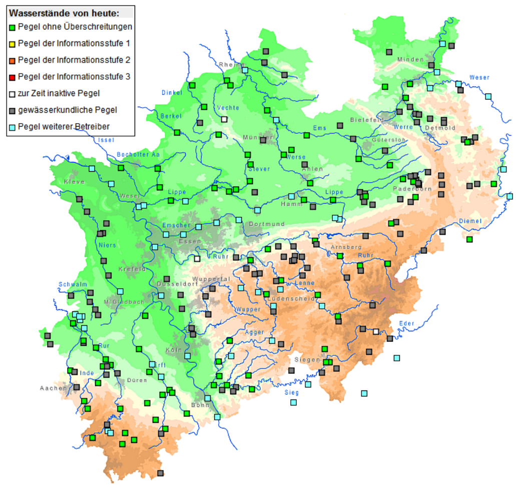


Figure 2.4: Water levels in North Rhine-Westphalia (NRW), Germany [55].

new privileges, such as the extension of information exchange between authorities, more corporation between the federal states and the government and more effective crisis management of federal states and government in extraordinary hazardous situations [5]. These new capabilities are supported by the new German emergency preparedness information system **deNIS I** and **deNIS II** and the upcoming version: **deNIS II**^{KM}.

deNIS I and deNIS II^{KM}

deNIS I is considered for the public and is essentially a huge database containing material about hazards and basic data of natural disasters in Germany. It also offers a view in hazardous materials and behavioral measures [5]. Figure 2.4 represents the water levels in NRW provided by deNIS I. deNIS II is not available for the public but for decision makers in action committees of federal states and government of Germany. The core element

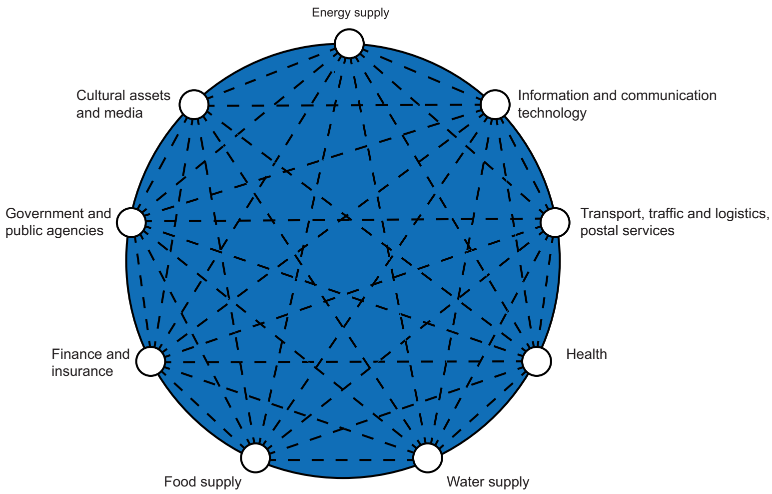


Figure 2.5: Interdependencies of CIs [29].

of this system is a GIS that combines data with spatial context for reviewing loss events and damages [5]. The architecture of this system is a typical client-server architecture combined with web-based standards. New features have been added, e.g. notification management, dynamical data integration from other databases, better usability and new map capabilities (deNIS II^{plus}). Past experience has proven the added value of this system. New specifications have been requested for the next version, deNIS II^{KM}, for instance the simplification of the system in order to focus on relevant information and reduce maintenance by using open-source-software [5].

Critical Infrastructure Protection

Infrastructures are considered to be vital for modern society because of the dependence on their availability. Hence, their protection is of high importance. CIs can be categorized into nine sectors:

- Energy supply (electricity, oil, natural gas)
- Information and communication technology
- Transport, traffic and logistics, postal service
- Health
- Water supply
- Food supply
- Finance and insurance
- Government and public agencies
- Cultural assets and media [29]

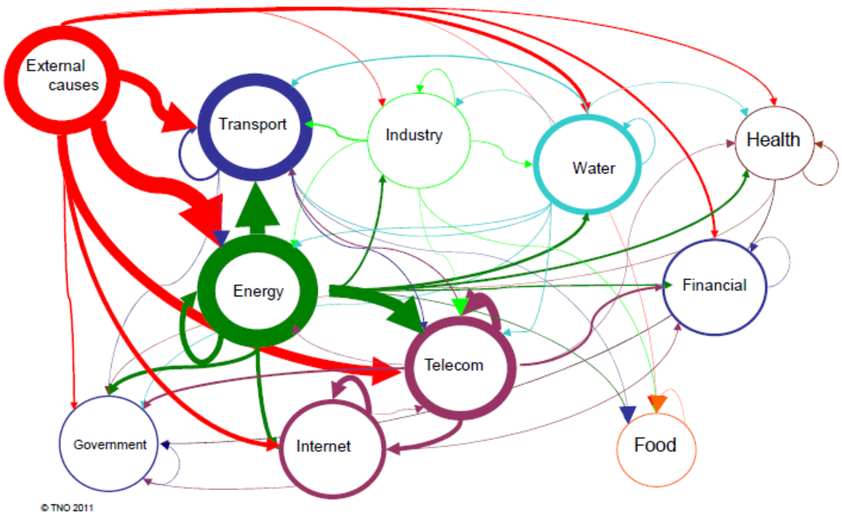


Figure 2.6: Dependencies between CI-sectors in Europe from empirical findings. [20]

CIs show specific characteristics. One of them is the internal networking. Services are provided through physical, virtual and logic nets, which grow in size and sophistication [29]. These nets form *critical points* whose outage can cause regional, national or worldwide disadvantageous effects. Another characteristic is the *interdependencies* of CIs; an outage of one or more critical points can have cascading effects on other CIs [29]. A dependency between two CIs is defined as a connection "through which the state of one infrastructure influences or is correlated to the state of the other", whereas an interdependency is a bidirectional dependency of two CIs [1]. In other words, an interdependency is a mutual dependency of two CIs. Considering this characteristic, it is evident that most CIs rely on the energy sector (see Figure 2.6). The width of the line originating from a CI represents the "number of external or dependency events" for other CIs [20]. For instance, the transport and telecommunication sector rely on the energy sector the most. Even small interruptions in this complex system can have dramatic consequences. The technological progress intensifies the susceptibility of CIs since improvements cannot be applied on all CIs simultaneously. Therefore, CIs build a complex of new and partially new technologies and processes [29]. Moreover, there exists different *damage types* in CIs. These can range from physical and economical damages to psychological damages, for instance loss of trust from customers on services and products, respectively. In order to overcome the drawbacks of these characteristics, the BBK developed a five phase concept especially for CIP. The *first phase* constitutes a preliminary planning with the purpose of establishing risk and crisis management, defining aims for CIP and facilitating the situational awareness (see Section 2.3.1). Furthermore, responsibilities have to be set for leadership and teams and an estimation of the need for resources calculated. The *second phase* is the risk analysis that determines types of hazards, their probabilities of occurrence, weak points in the system and consequences by certain disruptions of CIs. One part of the risk analysis is the *criticality analysis*. This is the evaluation of processes in CIs that cause "wide-ranging consequences" by disruption. Criticality is defined as "a measurement for the importance of a process in terms of consequences whose failure causes an impairment of an institution" [29]. The *third phase* incorporates developing preventive measures and strategies that mitigate risks of critical processes [29]. The *fourth phase* is the actual crisis management, which is described in earlier sections. Crisis management can also be categorized in three instead of four phases is also possible. However, the transition from one phase into another is fluent. The stages of a crisis management can be differentiated and paired with the following phases: "before crisis" that corresponds to the preparedness phase, "during crisis" that is equal to the respond and recovery phase; and finally "after crisis", which can be compared with the mitigation phase [29]. Finally, the *fifth phase* of CIP is the evaluation of all previous phases. CIP is a cyclic, permanent changing process confronted with the emergence of new threats, increasing dependencies and interdependencies of CIs. Therefore every phase needs to be checked in effectiveness, efficiency and topicality.

German Federal Agency for Technical Relief

The German Federal Agency for Technical Relief (THW) is a civil- and crisis management protection organization in Germany with about 80,000 trained volunteers. It is subordinate to the Federal Ministry of the Interior and provides technical support for managing crises, public emergencies and large scale accidents according to THWG §1 [3]. It also can operate abroad on behalf of the government (THWG §1 [2]).

2.3 Role of GIS for Crisis Management Preparedness

Geographical information is becoming more important in political and economic affairs, particularly with regard to civil protection and disaster response, by providing data processing and integration of various subject matter [4]. The spatial context, i.e. knowing "where" something happened, gives statements a higher significance in terms of the situational awareness [4].

2.3.1 GIS and Situational Awareness

Situational Awareness (SA) can be understood as “the human user‘s internal conceptualization of a situation” [18]. Moreover, there exist multiple levels of SA. The first level is the recognition of objects or events, for instance buildings, streets or points of interests on a map and explosion or flooding. The second level of SA is the “comprehension of the significance of the objects or events” forming a comprehensive view of the situation. The third and last level is the capability of “projecting future actions of the elements on the environment” [18]. A crisis manager has the highest SA, for instance by recognizing continuous raining on a location including CIs (level one), classifying the raining as a significant event with increased risk for flooding (level two) and, lastly, forecasting flooding and outages of the surrounding CIs based on experience and a comprehensive view of the current situation (level three). Achieving the highest level of SA is difficult and requires intensive training and access to relevant data in a short period of time. A GIS, including technology like remote sensing and comprehensive analyses, is capable of providing all necessary information in order to be informed and to understand the dynamics of the situation, and based on that to be able to make the right decisions [25]. Simulating crisis scenarios on the basis of GIS can help to understand dynamics and patterns in the environment more extensively and therefore enhances the crisis manager‘s SA.

2.3.2 Integrated Modeling and Simulation for Crisis Preparedness

As described in Section 1.3.2, integrated modeling and simulation relies on a single model in order to analyze the behavior of a system. In the recent past, the usage of modeling and simulation (M&S) has become advantageous in providing scientific information for performing training and exercises [22]. This section describes the recent software that utilizes M&S for Crisis Preparedness.

Standard Unified Modeling, Mapping and Integration Toolkit

SUMMIT (Standard Unified Modeling, Mapping and Integration Toolkit) is a recent software project developed by the Federal Emergency Management Agency (FEMA), Department of Homeland Security, Science and Technology Directorate (DHS S&T) and Sandia National Laboratories (Sandia) that “enables users to discover and reuse models, integrate them quickly and economically, and apply them in analyses” in order to enhance preparedness activities significantly [22]. Figure 2.7 depicts the capabilities of SUMMIT. SUMMIT has a typical server-client architecture with underly-

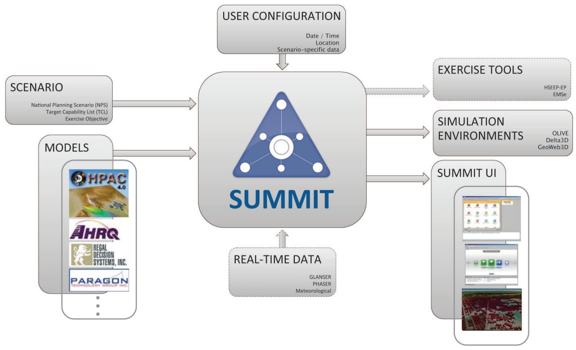


Figure 2.7: SUMMIT incorporates predefined science-based scenarios and models, allows user configuration, real-time data integration, web-based access to the UI and sophisticated exercise tools and data representation [21].

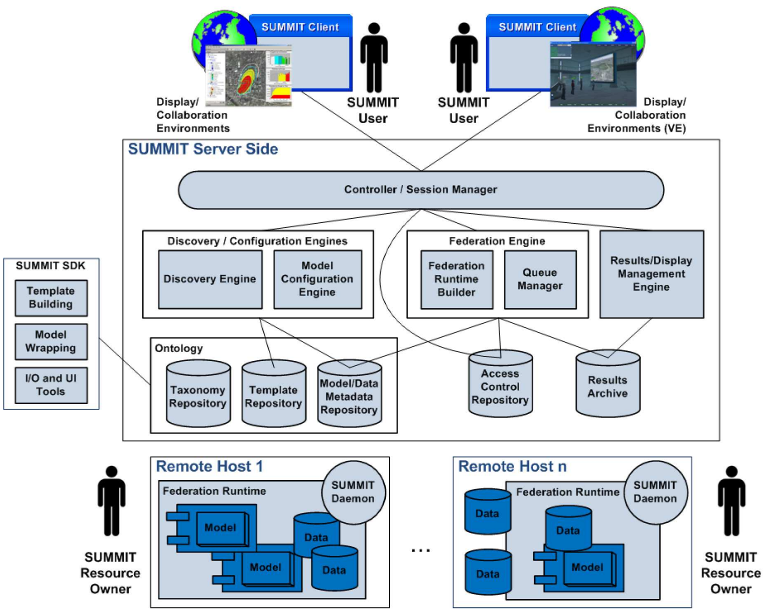


Figure 2.8: SUMMIT architecture consists of web-based clients, server and databases making data and models available [24].

ing databases containing models and data that are hosted by different contributors (see Figure 2.8) [24]. The server establishes so-called “simulation templates” that essentially correspond to “abstract representations of an incident” that are supposed to be simulated [22]. Users are eligible to “connect, execute and access results of modeling and simulation runs” [22]. However, they are classified into three categories having different privileges: scenario planner, model owner and crisis responders [24]. Model owners have access

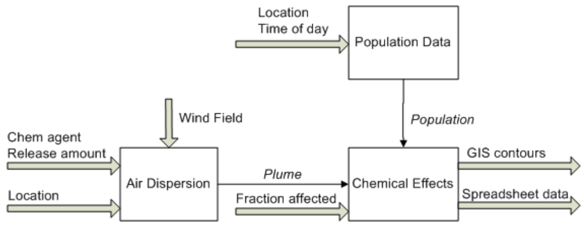


Figure 2.9: Scenario example for chemical effects containing functions, inputs and outputs [24].

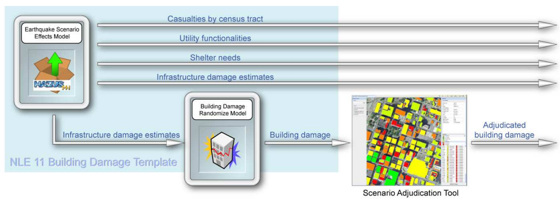


Figure 2.10: Scenario for estimating earthquake damages [30].

to the SDK Model Wrapper enabling models being applied on the SUMMIT Federation Unit. Scenario planners are privileged to have access to the SDK Template Builder for creating scenarios. Finally, crisis responders or the “final end user” are able to sign into the system and choose the desired scenario, configure specific parameters, run the simulation and view the results [24]. A scenario consists of functions, data flow links, inputs and outputs. The example in Figure 2.9 depicts three functions: Air Dispersion, Chemical Effects and Population Data. The function “Population Data” computes the number of population based on location and time. “Air Dispersion” requires information about location, wind field and release amount of chemicals in order to compute a plume that corresponds to the input of the linking function ”Chemical Effects”. Finally, the computed chemical effects on population and infrastructures are available on a GIS or Spreadsheet. Templates can be saved and reused with different parameters, which offer ‘what if’ characteristics since different simulation results can be reviewed and compared [22]. Another example is the catastrophic earthquake scenario (see Figure 2.10) based on “simulated ground truth data” provided by HAZUS, which has the capability of calculating an estimation of CI damage probabilities, giving a prognosis of frequent requests of shelter needs. Moreover, an additional function can estimate building damages, which can be reviewed and customized with the Scenario Adjudication Tool in order to meet the requested objectives for emergency planners.

Chapter 3

Web-based Support of Crisis Management Training

This chapter includes the general approach for designing the front-end of the CIPRTrainer, a description of the CI models, the prototype requirements and lastly the use case definitions.

3.1 General Approach

To design an approach for developing the front-end, a blueprint of the overall system is required. The CIPRTrainer is divided into two main components: Design- and Training Engine [35]. The Design Engine enables *scenario designers* to create and edit scenarios for the training application [35]. The core component of the CIPRTrainer is the Training Engine (see Figure 3.1), which is considered for *trainers* and *trainees*, who are able to set up and conduct training sessions, respectively. Furthermore, the Training Engine incorporates several deployments[1], which include: CIPRTrainer front- and back-end, simulators, databases for storing socio-demographic and scenario data, WMS- and WFS-Server, Tile-Server and a NGINX-Server. The core of the system is the back-end of the CIPRTrainer, which provides all necessary services for the CA, WIA, Federated Simulation Controller and Action Module. The back-end also provides a Scenario Module, which loads and executes scenarios [35]. The Federated Simulation Controller is capable of pushing and receiving events from the different simulators through federated simulator adapters. Lastly, the back-end provides the “interaction with trainees and trainers by sending options and receiving actions” from

[1]Figure 3.1 depicts the current state of the system architecture. Changes may occur since it is based on an ongoing research project. Furthermore, Design Engine and flooding simulator are not depicted.

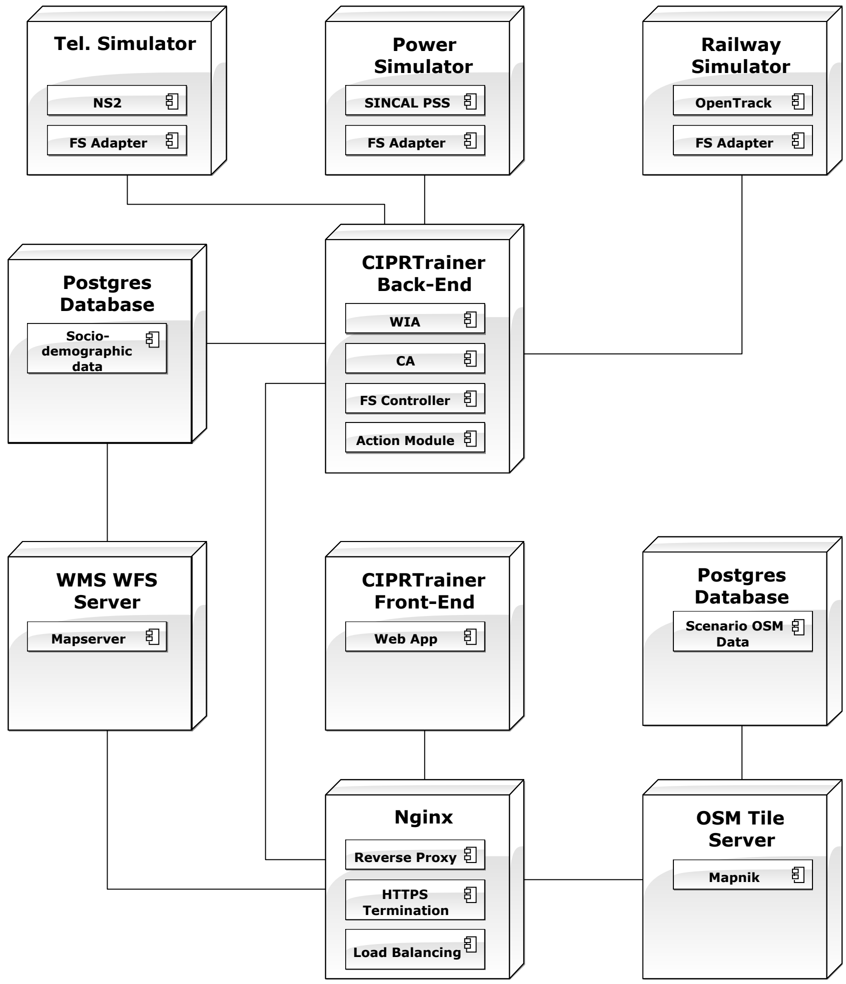


Figure 3.1: Software deployments of the CIPRTrainer Training Engine.

the front-end [35]. Actions are operative measures that can influence the states of the CI models. The CA module requires socio-demographic data in order to apply methods that calculate consequences and damage assessments. Since socio-demographic- and scenario data contains spatial information, it is serialized into Postgres databases. The connecting NGINX-Server provides Load Balancing, HTTPS termination and Reverse Proxying. Tile-Server such as Mapnik and Mapserver, are used to provide base maps, which can be accessed by the front-end of the CIPRTrainer. The Mapserver incorporates the WMS and WFS standards. The main focus of this thesis is the front-end, which will be implemented based on an example scenario. Since this system is a part of an entire scope of the long-term CIPRNet project and most of the components are in the design phase, mockups are used to replace missing functionalities. The components can be integrated as soon as they are designed, implemented and tested. Furthermore, a scenario specification is introduced that is applicable to the web-based GIS. The front-end is implemented on the basis of lessons learned in web-based GIS and crisis management, particularly for CIP in Germany. The general approach of developing a web-based GIS prototype for crisis managers includes the specification for the scenario and CI models. The introduced scenario defines a railway accident in Emmerich am Rhein. Additionally, two important CI models are introduced that are affected by the scenario events. Finally, a usability evaluation with regard to the human-machine-interaction and user satisfaction is performed.

3.2 Application Scenario

Scenarios allow crisis managers to outline a sequence of events and provide the basis for the CA, thus evaluating susceptibilities of CIs by revealing dependencies, interdependencies and cascading effects [1]. In this thesis, a scenario is defined as, without the loss of generality, a composition of *CI models* that feed the federated simulators, a *storyline*, which is spatially and temporally limited, and a *set of options* that contain operational measures or actions. The measures are restricted to the available local resources. Scenarios can be best outlined by choosing accidents, which have occurred in the past and resulted in tremendous impacts and consequences on society and CIs. In the following, a scenario is described, on which the system will be illustrated.

3.2.1 Storyline Design based on Derailment in Emmerich am Rhein Example

Emmerich am Rhein is a city with a population of $30,000$ located near the lower part of the Rhein river and adjoining the border of the Netherlands. The city includes CIs such as a harbor, railways, motorway A3, power generators and transmission grids [1]. The storyline defines a derailment of a train near the main station of Emmerich (latitude: 51.83528, longitude: 6.246653) containing two more damage-causing events (see Figure 3.2). The storyline is essentially a list of time-related events. Each event contains a list of affected CIs that recognize a loss of functionality, the occurrence date, incident location, duration timespan and an incident description (see Figure 3.3). The first event of the storyline occurs at 10:30 a.m. on a Monday. Due to a defective switch on the Betuwe route, the train, an engine coupled with

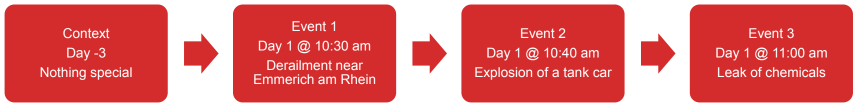


Figure 3.2: Scenario timeline of the railway accident in Emmerich am Rhein [1].

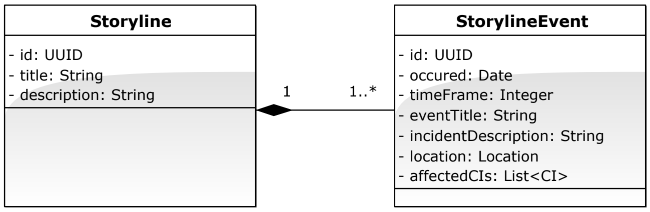


Figure 3.3: Storyline specification.

24 wagons and loaded with environmentally dangerous chemicals and liquid gas, loses the coupling of the front engine, which collides with trailers into surrounding houses at "Am Löwentor" and Bundesstrasse 8. A disruption of power grids, motorway and railway traffic near Emmerich am Rhein is detected. The second event is the explosion of a tank car on the same day at 10:40 a.m., which sets fire to several houses and other trailers and causes a rise of plumes of smoke. The wind blows chemicals and gas towards motorway A3 leading to a blockage of the highway. The last event occurs 20 minutes later. A continual loss of chemicals from the aforementioned trailers is recognized. Some of the trailers start to ignite. Components of the railway are heavily destroyed including "overhead wires (causing traction current short circuits) and masts, signal cables, tracks, and track beds" [1].

3.2.2 Modeling Scenario Operations and Resources

Operations within a scenario are defined as measures that are performed by trainees. More importantly, the operations mitigate CI damages and thereby influence the states of the CIs. Realizing rescue and mitigation operations requires a complete module, which is still not researched within the scope of the CIPRNet project [1]. This module is referred to as the *Action Module*. However, the front-end includes a mockup of operational measures, illustrating the functional principle. The most important organizations in North Rhine-Westphalia who are responsible for CIP and perform direct measures at accident sites are the crisis management committee and THW, respectively. In order to speak the 'same language', they use tactical symbols,

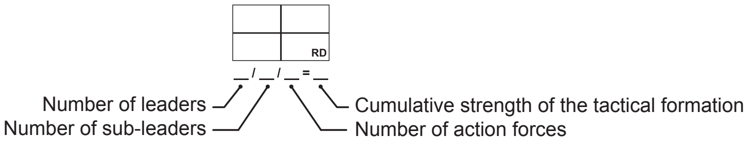


Figure 3.4: Tactical symbol notation for strength details of units [7].

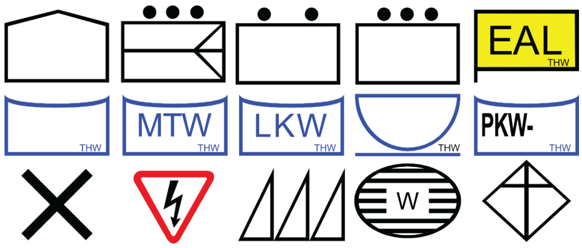


Figure 3.5: THW and BBK tactical symbols for the use of showing features and status reports of accidents on maps [7].

which are standardized symbols depicting status reports and features on maps. Figure 3.5 shows different symbols covering buildings and units in the first row, vehicles and equipments in the second row and finally, status reports such as destruction, high-voltage hazard, fire, flooding and fatalities. Then, physical units like fire brigades, the police and special rescue troops can assist at the accident site. A special notation allows a quantization of units (see Figure 3.4). Thereby, crisis managers are able to outline the number of local resources that are ready for action at the location of the accident site. This special notation is incorporated into the CIPRTrainer user interface.

3.3 Critical Infrastructure Model

The quality of the CA depends on the accuracy of the CI models. However, modeling *all* CIs for the front-end goes beyond the scope of this thesis. Hence, the system components and relations of the most relevant CIs, particularity for the Emmerich scenario, are introduced: power and railway networks. The prototype depicts the CI systems, which are not complete. However, it illustrates the concept of how to represent CIs on web-based GIS. The following sections describe the CIs models for the power network simulator **PSS SINCAL** and the railway simulator **OpenTrack**.

3.3.1 Railway Infrastructure

OpenTrack allows the building sophisticated railway infrastructures, define timetables, set up rolling stock (locomotives and wagons) and provides interactivity simulation and animation [14]. Moreover, analysis tools are accessible, which enable the user to view train graphs, statistics and occupations of railways [14]. In the context of CIPRTrainer, scenario designers use OpenTrack in order to build a realistic model of the railway infrastructure of Emmerich. Furthermore, realistic timetables have to be implemented in order to provide realistic data for the CA. Additionally, a correct amount of rolling material has to be inspected carefully. One key feature of OpenTrack is the capability of defining incidents. The accident in the Emmerich scenario has to be interpreted in the OpenTrack formalism. It is not possible to simulate the derailment, but an adequate interpretation has to be chosen that corresponds to the accident. For instance, a constant occupation of a route element or a power outage could simulate the derailment since no trains are able to use it. In the following, main entities of OpenTrack are presented that have significant importance for the web-based GIS. These are trains, paths, routes, itineraries and stations. Figure 3.6 illustrates the composition of the railway infrastructure including entities with underlying attributes. For instance, a train consists of one or more engines and a set of wagons (trailers). An itinerary is a composition of multiple paths and can be associated with stations. A path is a set of routes and can be considered as a "group of track sections". Routes essentially consist of a set of vertexes and edges, which are connected to each other. Additionally, paths rely on power supplies. An outage of a power supply can cause disruptions, which can lead to time delays or blockades. The diagram shows that multiple trains can drive on one or zero itineraries. The number zero indicates that a train can move to another itinerary. For the web-based GIS a simplification of the entire infrastructure is necessary since depicting all components of OpenTrack is too broad and most of them may not be relevant for the decision maker. Hence, only the necessary information that is relevant for the decision making process must be accessible. However, determining which railway component should or should not be depicted on the GIS map requires further analyses. Nevertheless, animations of driving trains on a GIS map has firstly a high computational effort and secondly is distracting. A decision maker should be able to determine at least the operational status of important components like stations, itineraries and trains.

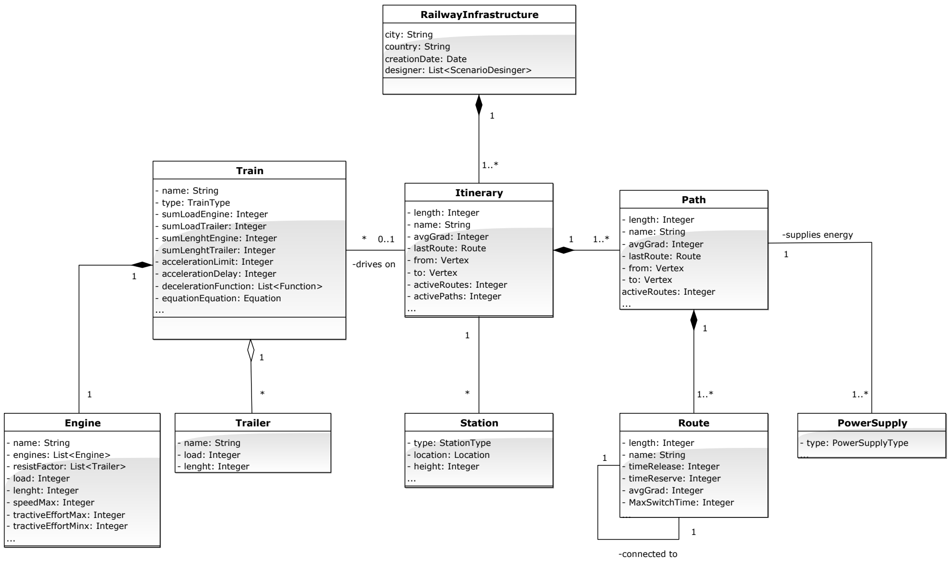


Figure 3.6: Railway infrastructure provided by OpenTrack.

3.3.2 Power Infrastructure

The most important CI is the energy sector that has to be implemented in every designed scenario. PSS SINCAL provides modeling low-, medium-, and high-voltage grids, which simulate power generation, transmission and distribution [56]. Figure 3.7 illustrates the system structure based on the power infrastructure in Germany [57]. Plants like coal-, hydro-electronic-, or wind plants produce power and transmit it through transmission grids to distribution substations. Transformer stations convert the voltage into an appropriate voltage class that is applicable for consumers. Distribution substations transfer the power from transmission substations to distribution systems in which consumers acquire the power. Consumers can be categorized into three areas: Residential areas, commercial areas, and industrial areas. Residential areas (households, small industries) need low-voltage grids (230 to 400 V). Commercial areas can be small cities or industries and require middle-voltage grids (6-30 kV). Finally, industrial areas are for power-intensive industries, infrastructures (e.g. railway system) and big cities, all of which require high-voltage grids (60 to 110 kV).

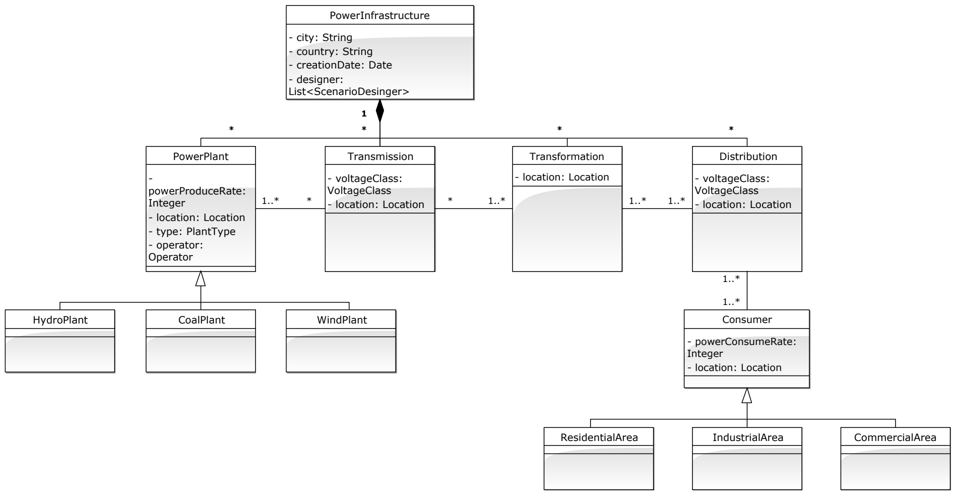


Figure 3.7: Power infrastructure provided by PSS SINCAL.

3.4 Prototype Requirements

3.4.1 Functional Requirements of CIPRTrainer

The functional requirements of the CIPRTrainer are outlined in the following schema: Each requirement contains an ID, priority level (**Must**, **Should**, **Can**), and a formal specification description.

ID	RF-1	**Priority**	Must
Requirement	Trainee is be able to explore the scenario model including events, CIs, resources and operational measures.		

ID	RF-2	**Priority**	Must
Requirement	Simulation events are depicted on the map and highlighted via coloring and animations.		

ID	RF-3	**Priority**	Must
Requirement	Notifications are pushed by the back-end and displayed in message boxes, which appear on the corner in order to avoid interrupting the user.		

ID	RF-4	**Priority**	Must
Requirement	User is able to check other participant's status (online, offline).		

ID	RF-5	**Priority**	Must
Requirement	Map control: Zoom in, zoom out, pan operations in the map view are provided.		

ID	RF-6	**Priority**	Must
Requirement	WIA: User is able to control the federated simulation: Start, stop, pause, continue, jump back (rollback) to time point (x_t). Furthermore, the user is able to observe impacts, perform measures (actions), and select and compare consequences of different courses of action.		

ID	RF-7	**Priority**	Should
Requirement	Users need to authenticate themselves by giving their username and password.		

ID	RF-8	**Priority**	Should
Requirement	User is able to manage username, password, E-Mail and view settings.		

ID	RF-9	**Priority**	Must
Requirement	User is able to filter resource information and CIs on the map.		

ID	RF-10	**Priority**	Must
Requirement	User is able to manage training logs.		

ID	RF-11	**Priority**	Can
Requirement	User is able to customize the CIPRTrainer.		

3.4.2 Nonfunctional Requirements of CIPRTrainer

The nonfunctional requirements of the CIPRTrainer will be outlined in the same schema.

ID	RN-1	**Priority**	Should
Requirement	Users do not require any further training or courses for using the application. No configurations are required to launch the application.		

ID	RN-2	**Priority**	Should
Requirement	Consequences of different decision branches should be presented in an “easy to understand” way.		

ID	RN-3	**Priority**	Must
Requirement	The simulation results should be pushed from the back-end to the front-end using advanced socket technology.		

ID	RN-4	**Priority**	Should
Requirement	The system uses advanced technologies (e.g. NodeJS, TypeScript, CytoscapeJS) to enhance user experience.		

ID	RN-5	**Priority**	Can
Requirement	The system uses third-party CSS libraries (such as Twitter Bootstrap) to achieve a modern look and feel.		

ID	RN-6	**Priority**	Can
Requirement	The system must support at least one of the following web browsers: FireFox, Safari or Chrome, in the most recent stable version available at delivery of the project.		

3.4.3 Use Cases of CIPRTrainer

Prior conception of the use cases of CIPRTrainer has been made in [33], which encompasses basic use cases. Since this conception is not sufficient, further detail level will be added. In the following, first level use cases for the trainee are explained. A use case contains an ID, use case name, involved actors, pre- and post-conditions and a formal specification.

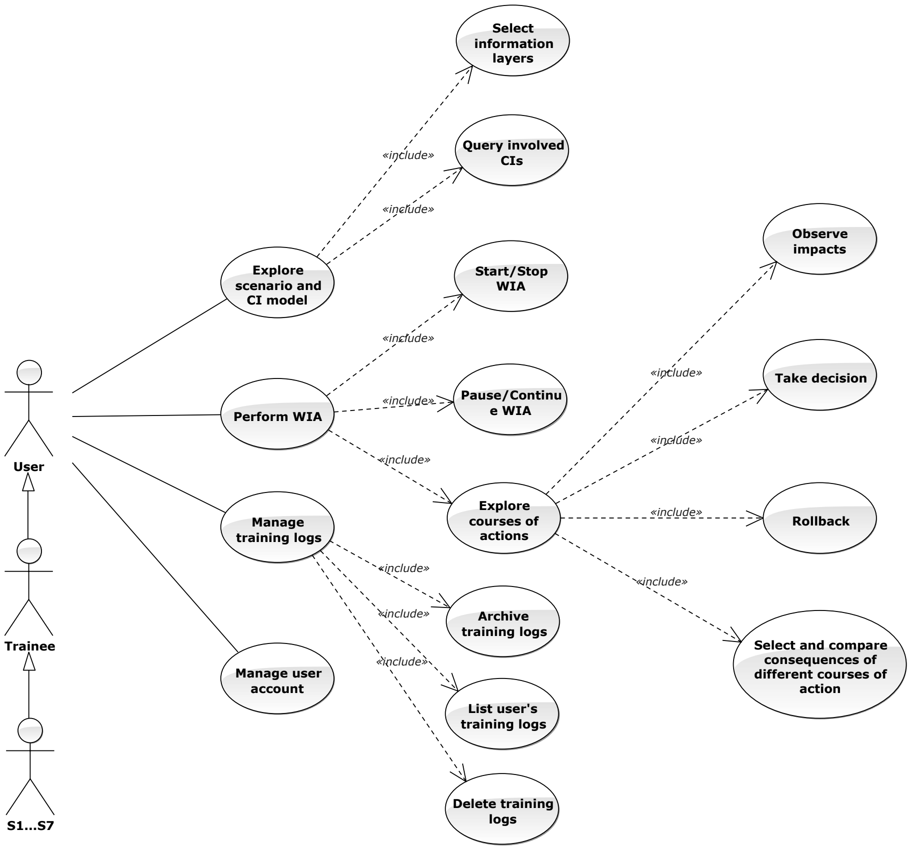


Figure 3.8: Use cases of the CIPRTrainer [33].

ID	**UC-1**
Use Case	Explore scenario and CI model
Actors	Trainee
Precondition	Trainee is authorized.
Specification	Trainee is able to explore the scenario so that he is able to receive a situational awareness level of S1. CIs and resources can be queried and information-layer selected.
Postcondition	Trainee is authorized.

ID	**UC-2**
Use Case	Perform WIA [33]
Actors	Trainee
Precondition	Trainee is authorized. Federated simulation is started.
Specification	Trainee is able is perform WIA capabilities including start/stop, pause/continue of the application scenario, explore impacts, perform measures (actions), rollback, select and compare different courses of action (CA).
Postcondition	Trainee is authorized.

ID	**UC-3**
Use Case	Manage Training Logs [33]
Actors	Trainee
Precondition	Trainee is authorized. Training is completed.
Specification	Trainee is able view, download, delete, list and filter training logs.
Postcondition	Trainee is authorized. Training is completed.

ID	**UC-4**
Use Case	Manage User Account
Actors	Trainee
Precondition	Trainee is authorized.
Specification	Trainee is able change username, e-mail and password, and configure view settings.
Postcondition	Trainee is authorized.

Chapter 4

System Design

4.1 Logic and Architecture

In the following, the logic and architecture of the front- and back-end are examined. The CIPRTrainer is a Singe-Page-Web-Application and has a single main view (HTML-page). Content will be loaded dynamically by sending AJAX-requests and receiving HTML-PUSH-notifications from the web-server. The system embraces a 3-tier-architecture, which contains a presentation, logic and data-tier (see Figure 4.1). The client-side contains the user interface (UI) for the users. It also applies the Angular MVC pattern, which includes UI logic. The `Models` are binded to the View (HTML-page) and can be manipulated through `Controller`-functions. `Service`-functions handle the communication to the Web-API. Figure 4.2 illustrates the Angular MVC pattern. The web-server is based on NodeJS, which includes an event-driven Javascript runtime environment [58]. It incorporates the application- and business logic, and provides a RESTful Web-API for CA- and WIA capabilities. It also provides scenario services as well as the federated simulation controller that is able to set up, start and stop the federated simulation. Section A.1 shows the interface definition of WIA- and Scenario services (`CIPRTrainerLogic.ts`). The web-server has access to the databases, which serialize spatial- and socio-demographic data, CI models, user configurations and training protocols.

4.2 CIPRTrainer Front-End Module Descriptions

A module is a composition of an Angular service and controller and has an optional HTML-template. Angular services are lazy instantiated singletons using dependency injection [59]. Controllers are constructor functions that manipulate or augment application models [59]. The front-end mainly con-

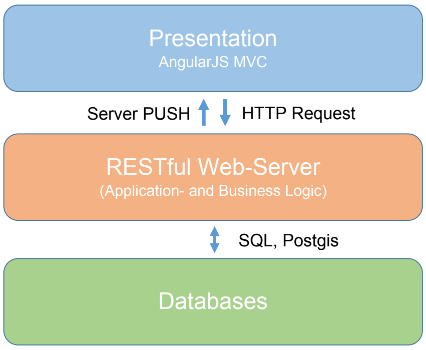


Figure 4.1: System architecture of the CIPRTrainer.

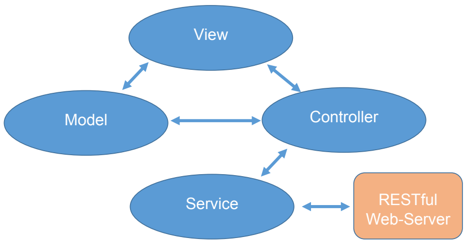


Figure 4.2: AngularJS MVC pattern.

sists of modules that fulfill specific functions. The following describes the modules of the front-end of the CIPRTrainer.

Module	**Scenario**
Description	The Scenario module loads the scenario and provides functions for exploring the training scenario (**UC-1**).

Module	**WIA**
Description	The WIA module provides all capabilities that are described in use case **UC-2**.

Module	**CA**
Description	The CA module enables the user to examine consequences of different courses of action.

Module	**Sidebar**
Description	The Sidebar module provides all necessary controls in order to perform **UC1-4** and capabilities described in use case **UC-4** including start, stop, pause, or continue scenario.

Module	**Timeline**
Description	The Timeline module enables the user to examine scenario and simulation events. Also, it provides a cursor that is able to perform a rollback on a specific time.

Module	**Notification**
Description	The Notification module pushes information of scenario- and simulation-based events as well as general information like error or confirmation notifications.

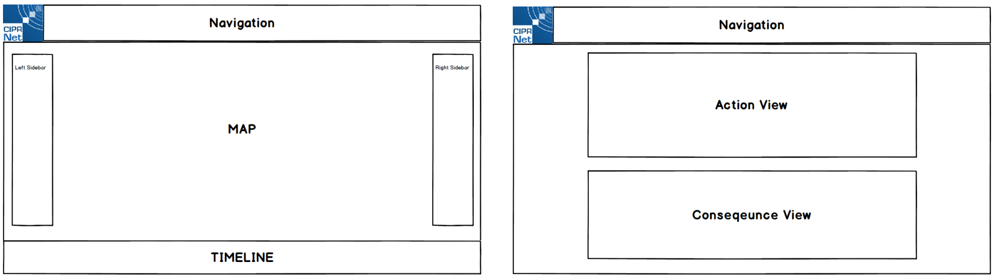
Module	**Map**
Description	The Map module provides the map on which the CI features and events are depicted.

Module	**Layer**
Description	The Layer module provides the option to remove or add CI information in the form of GIS overlays.

Module	**Filter**
Description	The Filter module enables actors to select important CIs and hide unimportant features.

Module	**Log**
Description	The Log module provides use case **UC-3**.

Module	**Participant**
Description	The Participant module provides status information of other participants.



(a) Main view (b) CA view

Figure 4.3: UI designs of the CIPRTrainer.

Module	**Dialog**
Description	The Dialog module handles all sorts of dialogs within the system (e.g. log out, confirmations, rollbacks).

Module	**Navigation**
Description	The Navigation module enables the user to switch between the Home view and WIA view.

Module	**Authentication**
Description	The Authentication module enables the user to log in to the system.

4.3 UI of Web GIS

In the following, two views of the CIPRTrainer are presented: main- and CA view (see Figure 4.3). The main view includes the map, two collapsible sidebars, a navigation on the top and a timeline on the bottom. The CA view consists of two sub-views: One view that depicts the performed actions and the second view that provides information about the consequences. Further details are described in the next chapter. The designed UIs will be evaluated for the usability and user satisfaction (see Chapter 6). If the evaluation reveals tremendous weak points in the human-machine-interaction, customizations and additional evaluations have to be performed, until the evaluation does not reveal notable weak points. This method is also referred as to the *iterative design*-approach [13].

Chapter 5

Implementation

This chapter describes the device specifications and technologies used, and the technical realizations of the Features.

5.1 Device Specification and Used Technologies

CIPRTrainer is a classic web application and uses modern web technologies. Due to security reasons, this application is not connected to the Internet. An Intranet has to be established with all necessary components that are accessible through HTTP protocol. In order to launch the application, only a regular computer with the capabilities to be on a network and a modern web browser are required (RN-6). The CIPRTrainer uses GIS capabilities that are provided by a web-based open source GIS application called **csMap** [60, 61]. It provides capabilities like displaying features on maps, **GeoJSON** support, filtering and searching. Features that are most relevant for the CIPRTrainer are map and layer capabilities. csMap applies LeafletJS for creating and manipulating maps [52]. The application is implemented using **AngularJS**, which supports creating web-based single-page applications by applying the MVC design pattern [59]. **Bootstrap** [62] is used for CSS styling (RN-5). Instead of writing plain JavaScript code, **TypeScript**, a typed superset of JavaScript, is applied [63] with the advantage of supporting basic types (i.e. boolean, string, numbers), interfaces, classes, modules and generics. **CytoscapeJS** is an open-source library for the visualization of complex graph structures [64] and is used for drawing the different courses of action. **PnotifyJS** provides a notification capability for web-based applications [65] and is used for providing scenario and simulation events as well as general notifications. The timeline is realized using **visJS** [66], which enables the user to keep track of all important events. **Socket-io** is used in order to push notifications and changes onto the front-end (RN-3) [67].

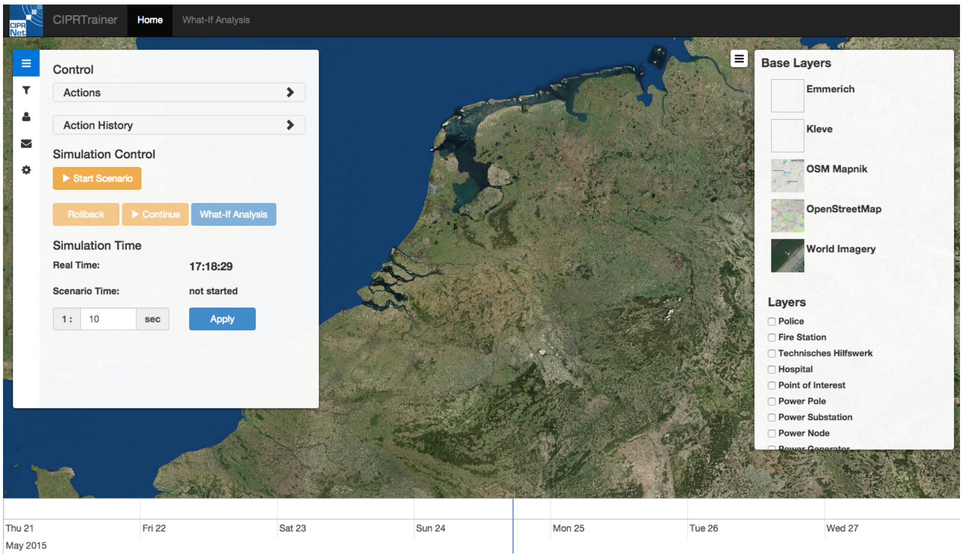


Figure 5.1: Main view with opened sidebars.

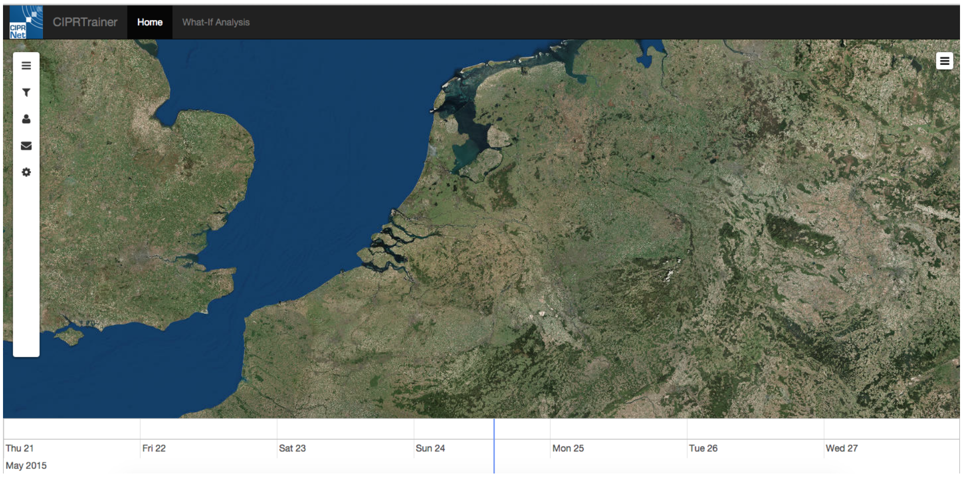


Figure 5.2: Main view with closed sidebars.

5.2 Technical Realizations of the Features

In the following, the features of the CIPRTrainer will be described and explained on the basis of the implemented UI. The main view contains two sidebars (left and right), a navigation (top), a timeline (bottom), and the main map in the center covering the complete browser window (Figure 5.1). Sidebars can be closed in order to avoid an overload of information (see Figure 5.2).

5.2.1 Exploring the Scenario

Scenario models and resources can be examined in the form of GIS overlays (RF-1), which are common practices in GIS. The user is able to visualize or hide overlays by clicking on the listed CI on the right sidebar and thus examine important CIs or resources (see Figure 5.3). The CIPRTrainer also provides classic map controls like zooming and panning (RF-5). Resources like fire stations, police stations or hospitals are also accessible through GIS overlays which can be filtered by their names. CIs or resources are represented as GIS markers containing CI- or resource-specific icons. Icons are carefully chosen in order to avoid misinterpretations. BBK evolved a guideline on how to depict units on maps [7]. For instance, police units are depicted in green colors, whereas THW units are in blue colors. A legend on the right side helps the user to interpret icons correctly (Figure 5.4). A CI infrastructure comprises multiple elements; showing them all at once can disrupt the focus of the user. For a crisis manager it is important to immediately know the operational status of CIs, so these icons, colors and their legend are crucial for accurate interpretation. The operational status (x) has an interval of $[0, 1]$. Every icon contains a small LED light on the upper right corner. A green light illustrates an operational status without any interferences ($x = 1$), whereas a red light symbolizes a complete loss of operability or functionality ($x = 0$). The crisis manager can immediately interpret multiple statuses of CIs by their LED light. States in between $[0, 1]$ are scaled by colors ranging from green to red. This is realized by applying HSV space color and the following equation:

$$\begin{pmatrix} H \\ S \\ V \end{pmatrix} = \begin{pmatrix} 120 \times x \\ 1 \\ 1 \end{pmatrix}, x \in [0, 1].$$

The HSV values can be easily transformed into RGB values, which again have to be transformed into HEX values for the web application. Figure 5.5 illustrates transmission lines with their operational status. Each GIS element contains CI-specific properties, which can be seen by clicking on the element. A pop-up appears containing the most important information about the properties. More information can be received by clicking the provided 'Read More' button on the bottom of the pop-up window. Figure 5.7 depicts a hospital showing the number of available beds, the operational status and its name. BBK uses map icons not only to identify CIs but also to pin status reports by applying tactical symbols. Events and status reports are depicted on the map by the CIPRTrainer as GIS elements with the corresponding tactical symbol. An example of an event represented by the CIPRTrainer is the destruction of buildings or the number of dead people.

CIs like railways are represented as `LineStrings` with their corresponding train-stations depicted as classic GIS icons (see Figure 5.6). The green color of the line represents an operational status of 1. If any change in the CI models is recognized by a simulator, a message and the involved CIs will be pushed in an asynchronous way on the GIS map (RF-3). Messages mainly contain the cause of the change, a formal event description and the affected CI attached with the new calculated operational status. The icons will blink slightly so they draw focus to the changes without disturbing the user (see 5.8). Figure 5.9 illustrates the occurrence of the first event described in the application storyline. Simultaneously, the event will be added onto the timeline such that the user is always able to see when an event happened and to get further information by clicking on the timeline element (see Figure 5.10 and 5.11). Since CIs can contain multiple elements, it is likely that the user loses track of the depicted CIs on the map. A well-known practice in GIS is clustering elements. It can be used to group CIs, which helps the user to maintain overview of the CIs. When the user zooms out of the map and passing a predefined zoom level, the system clusters CI elements into groups showing the number of the elements that are being clustered. Furthermore, when the user hovers over the cluster, the convex hull is shown (see Figure 5.12). This helps the user to examine the distribution of the clustered GIS elements. However, clustered elements are not able to show any further specific information. Hence, filtering becomes an important feature of the CIPRTrainer (RF-9). Utilizing filters allows the user to focus on a segment of CIs without loss of operable functionalities. A simple filter called the KNN filter is used as an example of this feature. KNN stands for K-Nearest-Neighbors and is capable of removing all neighbors of a selected GIS element but his k nearest neighbor elements. For cases having a widely distributed set of CIs, it is also possible to define a radius and remove all CIs outside of that radius (see Figure 5.13 and 5.14).

5.2.2 Performing WIA

WIA enables the trainee to practice decision-making and evaluate consequences (RF-6). This requires scenario controls such as starting, stopping, continuing and pausing a scenario. Figure 5.2 depicts the controls on the right sidebar including a rollback button, a collapsible list of provided actions and a list of already performed actions (action history). Utilizing the rollback capability, the user is able to jump back to any prior state of the scenario and continuing his operations starting from that point. A rollback can be perform by selecting an already performed action in the action-history-list or by dragging the vertical line of the timeline, representing the current scenario time, to the desired state. WIA also includes commanding mea-

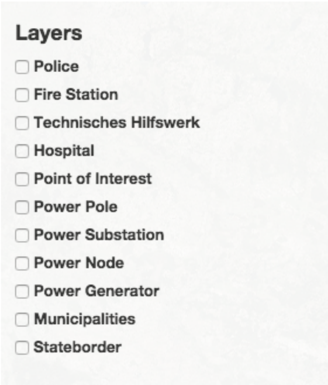


Figure 5.3: GIS overlays can be visualized or hidden by clicking on them.

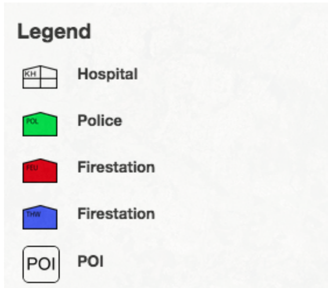


Figure 5.4: Legend helps the user to interpret the meaning of icons correctly.

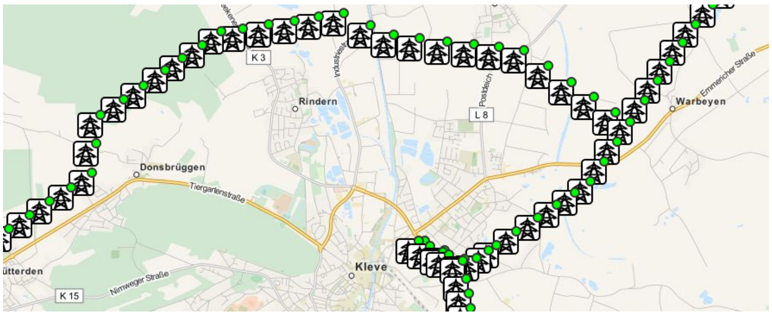


Figure 5.5: Transmission lines in Kleve with LED lights depicting their operational statuses.

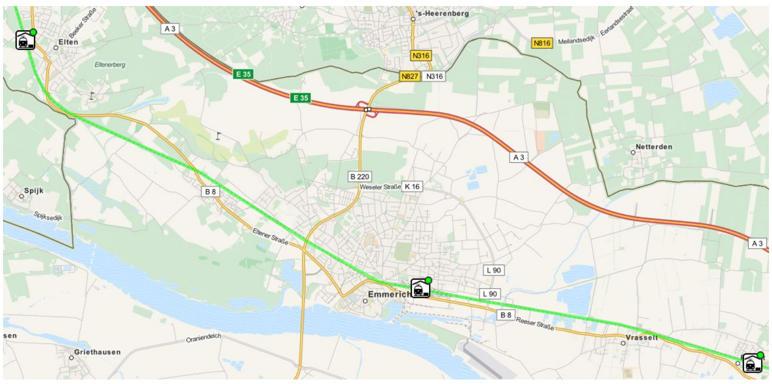


Figure 5.6: Train route represented as GeoJSON `LineString`.

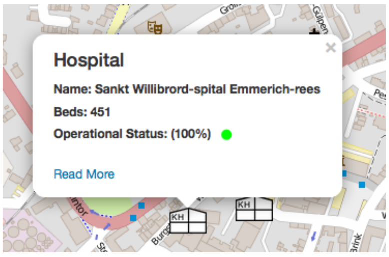


Figure 5.7: Pop-ups provide further information about GIS elements.

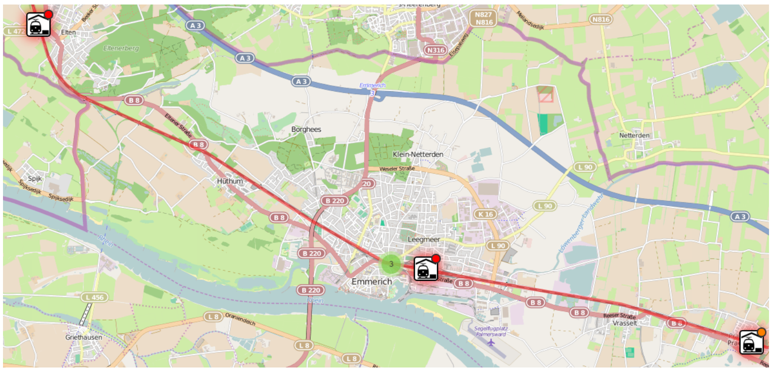


Figure 5.8: Train route representing a loss of functionality.

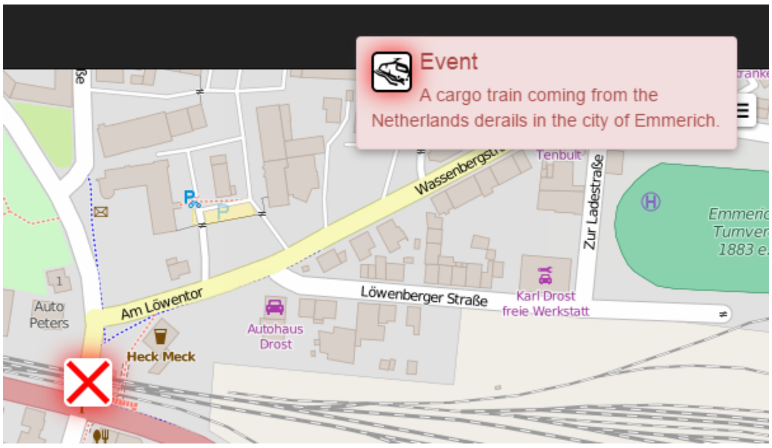


Figure 5.9: Event notification of the CIPRTrainer.

sures or actions, given by the scenario, such as sending fire brigades to the accident site or block the motorway A3 (see Figure 5.15). Measures include a description, tactical symbol with its available capacities using the special BBK notation. These actions influence the states of the CIs and can

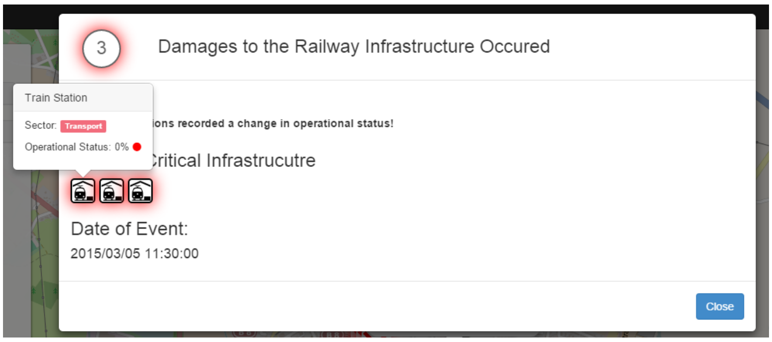


Figure 5.10: Further information about the event can be accessed by clicking on the timeline event element.

Figure 5.11: Timeline capability enables the user to keep track of past events.

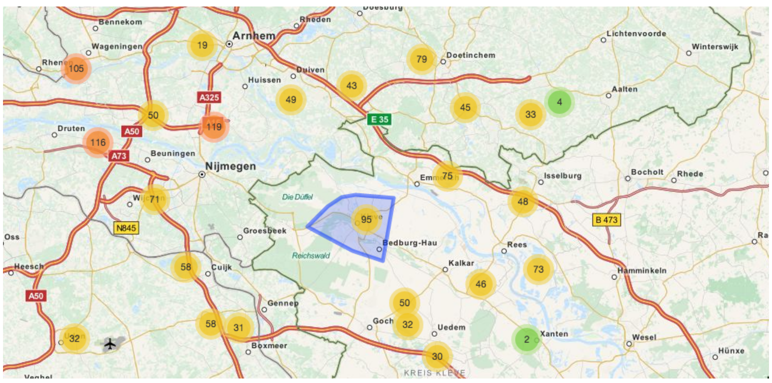
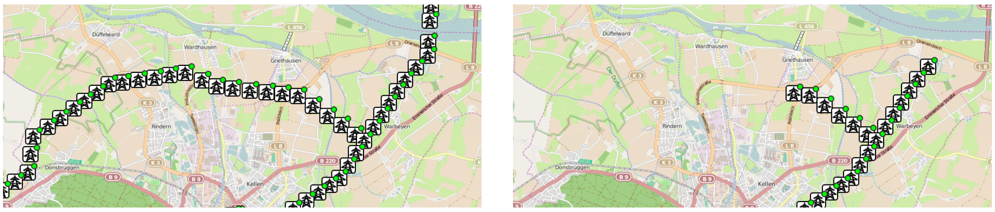


Figure 5.12: Clustering GIS elements.



(a) CIs not filtered. (b) CIs filtered using KNN ($K = 20$).

Figure 5.13: KNN filter capability of the CIPRTrainer.

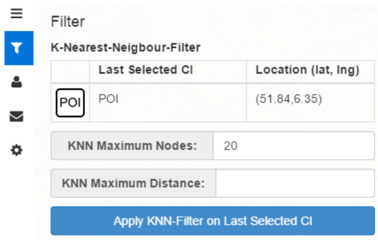


Figure 5.14: UI of the KNN filter.

mitigate damages. Further research has to be conducted on how to design realistic measures that are useful for the BBK. The analysis of CI disruptions and damages are evaluated by the CA. The CIPRTrainer allows the user to select and compare consequences of different courses of action. This is visualized by applying a multidimensional tree (RN-2, see Figure 5.17). The nodes represents the actions commanded by the trainee. When the user jumps back to a prior state (x_t), he automatically creates a new branch on the last performed action before x_t, on which the upcoming actions are attached (see Figure 5.16). A final action is marked with the color green; the last performed action contains the color orange and all other nodes are depicted in the color blue. The graph is provided with a small legend on the right side (see Figure 5.17). Each note contains a brief title. The user can click on green nodes and acquire the CA once the calculations have been completed.

5.2.3 Managing Training Logs

Training logs keep track of the entire activities throughout the training sessions (RF-10, see Figure 5.18). At the end of a training session, the user is able to print and download all activities in PDF-format. Log entries can be distinguished in info-, scenario-, simulator- and action logs. Each log entry contains a description and a time stamp. Info logs contain general informa-

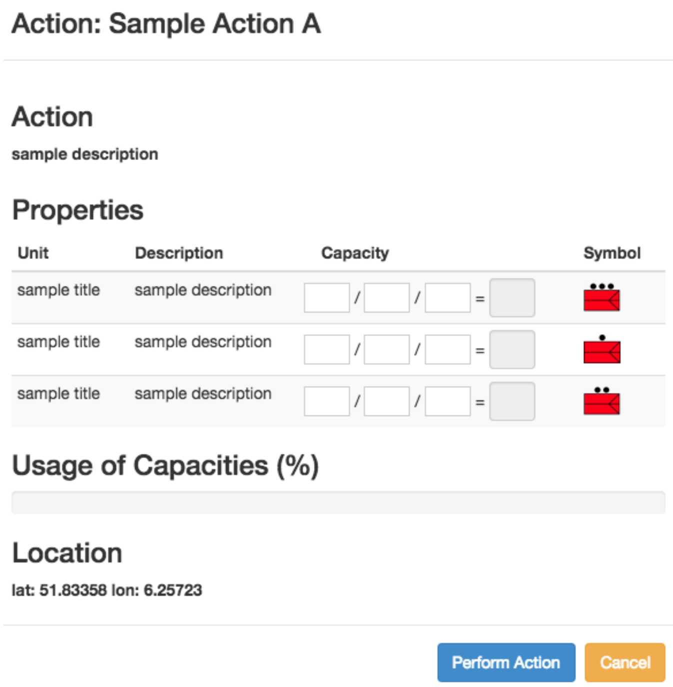


Figure 5.15: Units can be parametrized with specific capacities and are visualized as tactical symbols applying the special BBK notation.

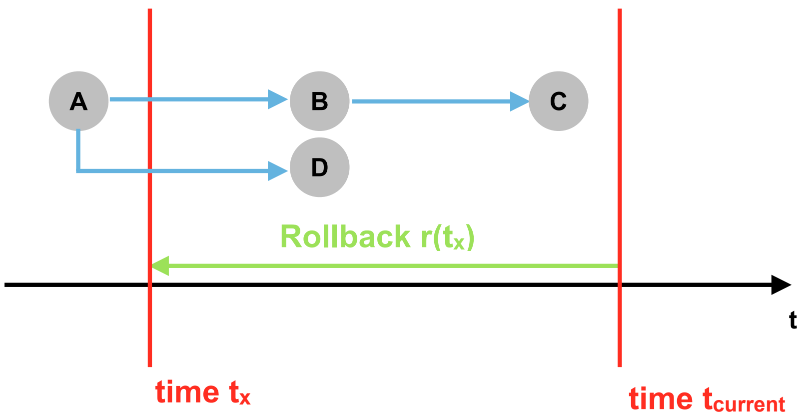


Figure 5.16: CIPRTrainer rollback capability. Order of instructions: $action(A(t_1)) \rightarrow action(B(t_2)) \rightarrow action(C(t_3)) \rightarrow rollback(t_x) \rightarrow action(D(t_4))$.

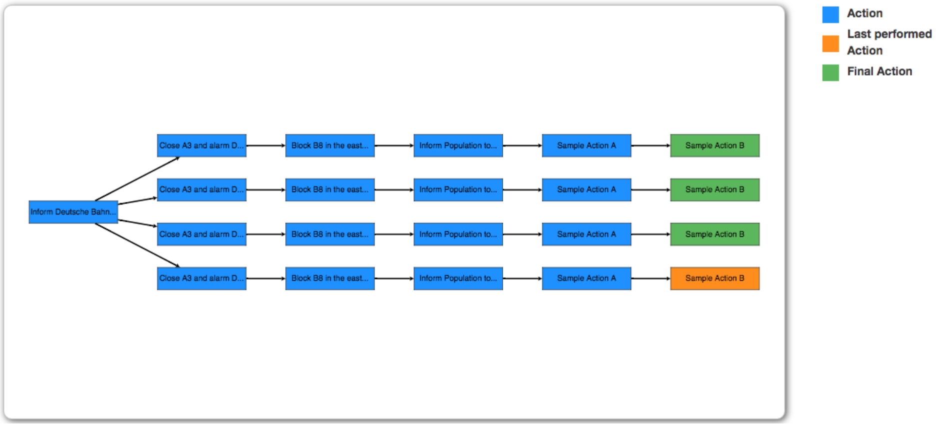


Figure 5.17: An example of an action tree.

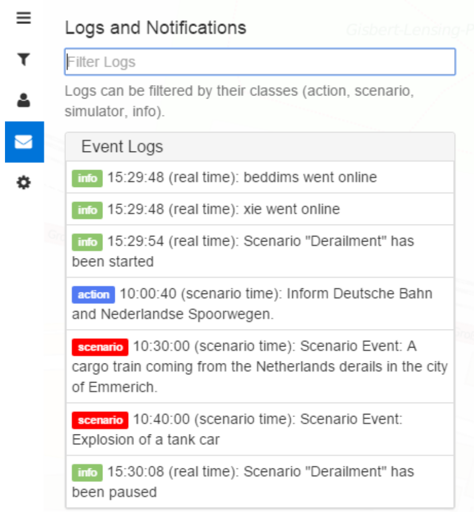


Figure 5.18: Managing training logs capability of the CIPRTrainer.

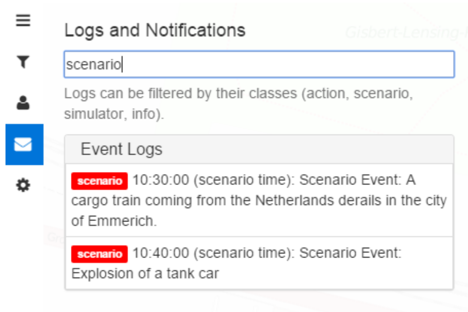


Figure 5.19: CIPRTrainer enables the user to filter logs.

tion like participant status changes or status of the scenario (e.g. start/stop). Scenario logs cover the storyline events. Simulator logs represent operational status changes of CIs. Finally, action logs track the decisions made by the user including chosen parameters. Logs can be filtered by their classes (see Figure 5.19), enabling the user to focus on specific decisions or events.

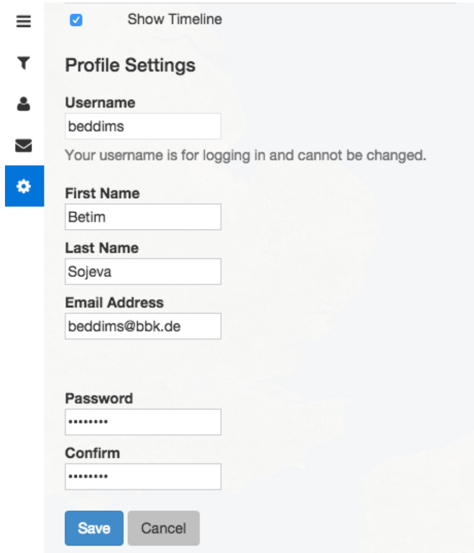


Figure 5.20: Managing user account of the CIPRTrainer.

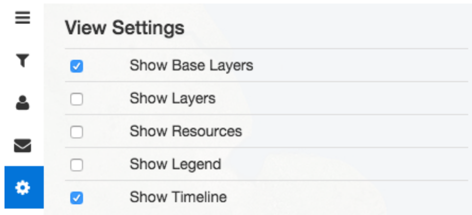


Figure 5.21: Customizing components of the CIPRTrainer.

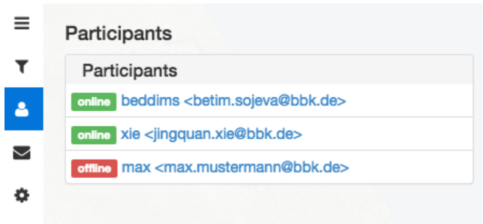


Figure 5.22: Statuses of other participants.

5.2.4 Managing User Account and View Settings

Managing the user account includes changing E-Mail, password, first- and last name. The username and password are used for launching the application (RF-8). The username cannot be changed. The E-Mail must be provided for resolving cases like forgetting password or username. Figure 5.20 illustrates the user interface for managing the account. The password must have at least 8 characters containing at least one number, one uppercase letter, and one special character. In order to avoid mistypings, the password has to be re-entered in an additional confirmation field. Furthermore, the user is able to customize CIPRTrainer components like showing or hiding timeline, base layer or layer, resource list and legend (RF-11, see Figure 5.21). Other participants' status can be viewed by clicking person icon on the right sidebar (RF-3, see Figure 5.22).

5.3 Test-Driven Development Approach

The applicability of test-driven development (TDD) on complex software projects has shown significant improvements concerning the software quality. TDD is defined as “a software development strategy that requires automated tests be written prior to writing functional code in small, rapid iterations.” In other words, when a software developer desires to add a new feature to the software system, he or she first develops a test that incorporates the specification and validation of the function [15]. The development of the CIPRTrainer front-end follows this approach by utilizing JasmineJS, “a behavior-driven development framework for testing JavaScript code” [68]. Each AngularJS module is nested in a `describe`-function that contains function-specific unit tests (`it`). Expectational behaviors can be tested by applying the `expect`-function. In the following, two simple examples of unit tests are presented in order to illustrate the TDD approach.

```
describe("WIA suite", () => {
  ...
  var actions = scenarioService.getActionPool();
  it("If a rollback is performed while the scenario is paused, throw an
    exception!", function() {
    scenarioService.startScenario();
    wiaService.performAction(actions[0]: Models.Action);
    setTimeout({
      wiaService.performAction(actions[1]: Models.Action);
      setTimeout({
        wiaService.performAction(actions[2]: Models.Action);
        setTimeout({
          scenarioService.pauseScenario();
          wiaService.performRollback(actions[1].performedAt: Date);
          expect(wiaService.performRollback).toThrow();
        }, 2000);
      }, 2000);
    }, 2000);
  });
  ...
});
...
describe("Timeline suite", () => {
  ...
  it("If the user drags the vertical line of the timeline onto the time
    that lies in the future and pushes the rollback-button, throw an
    exception!", () => {
      Date current = scenarioService.getCurrentScenarioTime();
      current.getTime() + 20000;
      timelineService.performRollback(current);
      expect(timelineService.performRollback).toThrow();
  });
});
```

Chapter 6

Usability Evaluation of the Prototype

An empirical evaluation will be performed in order to measure the usability of the prototype and thereby reveal unforeseen issues. It enables system designers to make further improvements and thus increase the quality of the system. The usability evaluation includes defining the aim and choosing evaluation methods, test persons and the location.

6.1 Evaluation Approach

In the following, each step of the evaluation approach is described, which contains the definition of the aim, user profile, location, applied methods and the performance and satisfaction metrics.

6.1.1 Evaluation Aim

The evaluation aims at analyzing the usability of the provided features of the prototype and revealing weak points to the human-machine interaction. The end-users of the CIPRTrainer are crisis managers. However, the current progress of the project is not sufficient for performing an empirical evaluation of WIA capabilities and the management of training logs (UC-2 and UC-3). Hence, the evaluation focuses on analyzing UC-1 and UC-4. The following questions are evaluated:

- How well does the user perceive the provided information of the scenario?
- How well is the user able to manage the user profile and settings?

The first question refers to UC-1, which the exploration of the scenario and CI models. The second question refers to UC-4, which is the management

#	Sex/ Age	Academic Level	Computer Skills	Experience in GIS
01	w/27	Graduate (B.A.)	basic	basic
02	m/27	Diploma	advanced	basic
03	m/27	Post Graduate (M.Sc.)	advanced	basic
04	m/25	Graduate (B.Sc.)	advanced	basic
05	m/26	Post Graduate (M.Sc.)	high	advanced
06	m/24	Graduate (B.Sc.)	advanced	high
07	m/22	Graduate (B.Sc.)	advanced	basic
08	m/33	Post Graduate (M.Sc.)	advanced	basic
09	m/24	Graduate (B.Sc.)	basic	basic
10	m/26	Graduate (B.Sc.)	basic	advanced

Figure 6.1: User profile of the evaluation.

of the user profile.

6.1.2 User Profile Requirements

Test persons with basic computer skills and a minimum level of experience with GIS fulfill the user profile for testing. For instance, a student that is capable of using Google Maps for finding points of interest fulfills the required qualifications. Ten users performed the evaluation (see Figure 6.1). The average age of the user profile is 26.1. The majority of the test persons is male and currently studying at a university. Among the ten users, there are three users with basic-, six with advanced- and one with high computer skills. Seven of them have basic experience in using GIS.

6.1.3 Location

The location of the testing is a standard work office with a provided computer and includes the necessary peripherals, chair and desk.

6.1.4 Evaluation Tasks

The test persons are required to complete "process-based tasks" [23]. This includes an exploration of the application scenario by using Web GIS techniques such that the experimentee is able to summarize all events of the storyline. The user is also asked to perform changes in the user settings as well as user profile. An incident or CI is considered as *explored* when the user names three properties of the incident or CI. The tasks are:

1. Change the base map, which is also refereed as to base layer.
2. Select a desired layer (e.g. Power Poles) and explore the displayed GIS elements.
3. Apply the KNN filter to the Power Pole layer as followed: Select the power pole layer, choose an element and apply the KNN filter with $K = 20$. *Note: KNN filter (K-Nearest-Neighbor) removes all neighbors but the closest K.*
4. Start the scenario by clicking on "Start Scenario" button and examine the scenario. Summarize all occurred incidents.
5. Change the first and last name to "Max Mustermann" in the profile settings.

6.1.5 Evaluation Method

"Thinking Aloud" will be applied as the evaluation method. As the name suggests, the test person is asked to verbalize his or her thoughts and problems while solving the tasks. This method has the advantage of revealing weak points in the human-machine-interaction efficiently. Comments will be recorded and are included in the evaluation. After the tasks are completed, the user is asked to fill out a questionnaire that measures the user interface satisfaction.

6.1.6 Performance- and Satisfaction Metrics

The evaluation includes a measurement of the needed time per task. The satisfaction will be examined by a questionnaire[1] with a seven class scale (1 for "strongly disagree" and 7 for "strongly agree").

6.1.7 Evaluation Conduct

The evaluation starts with a complete introduction to the system and the purpose of this evaluation. The test person has the opportunity to ask questions in order to avoid misunderstandings. Afterwards, the test location and equipment will be introduced. The task sheet will be handed over and explained. In addition, the applied methods ("Thinking Aloud") will be explained. If the test person is prepared and has no additional questions, he or she can start completing the tasks. When a task is completed, the test person will be asked if noticeable problems occurred. After all tasks are completed, the test person is asked to fill out a short questionnaire. After

[1] A questionnaire that measures the user satisfaction requires at least 30 participants in order to make reliable conclusions [23].

completion of the evaluation tasks and questionnaire, a small gift is given to the user.

6.2 Evaluation Results

6.2.1 Performance of Task Completion

The following table shows the time in seconds that was needed for completing a task by a user:

#	**Task 1**	**Task 2**	**Task 3**	**Task 4**	**Task 5**	**Total**
01	25	49	20	398	19	511
02	60	182	58	320	35	655
03	83	39	122	202	32	478
04	25	50	23	235	15	348
05	17	33	16	198	11	275
06	32	31	38	156	14	271
07	35	53	25	239	25	377
08	25	49	21	191	32	318
09	76	52	89	283	38	538
10	11	31	43	187	13	285
Avg:	**28.9**	**56.9**	**45.5**	**251.7**	**23.4**	**405.6**

6.2.2 "Thinking Aloud" Notes and Comments

Task 1

The first task included the change of the base map. The user is asked to first activate the base map list in the view settings and then change the base map on the right sidebar. The majority of the users started by clicking all possible provided icons on the navigation, left- and right sidebar and examined them for a short while. Six users noticed the hint message on the right sidebar and followed the denoted instructions. Afterwards they were immediately able to solve the task. Some users tried to right-click on the base map with no success. After clicking on several icons, they managed to change the view settings and complete the task. Some users commented that it was not evident, which base map was active. Additionally, two users were confused by the provided icons on the left sidebar. For instance, they could not figure out the meaning of the toggle- and the filter-icon. Overall, every user managed to solve the task in an average time of 28.9 seconds.

Task 2

The second task included the selection of the power pole layer and the exploration of the provided elements on the base map. Four users had trouble understanding the meaning of the ‘Show Layer’ option in the view settings. However, as they clicked on it, they immediately saw the provided layers on the right sidebar and chose the right layer. The elements appeared in clusters with the number of the containing elements. Clusters with a high number of elements appeared in red colors whereas cluster with few elements appeared in green colors. Three users were confused by the color of the clusters. However, one user knew immediately the meaning of the depicted number and commented: “oh, 1330 power poles!” All users clicked on the cluster elements such that the clusters disappeared. All users were familiar with the provided zoom and pan capabilities of Leaflet and had no problems examining the elements. The majority of the users clicked on a power pole element in order to read the provided information. One user commented that the mouse pointer switched over to a flat hand by hovering over a power pole element, which lead the user to click on it. Two users commented the presence of the LED light on the upper-left corner of the icons. However, they did not know the meaning of it. The average time of solving the task was 56.9 seconds.

Task 3

In the third task the user is instructed to apply the KNN filter on a desired power pole element, which can be done by clicking on any power pole element, navigating to the filter section on the left sidebar and clicking on the ‘Apply KNN Filter’ button. Six users started with clicking on one element. Some of them commented with “what now?” or “where can I find the filter?”. After a while they clicked on the filter icon on the left sidebar and performed the KNN filter properly. Two users immediately navigated to the filter section and immediately clicked on the ‘Apply KNN Filter’ button. The filter was applied to any clicked element beforehand, which triggered an ’oh’-reaction to one user. Three users clicked on an element and tried to find the filter on the appeared pop-up. However, after a short while, they managed to find the filter section. The average time of solving the task was 45.5 seconds.

Task 4

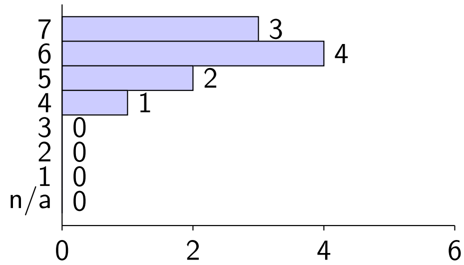
The fourth task included the exploration of the scenario. The user is asked to click the ‘Start scenario’ button and summarize all occurred incidents. Information could be received by using the timeline, notification features as well as the depicted GIS elements by clicking on them. Every user found the 'Start scenario' button without any noticeable problems. Also, all of them noticed the notification on the upper right corner with the message "Scenario has started successfully.", which appeared after starting the scenario. The users waited a few seconds until the first incident occurred, some of them felt insecure and confused during that time. However, after the first incident occurred, the uncertainty and confusion vanished and all users focused on the appeared tactical symbol that was slightly animated with a red color (Note: All necessary tactical symbols were explained beforehand). The incident triggered an 'oh'- or 'wow'-reaction to the majority of the users. All users examined the depicted tactical symbol and clicked on the item. Every user was able describe the first incident by reading the first description on the pop-up. Many users noticed the appeared event on the timeline. After the second incident occurred, three users started to pay more attention to the timeline. They clicked on the depicted event on the timeline and noticed that they can receive more information about the incident. The other seven test persons used the map icons to fulfill the task. However, only four out of seven clicked on the 'Read More' button on the pop up. The average time of solving the task was 251.7 seconds.

Task 5

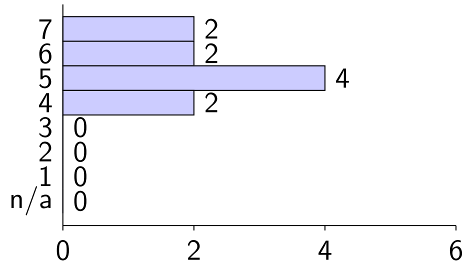
This task included the change of the first and last name in the profile settings. The user is asked to click on the view- and profile setting icon, scroll down to the profile settings, change the name to "Max Mustermann" and click on the 'Save' button. Many of them noticed the profile settings by completing the first task as they tried to get a first impression of the functionalities of the web application. The fifth task was performed very quickly by all users. However, three users missed to click the 'Save' button. The average time of solving the task was 23.4 seconds.

6.2.3 Results of the Questionnaire

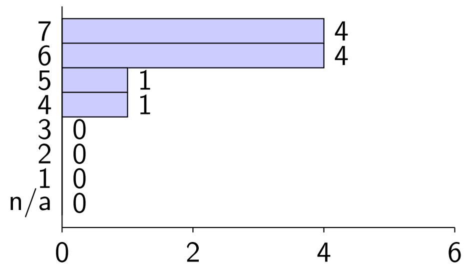
The following shows the results of the questionnaire. The x-axis of the chart depicts the amount of votes and the y-axis shows the corresponding seven scales of the item including the option 'not applicable' (n/a).



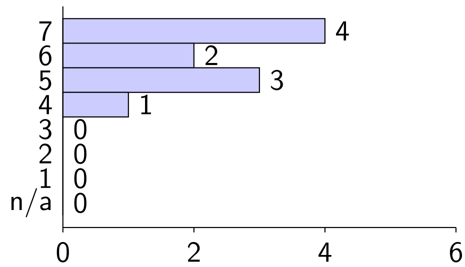
*E*1: General impression of using system was satisfying.



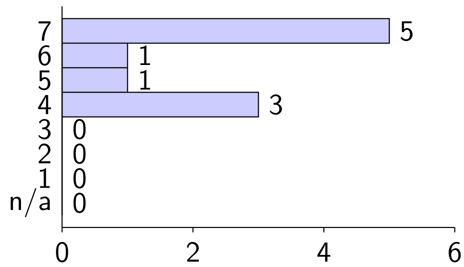
*E*2: The system was easy to use.



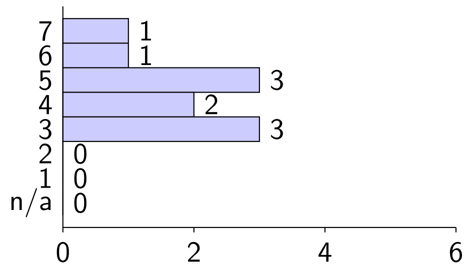
*E*3: The system was well designed.



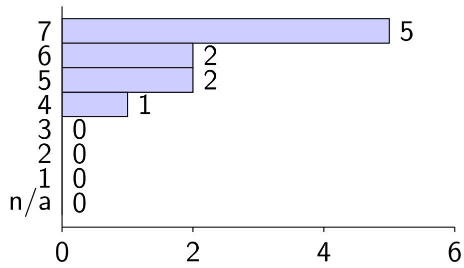
*E*4: I was able to solve the tasks effectively.



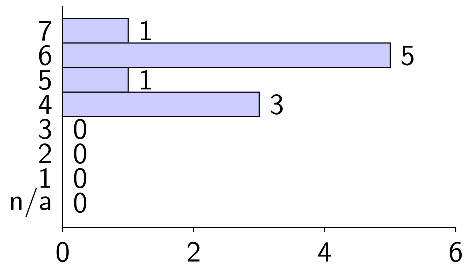
*E*5: I was able to solve the tasks quickly.



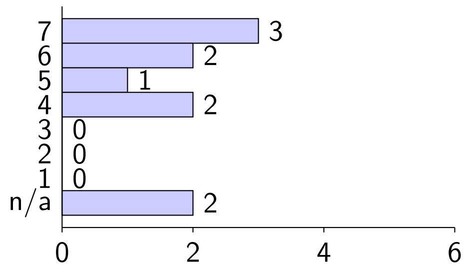
*E*6: The icons used were meaningful.



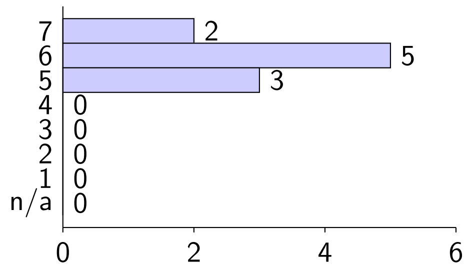
*E*7: The organization of provided information was clear.



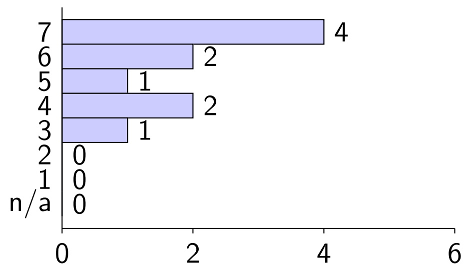
*E*8: It was easy to learn the features of the system.



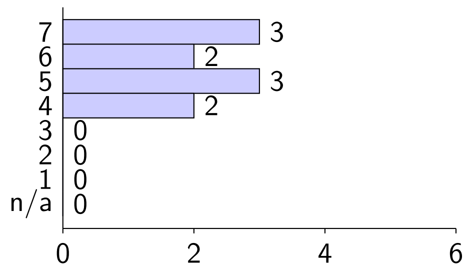
*E*9: Help messages supported me in solving the tasks.



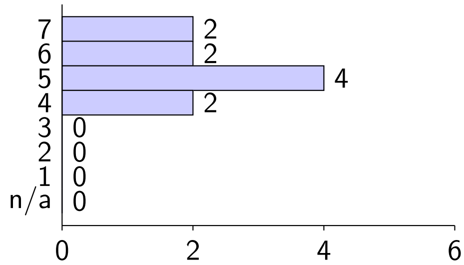
*E*10: Exploring the features was easy.



*E*11: Provided information was easy to understand.



*E*12: Completing a task required few steps.



$E13$: The presentation of information helped me to complete the tasks.

The following table depicts the mean, median, standard deviation and number of votes of each item of the questionnaire:

Item	**Mean**	**Median**[2]	**Standard Deviation**	**Votes**
$E1$	5.9	6	2.373	10
$E2$	5.4	5	2.407	10
$E3$	6.1	6	2.446	10
$E4$	5.9	6	2.558	10
$E5$	5.8	6.5	2.335	10
$E6$	4.5	4.5	3.298	10
$E7$	6.1	6.5	2.694	10
$E8$	5.4	6	2.845	10
$E9$	5.25	5	2.478	8
$E10$	5.9	6	2.722	10
$E11$	5.6	6	2.653	10
$E12$	5.4	5.5	2.791	10
$E13$	5.4	5	2.407	10

6.2.4 Conclusion of the Evaluation

It is important to note that ten users filled out the questionnaire. Therefore only indications of the user satisfaction can be provided. Nevertheless, the “Thinking Aloud” method requires at least 3-5 participants and provides

[2]The median of a sorted list with an even amount of numbers is the average of the middle pair.

profound conclusions about the usability. Overall, every user was able to complete the tasks within a short amount of time. The user profile and performance measurements show that there is correlation between the GIS skills of the users and the amount of time that was needed to fulfill the tasks: The users who completed the tasks in the quickest amount of time were those, who had prior advanced GIS skills. This can be justified that those users were already familiar with how GIS provides information on maps. Moreover, $E2$, $E4$ and $E5$ indicate that even users with basic GIS skills were able to solve the tasks with low efforts. The results of item $E7$, $E11$ and $E13$, which have a mean value of at least 5.4, refer to an easy use and clear design of the system. The result of item $E1$ denotes the second lowest standard deviation and a mean value of 5.9 and indicates that the users were satisfied using the system. Moreover, the users commented that the system was well designed (see also $E3$). The item $E6$ has the lowest mean value of 4.5 and the highest standard deviation (3.298). This illustrates that there were inconsistencies by interpreting the used icons in the system. Few users also complained about the icons on the left sidebar. However, since the sidebars were not overloaded with information, the users were still able to explore the features and find the right functions in an appropriate period of time (see $E10$). The observation while the users solved the fourth task shows that the timeline feature was intensively used by the users with advanced or high GIS experiences. Every participant was able to use of map operations like pan or zoom capabilities. Moreover, the system enabled the user to focus on the important objectives of the scenario and completely describe the presented incidents. As a result, the system is capable of providing a SA-level of two, which is defined as the comprehensive understanding of the situation [18]. The last task denote the lowest time requirement, which indicates that there were no noticeable problems. Furthermore, the observation shows that this tasked was the easiest one. Overall, the results show that the system is able to provide sufficient information and enables the user to perceive information about the scenario with low effort.

Chapter 7

Conclusion

7.1 Summary

This thesis introduced an interactive web application, which encourages a significant contribution towards decision-support in crisis management by integrating modern Web 2.0 technology and best practices in GIS. It illustrated the capabilities of exploring complex scenarios, performing WIA and managing the user profile. Scenarios were designed specifically for crisis managers and incorporate tactical symbols using a special notation that are suited for the BBK and thereby enable a comprehensive understanding of the situation. The evaluation showed that the design of the main view, which consists of a base map, two information tabs (left and right), one navigation-bar and one timeline, provided during use a easily manageable feeling. Meaning, users were able quickly complete tasks without complex directions. Furthermore, it showed that the exploration of the scenario received an above-average acceptance by the users, which concludes that the user interface is well-designed and supports the human-machine interaction. The users were capable of receiving a SA level of at least two. Hence, it demonstrated that spatial information provided by a web-based GIS is not only exclusive to professionals, but also for users with basic computer skills.

7.2 Future Work

This thesis demonstrated the first version of the CIPRTrainer front-end, which includes core capabilities like exploring scenarios and performing WIA. However, it offers many opportunities for elaborating on the core features. Moreover, additional features have to be realized in order to make it applicable for crisis managers.

7.2.1 Trainer User Interface

The CIPRTrainer not only considers trainees but also trainers. The trainer must be able to choose the scenario, view specific details about the scenario, manage the federated simulation and assign the trainees to the scenarios. Furthermore, the trainer is able to track the complete training session. A user interface needs to be implemented that incorporates these features.

7.2.2 User Authentication

User authentication needs to be added in order to meet security requirements.

7.2.3 Action Module

An important feature is the *Action Module*, which enables the trainee to perform adequate measures that influence the operational statuses of the CIs and the extent of societal damages. A comprehensive analysis of how to perform actions has to be conducted. The current version illustrated an action-interface, which is able to depict the capacities of certain units.

7.2.4 CA Module

The CA module is one of the core capability of the CIPRTrainer. It incorporates CI changes with socio-demographic data and apply scientific proven methods for calculating different kinds of consequences.

7.2.5 Data Collection

The front-end illustrated different types of resources. However, a recording of the available resources of Emmerich has to be performed in order to enable a realistic CA. Moreover, each scenario requires complete models of the local CIs. Therefore, CI-related data containing properties and locations has to be acquired in order to provide a detailed modeling.

7.2.6 Flooding Scenario

CIPRNet precisely described two scenarios of which one was introduced and incorporated into the system (railway accident in Emmerich). The other scenario includes a cross border flooding with a major breach. However, the current system is not able to depict flooded areas on maps. The flood simulator used in CIPRNet calculates spatial height-maps, which depicts the water level on certain areas. A Leaflet-plugin has to be implemented, which is able to interpret and visualize the calculated height maps.

7.2.7 CI Database Schema

A database schema needs to be realized that incorporates *all* CIs models of which there are telecommunication-, power- and railway networks.

Appendix A

Implementation Files

A.1 CIPRTrainerLogic.ts

```
public interface CIPRTrainerLogic {
  // WIA Services
  public findActionById(id: number); // return an action with the corresponding id
  public findActionByInstanceId(instanceId: string); // return an action with the corresponding instanceId
  public performAction(action: Action) // performs an action
  public performRollback(date: Date); // performs a rollback
  public performRollback(actionId: number); // performs a rollback
  public getActionGraph(); //returns the current action graph
  //Scenario Services
  public loadScenario(url: string); // loads the scenario
  public startScenario(); // starts the scenario
  public stopScenario(); // stops the scenario
  public continueScenario(); // continues the scenario
  public pauseScenario(); // pauses the scenario
  public pushScenarioEvent(event: ScenarioEvent, index: number); // pushes a scenario event
  public pushSimulatorEvent(event: SimulatorEvent, index: number); // pushes a simulator event
  public findScenarioEvent(id: number); // returns scenario event with the corresponding id
  public findSimulatorEvent(id: number); // returns scenario simulator with the corresponding id
  public changeSimulationTimeRatio(simulationTimeRatio: number); // changesrns simulation time ratio
  public getActionPool(); // returns actions of the scenario
  ...
}
```

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