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1. Gutachten: Prof. Dr.-Ing. Uwe Rüppel
2. Gutachten: Prof. Dr. Jens Ivo Engels

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Dissertation

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Für meine Frau Clarissa und meinen Sohn Malio

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Abstract

Based on a reflection of the emergency sector as critical infrastructure and with reference to the concepts of preparedness and prevention as well as criticality, the dissertation examines to what extent software applications can be used to support the planning and evaluation of practical exercises in civil protection and disaster response. A network-theoretical approach is chosen which allows to model scenario-based exercises as dynamic networks. In particular, it is thereby achieved that actions and structures from the exercise can be represented and analyzed in their temporal context through different types of relationships or interactions.

First of all, the unique dual role of the emergency sector in the system of infrastructures is addressed and the importance of the practical exercise as a training method and for simulating real operations for the sector is explained. Based on a literature review and interviews with practice partners from different organizations and authorities of civil protection and disaster response in Germany, the exercise will be analyzed with regard to its objectives and the methods used. In this context, especially practical approaches and problems will be discussed and compared. The analysis shows that each exercise is very different in terms of its underlying objectives and approaches and depends strongly on the needs of the respective organizations and authorities. Furthermore, it becomes apparent that especially the planning of such exercises is very complex and therefore there is a need for support tools for the development of scenarios and the definition of exercise boundaries. Also in connection with the evaluation of the exercises, there is a need for a software solution to support the processes. It is apparent that, despite the existing awareness of the importance of evaluations, hardly any systematic procedures are available for this purpose, and that the evaluation as a whole is often not carried out with the necessary consistency, partly due to time constraints. It is particularly noticeable that communication between the participants is often identified as a potential for errors during the exercise, but that the actual communication interactions taking place during the exercise are not yet systematically recorded and analyzed.

In addition to the analysis of the practical exercise, the dissertation also evaluates the relevant research literature from the fields of organizational research, emergency management and risk and criticality research. The potential of social network analysis for the aspects of planning and evaluation of exercises is identified and decisively worked out, which, supported by statements from practice, allows to define requirements for a software system. In order to meet the specific requirements of the exercise, a concept for a network-based support software is designed and implemented in a tablet-based demonstrator application called *ScenarioBuilder BOS*. The application supports the user in modeling and developing exercise scenarios as well as in analyzing and evaluating them in various ways. For example, simulations of cascading effects can be carried out or the centrality of the various actors in the network can be compared. The aim of the application is to enable the user to develop interpretation approaches and to question actions and relationship structures by presenting the scenario in different perspectives. In order to evaluate the application and the benefit of social network analysis as a methodology to support the planning and evaluation of exercises, the thesis describes four use cases for the *ScenarioBuilder BOS*, three of which are evaluations of real civil protection exercises in different organizations and authorities. The fourth case describes the use of the application to develop

the scenario of a fictitious exercise and serves to validate the simulation and other functions of *ScenarioBuilder BOS*. The use cases show that the application and the associated methodology of social network analysis has a great potential especially for the evaluation of exercises. It enables a systematic recording and evaluation of communication relationships in particular and can therefore make a valuable contribution, for example, to assessing the workload of actors, analyzing compliance with command structures or explaining dynamics in teams.

Zusammenfassung

Ausgehend von einer Betrachtung des Notfallsektors als kritische Infrastruktur und unter Bezugnahme auf die Konzepte der Preparedness und Prevention sowie der Kritikalität wird im Rahmen der Dissertation untersucht, inwieweit Software-Anwendungen zur Unterstützung der Planung und Evaluation von praktischen Übungen im Bevölkerungsschutz eingesetzt werden können. Hierbei wird ein netzwerktheoretischer Ansatz gewählt der es ermöglicht, Szenario-basierte Übungen als dynamische Netzwerke zu modellieren. Insbesondere wird dadurch erreicht, dass Handlungen und Strukturen aus der Übung durch verschiedene Arten von Beziehungen bzw. Interaktionen in ihrem zeitlichen Zusammenhang dargestellt und analysiert werden können.

Zunächst wird auf die besondere Doppelrolle des Notfallsektors im System der Infrastrukturen eingegangen und die Bedeutung der praktischen Übung als Trainingsmethode und zur Simulation realer Einsätze für den Sektor erläutert. Darauf aufbauend wird auf Basis einer Literaturrecherche und Interviews mit Praxispartnern aus unterschiedlichen Organisationen und Behörden des Bevölkerungsschutzes in Deutschland die Übung in Bezug auf die mit ihr verfolgten Ziele und die verwendeten Methodiken hin analysiert. Hierbei werden insbesondere Handlungsweisen und Problemstellungen aus der Praxis thematisiert und verglichen. Dabei stellt sich heraus, dass jede Übung im Hinblick auf ihre zugrunde liegenden Ziele und Herangehensweisen sehr unterschiedlich ist und stark von den Bedürfnissen der jeweiligen Organisationen und Behörden abhängt. Weiterhin zeigt sich, dass insbesondere die Planung solcher Übungen sehr komplex ist und daher ein Bedarf an Unterstützungstools für die Entwicklung von Szenarien und die Definition der Übungsgrenzen besteht. Auch im Zusammenhang mit der Auswertung der Übungen besteht der Wunsch nach einer Softwarelösung zur Unterstützung der Abläufe. Es zeigt sich, dass trotz des vorhandenen Bewusstseins über die Bedeutung von Evaluationen hierzu kaum systematische Verfahren zur Verfügung stehen und dass die Evaluation als Ganzes, auch aus Zeitgründen, oft nicht mit der notwendigen Konsistenz durchgeführt wird. Besonders auffällig ist, dass die Kommunikation der Beteiligten untereinander häufig als Potenzial für Fehler während der Übung identifiziert wird, die tatsächlich stattfindenden Kommunikationsinteraktionen während der Durchführung der Übung jedoch noch nicht systematisch erfasst und analysiert werden.

Neben der Analyse der praktischen Übung wird in der Dissertation auch die einschlägige Forschungsliteratur aus den Bereichen der Organisationsforschung, des Notfallmanagements sowie der Risiko- und Kritikalitätsforschung ausgewertet. Dabei wird das Potenzial der sozialen Netzwerkanalyse für die Aspekte der Planung und Auswertung von Übungen identifiziert und dezidiert herausgearbeitet, um damit, gestützt durch Aussagen aus der Praxis, Anforderungen für ein Softwaresystem zu definieren. Um den spezifischen Anforderungen an die Übung gerecht zu werden, wird ein Konzept für eine netzwerkbasierte Unterstützungssoftware entworfen und in einer Tablet-basierten Demonstrator-Anwendung namens *ScenarioBuilder BOS* umgesetzt. Mit Hilfe der Anwendung wird der Anwender bei der Modellierung und Entwicklung von Übungsszenarien sowie bei deren Analyse und Auswertung auf verschiedene Weise unterstützt. So können Simulationen zu Kaskadeneffekten durchgeführt oder die Zentralität der verschiedenen Akteure im Netzwerk verglichen werden. Ziel der Anwendung ist

es, den Benutzer in die Lage zu versetzen, Interpretationsansätze zu entwickeln und Handlungen und Beziehungsstrukturen in Frage zu stellen, indem das Szenario in verschiedenen Perspektiven dargestellt wird. Um die Anwendung und den Nutzen sozialer Netzwerkanalyse als Methodik zur Unterstützung der Planung und Auswertung von Übungen zu evaluieren, beschreibt die Dissertation vier Anwendungsfälle für den *ScenarioBuilder BOS*, von denen drei Auswertungen realer Katastrophenschutzübungen in verschiedenen Organisationen und Behörden sind. Der vierte Fall beschreibt den Einsatz der Anwendung zur Entwicklung des Szenarios einer fiktiven Übung und dient der Validierung der Simulation und anderer Funktionen des *ScenarioBuilder BOS*. Die Anwendungsfälle zeigen, dass die Anwendung und die damit verbundene Methodik der sozialen Netzwerkanalyse ein großes Potenzial insbesondere für die Auswertung von Übungen hat. Sie ermöglicht eine systematische Erfassung und Auswertung speziell von Kommunikationsbeziehungen und kann damit einen wertvollen Beitrag zum Beispiel zur Einschätzung der Arbeitsbelastung von Akteuren, zur Analyse der Einhaltung von Befehlsstrukturen oder zur Erklärung von Dynamiken in Teams leisten.

Table of Contents

1. Introduction

1.1. Emergency Services – A Critical Infrastructure

“Infrastructure in general and critical infrastructure in particular are the lifeblood of modern, efficient societies. […] Therefore, ensuring the protection of this infrastructure is a key function of security-related preparedness measures taken by industry and government agencies […]” (BMI, 2009a, p. 3). These are the words with which the Federal Ministry of the Interior introduces the German “National Strategy for Critical Infrastructure Protection” and thus directly addresses two central aspects of the discourse within this context. On the one hand, the importance of infrastructures and especially critical infrastructures is highlighted and on the other hand the significance of the protection of these complex socio-technical systems is emphasized. Critical infrastructures (CIs) are defined as “organizational and physical structures and facilities of such vital importance to a nation's society and economy that their failure or degradation would result in sustained supply shortages, significant disruption of public safety and security, or other dramatic consequences” (BMI, 2009a, p. 4). An awareness of critical infrastructures and the term ‘critical infrastructure’ has increasingly emerged in the 1990s and gained greater political relevance in Germany after the terrorist attacks in New York 2001, Madrid 2004 and London 2005 as well as the summer flood in 2002 (BMI, 2005, BMI, 2009a;). CIs can be divided into different sectors, whereby a distinction is made between two broader categories: technical basic infrastructures and socio-economic services infrastructures (BMI, 2009a). The technical basic infrastructures include power supply, information and communication technology, transport as well as water supply and sewage disposal. Examples of socio-economic services infrastructures are public health, food, government and administration, finance as well as media and culture (ibid.). Another sector belonging to the socio-economic services infrastructures are the emergency and rescue services as well as the disaster response and management, which are the focus of this work.

Compared to other infrastructure sectors, the emergency sector incorporates a special dual role as critical infrastructure due to the tasks assigned to it and its function for society. By providing “[...] a wide range of prevention, preparedness, response and recovery services during both steady-state and incident management operations” it is responsible for the safeguarding and protection of the general public and other critical infrastructure sectors (U.S. Department of Homeland Security, 2015, p. 3). Through these central tasks, the emergency sector as an infrastructure itself becomes a protection strategy in dealing with infrastructural functional crises and forms the main actor in the implementation of measures for preparedness and prevention (Haimes et al., 2008). The sector includes all authorities and organizations with security functions (Behörden und Organisationen mit Sicherheitsaufgaben – BOS), i.e. all governmental and non-governmental actors that perform tasks to maintain public security (BBK, 2019a; U.S. Department of Homeland Security, 2015). These include among others the police, the fire brigade, private aid organizations or the civil protection authorities, whereby this work focuses on the non-police actors. As in other sectors, emergency services are dependent on other critical infrastructures, which can lead to complex vulnerabilities and potential cascading effects (Rinaldi et al., 2001). The “Emergency Service Sector-Specific Plan” of the U.S. Department of Homeland Security (2015), which is an annex to the national infrastructure protection plan, lists in particular such interdependencies with the sectors energy, information and communication, transport, water as well as public health.

The most important asset within the emergency sector is its personnel (U.S. Department of Homeland Security, 2015). It is composed of professionals and volunteers, the latter representing the vast majority of non-police actors in Germany. In order to enable this personnel to carry out the tasks assigned to the sector, continuous training and exercises are of great importance (BMI, 2009b; U.S. Department of Homeland Security, 2015). The relevance and importance, especially with regard to the exercise, can be emphasized by considering the concept of *preparedness and prevention* and that of *criticality*, both of which are commonly used in infrastructure research (Engels, 2018).

The concept of preparedness and prevention describes the developed knowledge and capacities to anticipate, mitigate and react to damaging events, enhanced by preparatory strategies and measures to prevent these events from happening in the first place (Haimes et al., 2008; UNISDR, 2009). Due to their components that cannot be clearly separated, preparedness and prevention are considered as a conjoint concept as argued by King (2007) and Crespo et al. (2018) and provide strategies to act preventively, protectively, responsively and restoratively (Haimes et al., 2008). Measures and implications of preparedness & prevention should not only be understood as a forecasting process based on past events, but also as a dynamic adjustment process in which strategies are regularly reviewed even without an event having taken place, thus maintaining their effectiveness even as the complexity of the systems increases (Crespo et al., 2018). In this sense, preparedness and prevention measures take over attributes and functions from the resilience framework and have a positive effect on achieving resilience (Engels et al., 2018; Haimes et al., 2008).

Since the second half of the twentieth century, the concept of preparedness and prevention has been strongly linked to the emergency sector and especially to disaster control (Crespo et al., 2018; Hémond and Robert, 2012). Furthermore, the critical infrastructure of the emergency sector can, according to Haimes et al. (2008), be regarded as a ‘supporting infrastructure’ and thus as a preparedness & prevention measure for other infrastructures. Within the emergency sector, the exercise plays a central role in terms of preparedness and prevention (U.S. Department of Homeland Security, 2013). It allows strategies and plans to be validated and capacity limits to be identified. Exercises also enable the targeted strengthening of the preparedness & prevention capacity of all actors involved (ibid.). Adey and Anderson (2012) argue that the exercise has received the most attention in literature and discussion on preparedness & prevention and state that it can be seen as a function of preparedness and, by extension, prevention. The exercise therefore is an important part of the security apparatus (ibid.). In addition to this, Ellebrecht et al. (2013) note with regard to Germany that, in the light of the discussion on preparedness & prevention, exercises are increasingly moving away from their traditional forms and large scale exercises are more frequently being practiced.

A different view of the exercise is given by the concept of criticality. According to the German national strategy for critical infrastructure protection criticality is defined as “a relative measure of the importance of a given infrastructure in terms of the impact of its disruption or functional failure on the security of supply, i.e. providing society with important goods and services” (BMI, 2009a, p. 7). Thus, criticality is a measure that is determined in relation to another system (e.g. another infrastructure) or a function performed by another system (Dombois et al., 2018; Lukitsch et al., 2018). The concept is often described in the literature with the help of specific characteristics or properties (Dombois et al., 2018). In comparison to risk analysis, where the impact of a damaging event is assessed in relation to the organization or system under consideration, criticality analysis tends to assess the impact on society (Theoharidou et al., 2009). Due to the relationship to other systems and their construction based on a perception of crisis (Fekete, 2011), the criticality of a system is dynamic and can change over time, which is particularly evident in the case of cascading effects (Hempel et al., 2018). In research, different approaches are used to determine the criticality of a system. The most widespread is the consequence-based approach that also emerges from the aforementioned definition and measures criticality on the basis of the effects in case of system failure (Lukitsch et al., 2018; Theoharidou et al., 2009). Another approach is the pragmatic one which ascribes criticality primarily on the basis of changing discussions or where criticality is defined as a means of expressing urgency or social pressure (Lukitsch et al., 2018).

When investigating the criticality of different sources of information within the emergency sector in a preliminary work for this dissertation the exercise was identified as particularly critical (Dombois et al., 2018). The rationale behind this was that the exercise, through the practical implementation of plans and processes, provides participants with knowledge and information that is difficult to retrieve from other sources (ibid.). In this respect, the exercise represents a critical source of information and acts as a central element of the training.

From the perspective of the observed concepts, the relevance of the exercise to the emergency sector as critical infrastructure is evident. Especially the strong dependence of the sector on its personnel as the most important asset and the necessity to enable these personnel through training and exercises to cope with the tasks of the emergency service make clear how important it is to focus on this part of the infrastructure sector. The present work, which was developed in the context of the interdisciplinary research training group KRITIS (GRK 2222 – Critical infrastructures: Construction, function crises, and protection in cities), is intended to focus on the exercise in civil protection and disaster response (Bevölkerungsschutz) and to examine it as an essential part of the emergency sector in the federal system of Germany.

Amendment Concerning the Corona Crisis

The finalization of this work overlapped with the phase of a strong increase in the number of people infected with the new coronavirus Sars-CoV-2 in Germany. The corona crisis was classified as a global pandemic by the World Health Organization in March 2020 and shows a variety of effects on infrastructures and especially the emergency sector (WHO Europe, 2020). Although the crisis has not been explicitly investigated in the present dissertation, it illustrates the relevance of exercises in civil protection and disaster response and the importance of the exercise in the context of the preparedness and prevention of the emergency sector. In particular, this can be seen in the fact that many measures are implemented during the crisis that have previously been simulated and tested in exercises and included in pandemic plans following the exercise evaluation. For example, the “Interministerial and Interstate Crisis Management Exercise” (see section 3.4) in 2007 was based on the scenario of a global influenza pandemic and the results obtained in this exercise provided important insights for national pandemic plans and strategies that are used today (BBK, n.d.). By analyzing exercises and developing and implementing support tools for their planning and evaluation, this dissertation thus undertakes to contribute to future crises such as the current pandemic.

1.2. Research Aim and Objectives

The organization and structure of civil protection and disaster response in Germany is divided between the federal government and the individual states and is therefore managed differently in some cases. In this context, the distinction between urban and rural regions also plays a role. For example, only cities with a population of 100,000 inhabitants or more have a professional fire brigade and consequently a larger number of professional personnel (§ 7 *HBKG*, 2018). On the other hand, in rural regions or smaller towns civil protection is almost exclusively carried out by volunteers. Also, civil protection and disaster response is made up of many different actors. In addition to the civil protection authorities, fire brigades and various other organizations come together so that overall a heterogeneous field of actors and a considerable need for inter-organizational coordination can be assumed. While requirements for the training of e.g. fire brigade personnel are regulated centrally in service regulations (AFKzV, 2012), there are no clear specifications for the frequency and design of the exercise. Only the obligation to conduct exercises is regulated by law (§ 29, § 32, § 57 *HBKG*, 2018). Due to the different requirements and prerequisites placed on the exercises by the various actors, their planning, conduct and evaluation is very time- and resource-intensive. Furthermore, exercises are often planned and implemented on top of the regular tasks, which is why the evaluation of the exercise may not be carried out with the same consistency.

The problems described show the need for tools and methods to support exercises, which is the starting point for this work. The primary goal is to investigate to what extent software applications can support the planning and evaluation of exercises in civil protection and disaster response and which requirements are placed on the systems and organizations. The work focuses on scenario-based exercises in civil protection in Germany and thus follows the trend in practice towards large-scale exercises with a broad range of different actors. The scenarios of such exercises are composed of a multitude of individual situations that build on each other, each of which can be characterized by different relationships or interactions between various actors. In particular, the relationships and interactions that occur include different forms of communication or sequences of actions. Within the scenarios, relationships can occur both between human actors and between or with technical systems and other objects. With these characteristics, scenario-based exercises can be understood as dynamic networks. For the analysis and interpretation of such networks, social network analysis has established itself as the most important analytical method in many research areas, especially in the social sciences. This is particularly true for the empirical analysis of inter-organizational networks (Raab, 2010), which are often given in exercises in civil protection. Despite its widespread use in research, social network analysis has not yet been applied in the practice of civil protection and disaster response in Germany. With the help of software applications the dissertation tries to create possibilities to model scenario-based exercises as networks and examines to what extend social network analysis can be used as an analytical methodology within the planning and evaluation of exercises.

At first, the situation of the exercise in practice will be analyzed in order to derive requirements for software concepts. Following this, a concept for a software application will be developed, which is based on network analysis and can be used as a support tool in the planning and evaluation of exercises. To evaluate the software on the one hand and the benefit of social network analysis in planning and evaluation of exercises on the other hand, the software will be implemented and evaluated by means of case studies. In summary, the following objectives are pursued with this work:

- Analysis of the situation of exercises in civil protection and disaster response in Germany involving various actors.
- Development of a concept for a software application based on social network analysis to support exercise planners and leaders in the planning and evaluation phase of exercises.
- Implementation of a demonstrator application to verify the technical feasibility of the developed software concept.
- Validation and evaluation of the demonstrator application on different use cases to assess the benefit of social network analysis as a methodology for planning and evaluating exercises in civil protection and disaster response.

1.3. Methodology and Approach

Methodologically, this dissertation is based on an in-depth review and analysis of the relevant literature. The related work as well as regulations and recommendations for action have been analyzed specifically with regard to the understanding of the emergency sector as a critical infrastructure, the role and structure of the exercise in civil protection and disaster response as well as the use of social network theory in the context of organizational and emergency management research and in the context of risk and criticality research. In addition to reviewing the literature, various methods (see Kurz and Kubek, 2017) were used to collect empirical data from practice. In particular, practitioners were interviewed in two iterations to analyze the situation of the exercise in civil protection and disaster response and to define the requirements for the developed software concept. In the first iteration, various practitioners from fire brigades (professional and voluntary), fire brigade schools as well as from authorities at municipal, supra-regional, state and federal level were interviewed by means of informal discussions on the various topics of civil protection and disaster response and in particular regarding exercises. Building on the information communicated in the informal discussions, a second iteration of interviews with predefined questions was conducted with selected practitioners. A number of conditions were defined for the selection of the interview partners. For example, different administrative levels as well as different groups of actors were to be represented. The interview partners were also supposed to be active in the exercise control of their respective organizations and thus be familiar with all areas of the exercise and their coordination. Table 1.1 lists the interview partners with whom expert interviews in the second iteration were conducted.

Table 1.1: List of interview partners for the semi-structured expert interviews

Interview	Organization/Department	Date of Interview
Interview 1	LÜKEX project group at the Federal Office of Civil Protection and Disaster Assistance (BBK)	26 February 2019
Interview 2	Department of Fire and Disaster Control at the Regional Council Kassel	05 March 2019
Interview 3	Department of Crisis Management and Research at the State Fire Service Institute North Rhine Westphalia	18 March 2019
Interview 4	Department of Red Cross Work & Civil Protection at the Institute for Education and Communication (German Red Cross)	18 March 2019
Interview 5	Department of Operations at the Fire Brigade Darmstadt	13 May 2019

For the expert interviews an interview guideline with nine topics on exercises and requirements for support tools was defined that was based on the information communicated in the informal discussions and which served as a basis for open discussions. The interviews focused, among other things, on the objectives pursued by exercises and their role in training and everyday working life. In addition, the interviewees were asked about the specifications and requirements that are placed on the planning of exercises and about the actors involved in the planning process. Other topics were emerging problems and criteria for evaluation as well as their methods. Finally, the interview partners were asked about the requirements for potential modeling and analysis tools and in which phases of the exercise their use would be appropriate.

The requirements for the software tool extracted from the expert interviews and the related work were compared with existing solutions for the analysis of networks in the context of civil protection and disaster response and a concept for a software application was developed. Furthermore, the concept was implemented in a tablet-based demonstrator application for technical verification. As can be seen from the title of the thesis, the developed software concept and the implemented application based on it put special emphasis on the modeling and analysis of exercise scenarios using multilayer graph networks. These are dynamic network structures which are visualized in the form of graphs. The simultaneous use of multiple layers allows to represent and analyze temporal changes as well as different types of relationships. Thus, the tool enables the user to model various dependencies and interconnections within a scenario. The possible network structures range from communication networks to dependency networks, for example to be able to represent cascading effects, and combinations of the two as they occur in exercise scenarios. In order to test the application with the underlying concept for functionality and usability as well as to assess the added value of network analysis as a methodology for planning and evaluation of exercises, an exercise evaluation was planned and conducted on the basis of several use cases. The procedure was divided into two steps. First, for each exercise data was collected on the basis of a systemic observation and in some cases additional information could be obtained from staff software. An exemplary evaluation was then carried out using the software application. The evaluations were prepared in a report format without the participation of the practice partners and made available to the exercise leaders. In a second step, based on the presented evaluations, feedback discussions were held with the practice partners and a question-based written feedback was obtained from them. The questions addressed the previous knowledge of social network analysis on the one hand and the evaluation of the exercises on the other. In this context, questions regarding the comprehensibility of the presentation and its added value were asked. Furthermore, possible problems and missing functions were discussed and it was asked whether the tool could contribute to an overall improvement in the evaluation of exercises. Optionally, there was also the possibility to give an assessment for the use of the application in exercise planning.

1.4. Structure of the Work

The dissertation is divided into nine chapters. After this chapter has introduced the emergency services as a critical infrastructure and the objectives of the work, chapter 2 focuses specifically on civil protection and disaster response in Germany. First of all, the structures and responsibilities at federal level are discussed, followed by the municipal and state levels using the state of Hessen as an example. In both cases, the relevant terms are introduced and the regulatory basis explained. Finally, the second chapter addresses the work of crisis management staffs, which are frequently used in major damage situations.

Building on the fundamentals of civil protection and disaster response, the third chapter examines the exercise in its various forms. First of all, it discusses the objectives pursued by conducting exercises and how they can be differentiated according to the actors involved. It then proceeds to explain and compare the different forms of exercise as they are practiced today. Furthermore, the chapter discusses the methodological procedure within the exercise, from planning to conduct and evaluation. A special focus is laid on the LÜKEX exercise as an interministerial and interstate crisis management exercise, which was first held in Germany in 2004. Finally, the third chapter analyzes the exercise as it is lived in practice today and examines working methods and problems.

As the present study follows a network theoretical approach, forth chapter introduces the relevant principles of social network analysis. First, the social network fundamentals are explained in order to get an overview of the origins and ways of thinking in network research. Following on this, graph theory as the mathematical basis of networks is discussed and the central definitions and formulas are introduced. A particular focus of this section is on multilayer networks and their forms of modeling. In the following, the chapter addresses the concept of centrality as one of the most widespread in network research and discusses the different calculation methods and their implications. The last section of the fourth chapter focuses on the visualization of networks as it is one of the reasons for the wide use of this approach.

On the basis of the two previous chapters, the fifth chapter analyzes to what extent social network analysis is suitable as a methodology for planning and evaluating exercises. For this purpose, the related work from the fields of organizational research and emergency management on the one hand and from the field of risk and criticality research on the other hand are examined and positive and negative aspects in the context of social network analysis are worked out. In the following section the gathered findings are summarized and analyzed with regard to their use for the exercise. Possible implications and limitations are elaborated and explained. In the last section of the fifth chapter, building on the insights gained, requirements for a software solution are formulated and compared with already existing applications.

In the sixth chapter a software concept for a network-based support tool for exercise planning and evaluation is designed and explained based on the defined requirements. First of all, the software objectives and the underlying use cases are discussed and the various functionalities of scenario development and analysis are subsequently explained and discussed. For scenario development, special attention is paid to the modeling of scenario data in networks and the representation of their dynamics. In the analysis, the simulation and the assessment of centrality are in the foreground. Finally, the sixth chapter looks at the practical use of the software concept in various exercises and discusses possibilities for extension.

Based on the developed concept, the seventh chapter introduces the demonstrator application for the verification of the technical feasibility, which was implemented in the context of the present work. At first general implementation decisions are explained and the graph library "GraphStream" used in the demonstrator is introduced. Afterwards the data structure and the data storage are explained. The last section of the seventh chapter addresses the user interface and the different workflows for modeling and analyzing scenarios.

The evaluation of the demonstrator application developed in this dissertation and described in the previous chapter is presented in the eighth chapter. For this purpose, the chapter first introduces the four evaluated use cases and then discusses each use case individually. Building on a short introduction, the use of the software and exemplary results are described. Each section concludes with a use case specific discussion of the results and feedback from the practitioners. The eighth chapter ends with a concluding discussion of the software application and the methodological use of social network analysis in exercises.

Finally, the ninth chapter summarizes the work and highlights the research contribution. Furthermore, the future work and potential of the work are discussed.

2. Civil and Disaster Protection in Germany

In Germany's federal political system, responsibility for civil protection and disaster control is distributed between the 16 federal states (Länder) and the federal government as constituted by the German Basic Law (Grundgesetz). This chapter will give an overview of the "Bevölkerungsschutz" as a general term for all tasks and measures related to this area and explain the most relevant organizations and characteristics. The perspective of the federal states is shown using the example of the state of Hessen. At the end of the chapter, the leadership structure in disaster control through staff work is also examined.

Bevölkerungsschutz describes all non-police and non-military measures taken by municipalities as well as the federal states in the field of disaster control (Katastrophenschutz) and by the federal government in the field of civil protection (Zivilschutz). The term covers both the protection of the population and the animals as well as their livelihoods. The terminology Bevölkerungsschutz applies to the effects of catastrophes and emergencies as well as to armed conflicts or wars (BBK, 2019a).

2.1. "Zivilschutz" – Civil Protection at Federal Level

Article 73, subsection 1 of the Basic Law (Grundgesetz – GG) stipulates that civil protection (Zivilschutz) is the responsibility of the Federal Government, ensuring the defense and protection of the population in times of war (Art. 73 *GG*, 2019). The tasks regarding Zivilschutz are defined in the "Zivilschutz- und Katastrophenhilfegesetz" (ZSKG) and include not only measures to protect the population but also their homes, civil services, etc.. In addition to the actual protection against the effects of war and its consequences, the tasks also include their elimination or mitigation. Civil protection is intended to supplement the self-help of the population (§ 1 *ZSKG*, 2009). The Zivilschutz thus does not cover disaster control in peacetime, which is why the legislative competence remains with the states according to the provisions of the Basic Law (Art. 70 subsection 1 *GG*, 2019; Art. 30 *GG*, 2019).

In the context of administrative co-operation (Amtshilfe) and disaster assistance (Katastrophenhilfe) under Article 35 of the Basic Law, the federal government and the states are further interlinked. In the event of a natural disaster or a severe accident, for example, a federal state can request support from the federal police or the federal armed forces (Bundeswehr) as well as from the administrations of other federal states and the federal government (Art. 35 subsection 2 *GG*, 2019). Furthermore, in the event of a natural disaster or a severe accident in which more than one federal state is affected, the federal government may order the states to make police forces available (Art. 35 subsection 3 *GG*, 2019). The federal government thus has limited emergency competence in supraregional problems (Robbe and Grill, 2007, p. 12).

With the "New Strategy for the Protection of the Population in Germany", the Conference of German Ministers and Senators of the Interior (Innenministerkonferenz – IMK) started adopting a new framework for the Bevölkerungsschutz in 2002. This was preceded by the terrorist attacks of September 11, 2001 and the floods in the Danube and Elbe rivers in 2002. With the aim of improving cooperation between the federal government and the federal states in the preparation and management of major supraregional damage situations (BBK, 2010; Robbe and Grill, 2007). One of the central elements of the new strategy is the Federal Office of Civil Protection and Disaster Assistance (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe – BBK), which was established in 2004 as a federal information and coordination office. In addition, joint hazard analyses, new equipment concepts and the "Interministerial and Interstate Crisis Management Exercise" (Länderübergreifende Krisenmanagement Exercise – LÜKEX), a regular federal and state exercise, were established (BBK, 2010; Robbe and Grill, 2007).

The framework concept was legally transferred to the ZSKG in 2009 (BBK, 2010). In addition to the principle of disaster assistance, the ZSKG also defines that the federal government is materially involved providing disaster control equipment (§ 13 *ZSKG*, 2009) and complements the training programs offered by the federal states (§ 14 *ZSKG*, 2009). It can also undertake coordination tasks in the event of major emergencies if requested to do so by the states (§ 16 *ZSKG*, 2009). With the institutions and structures created or modified in the new framework a simple cooperation between the federal government and the states within the meaning of Article 35 of the Basic Law can be facilitated (Robbe and Grill, 2007). In conclusion, the federal government takes on tasks primarily in the context of preparedness and prevention, while its role in operational crisis management remains limited (Lamers, 2016, p. 115).

The Federal Ministry of the Interior, Building and Community (Bundesministerium des Innern, für Bau und Heimat – BMI) is responsible for civil protection at federal level. As the supreme federal authority, it coordinates the crisis units of the individual ministries and maintains numerous authorities and organizations that support the BMI in its tasks. The Federal Agency for Technical Relief, commonly referred to as Technical Relief Agency (Technisches Hilfswerk – THW) and the Federal Office of Civil Protection and Disaster Assistance (BBK) are particularly noteworthy (BMI, 2015; Knigge, 2019).

The central task of the THW, as defined in the "Gesetz über das Technische Hilfswerk" (THW-Gesetz), is to provide technical assistance in civil defense as well as in disaster relief, public emergencies and major damage situations at the request of the local and state authorities in charge of emergency response. In addition, the THW also performs the task of technical assistance on behalf of the federal government outside of Germany (§ 1 *THW-Gesetz*, 2013). The THW is organized in local associations and is carried out almost exclusively by volunteers (Terberl, 2015). The BBK is a key player in the organization of the Federal civil protection and serves as its coordination and service hub (BMI, 2009b; Terberl, 2015). It has an interdisciplinary orientation and performs many conceptual, planning and advisory tasks for the federal government and the states (BBK, 2009b). The BBK itself describes its activities as interdisciplinary and takes all areas of civil security into account (BBK, n.d.). In addition to its diverse tasks, the BBK also houses the "Joint Information and Situation Centre of the Federal Government and the Federal States" (Gemeinsames Melde- und Lagezentrum – GMLZ) and the "Academy for Crisis Management, Emergency Planning and Civil Protection" (Akademie für Krisenmanagement, Notfallplanung und Zivilschutz – AKNZ). They take on important roles in the joint assessment of the situation and the exchange of information as well as in training and further education (BBK, 2011a).

2.2. "Katastrophenschutz" – Disaster Control at State and Municipal Level

As already mentioned in the previous section, the legislative competence in disaster control in Germany lies with the states (Art. 70 subsection 1 *GG*, 2019; Art. 30 *GG*, 2019). They have established disaster control authorities at several levels. The lowest level is made up of the administrative districts and the cities, while the highest level is always made up of the ministries at state level. In some cases, there is also a middle level representing the regional administrative levels of the state (Fritzen, 2010). In order to support cooperation between the individual states at the political level, the ministers of the interior of the states meet twice a year at the so-called "Innenministerkonferenz" (IMK). An integral part of this conference of ministers of the interior is working group V, which, deals with disaster control and thus creates a permanent exchange on this topic. Through this exchange, country-specific rules and processes can be discussed and coordinated with each other, thus preventing divergent legislation (IMK, n.d.). In order to further explain the tasks and structures of disaster control, the example of the state of Hessen is used below.

In Hessen, disaster control is regulated in the "Hessisches Brand- und Katastrophenschutzgesetz" (HBKG). The HBKG defines disaster as "*[…] ein Ereignis, das Leben, Gesundheit oder die lebensnotwendige Versorgung der Bevölkerung, Tiere, erhebliche Sachwerte oder die natürlichen Lebensgrundlagen in so ungewöhnlichem Maße gefährdet oder beeinträchtigt, dass zur Beseitigung die einheitliche Lenkung aller Katastrophenschutzmaßnahmen sowie der Einsatz von Einheiten und Einrichtungen des Katastrophenschutzes erforderlich sind*" (§ 24 *HBKG*, 2018). Accordingly, a disaster refers not only to events in which parts of the population are exposed to great danger but also includes animals, the environment or material assets of great value, such as infrastructures. Whether there is an event that is so extraordinary in its extent that the state of disaster must be declared is to be examined for each individual case by the 'lower' disaster control authority in accordance with the requirements of the HBKG (HMdIS, 2016a).

Hessen distinguishes between three levels of disaster control authorities. The 'lower' level is made up of the 26 councilors (Landräte) in the administrative districts (Landkreise) often referred to as counties and the mayors in the cities that are not counties. They are primarily responsible for supra-local fire protection, general aid and disaster control (Fritzen, 2010; HMdIS, 2016a). One level above this are the three regional councils (Regierungspräsidien) of the state of Hessen as the 'upper' disaster control authority. The Hessian Ministry of the Interior (HMdIS) represents the 'highest' authority in disaster control (HMdIS, 2016a). In principle, the 'lower' disaster control authority affected is always responsible for disaster control. According to § 35 HBKG, in individual cases the responsible regional council can transfer responsibility to another administrative district or an independent town if the defense against the disaster from this area is more effective. Furthermore, especially in the case of supra-regional events, the ‘upper’ and the ‘highest’ disaster control authorities can take over responsibility (§ 35 *HBKG*, 2018; HMdIS, 2016a).

According to § 7 HBKG every municipality in Hessen must have a public (voluntary) fire brigade ready. For cities with more than one hundred thousand inhabitants, there must also be a professional fire brigade which is supplemented by the voluntary fire brigade (§ 7 *HBKG*, 2018). Furthermore, according to § 5 of the “Hessisches Rettungsdienstgesetz” (HRDG), administrative districts and independent cities are responsible for the organization and establishment of the rescue service and according to § 4 HBKG for a central control center which is always ready for operation (§ 4 *HBKG*, 2018; § 5 *HRDG*, 2018). The rescue service can be carried out by the districts and cities themselves (e.g. by the fire brigades) or commissioned to the relief organizations recognized in disaster control (Fritzen, 2010). The fire brigades, the rescue service and the control centers form the daily non-police emergency response. The emergency response units are always fully involved in disaster control and are supported in their tasks by other public and private aid organizations (HMdIS, 2016a).

Normally, a catastrophe begins as a regular emergency response operation. As the complexity and size of the mission increases, the ‘lower’ disaster control authority can determine a disaster according to § 34 HBKG and establish the mission as a disaster operation (§ 34 *HBKG*, 2018; HMdIS, 2016a). In order to cope with a disaster, various aid organizations have committed themselves to cooperate with the states. In the field of medical and rescue services these are the “Arbeiter-Samariter-Bund (ASB)”, the German Red Cross (DRK), the “Johanniter-Unfall-Hilfe (JUH)” and the “Malteser Hilfsdienst (MHD)” (Fritzen, 2010). The “Deutsche Lebens-Rettungs-Gesellschaft (DLRG)” supports the fire brigade in water rescue (ibid.). As mentioned in the previous section, the states can also call on the Technical Relief Agency (THW) and the German Federal Armed Forces in the course of administrative assistance under Article 35 of the Basic Law (GG) for disaster control assistance (ibid.). Apart from the German Federal Armed Forces, the majority of disaster control organizations are relying on the work of volunteers (ibid.). An overview of the non-police organizations is given in Table 2.1. In addition to public and private organizations, § 28 HBKG requires all municipal, administrative district and state offices to assist at the request of the disaster control authorities (§ 28 *HBKG*, 2018).

Table 2.1: Overview of the non-police organizations in disaster control according to Fritzen (2010, p. 12)

	Non-police	**Other**
Federal states (Länder)	▪ Fire brigade ▪ Arbeiter-Samariter-Bund (ASB) ▪ German Red Cross (DRK) ▪ Johanniter-Unfall-Hilfe (JUH) ▪ Malteser Hilfsdienst (MHD) ▪ Deutsche Lebens-Rettungs-Gesellschaft (DLRG)	
Federation (Bund)	Technical Relief Agency (THW)	German Federal Armed Forces

A disaster situation requires a distinctive management organization. In Hessen, the “Zwei-Stabs-Modell”, recommended in the “Feuerwehr-Dienstvorschrift 100 (FwDV 100)”, consisting of three central components, is used (AFKzV, 1999; HMdIS, 2016a; Lamers, 2016). At the highest level is the overall political responsibility, called disaster control management (Katastrophenschutzleitung – KatSL) in Hessen. It is performed by the 'lower' disaster control authority and thus either the district administrator or the mayor. The tasks include coordination and responsibility for all measures, both with regard to strategy and administration. It uses an operational-tactical and an administrative-organizational component for processing (AFKzV, 1999; HMdIS, 2016a).

The operational-tactical component, which is provided by the "Katastrophenschutzstab" (KatS-Stab), coordinates all technical-tactical measures. This includes, among other things, the definition of the focal points of operations, the spatial devision and the planning and organization of forces. The technical-tactical component, which is comprised of all subsequent command levels, is subordinate to the KatS-Stab (see Figure 2.1). The KatS-Stab mainly consists of representatives of the fire brigade and the organizations involved in the mission (AFKzV, 1999; HMdIS, 2016a). The administrative-organizational component, known in Hessen as the administrative staff or "Verwaltungsstab" (Vw-Stab), is concerned with the administrative tasks associated with an incident. The offices involved coordinate their procedures, taking into account the legal, financial and political requirements. Typical tasks include, for example, the planning of accommodation and care for the population in the event of an evacuation (AFKzV, 1999). The demand for the three components is also to be transferred analogously to the 'upper' and the 'highest' disaster control authorities (HMdIS, 2016a).

With the "Zwei-Stabs-Modell" Hessen follows the recommendations of the FwDV 100 similarly to some other federal states (e.g. North Rhine-Westphalia). Beyond that, however, two further structures have established themselves in Germany in different federal states. While the structures in the KatS-Stab are uniform throughout Germany, there are differences at the administrative level in particular. In Bavaria and Saxony, for example, a disaster staff is set up that resembles an administrative staff but has standard subject areas (see Figure 2.1). The operational command is subordinated to it. Alternatively, in Berlin or Hamburg, for example, a general staff with operational-tactical and administrative-organizational components is used (Lamers, 2016).

In addition to the three components described, § 29 HBKG also defines the establishment of an information and communication center (ICT center or IuK-Zentrale) for Hessen. Furthermore, a hazardous substance monitoring center (Gefahrstoff-ABC-Messzentrale) is to be available at all levels of the disaster control authorities for major events involving hazardous substances. Both facilities are subordinate to the KatS-Stab and support it in its operational tasks (§ 29 *HBKG*, 2018; HMdIS, 2016b). The technical-tactical component, which is subordinate to the KatS-Stab is represented by the technical operations management (Technische Einsatzleitung – TEL) and the operational sections (Einsatzabschnitte – EA) in Hessen. In general, the KatS-Stab sets up at least one TEL, however, depending on the size and the focus of the mission, several technical operations management units can be defined. Each TEL in turn defines different operational sections which coordinate the tasks in their section. A typical operational section is, for example, the "EA deployment", which coordinates the area to which the forces that are moving up arrive before they receive concrete deployment orders. An overview of the management structures in the event of a disaster in Hessen is given in Figure 2.1. Arrows drawn through represent the subordination, whereas dashed arrows represent communication and information relationships (AFKzV, 1999; HMdIS, 2016a, HMdIS, 2016b).

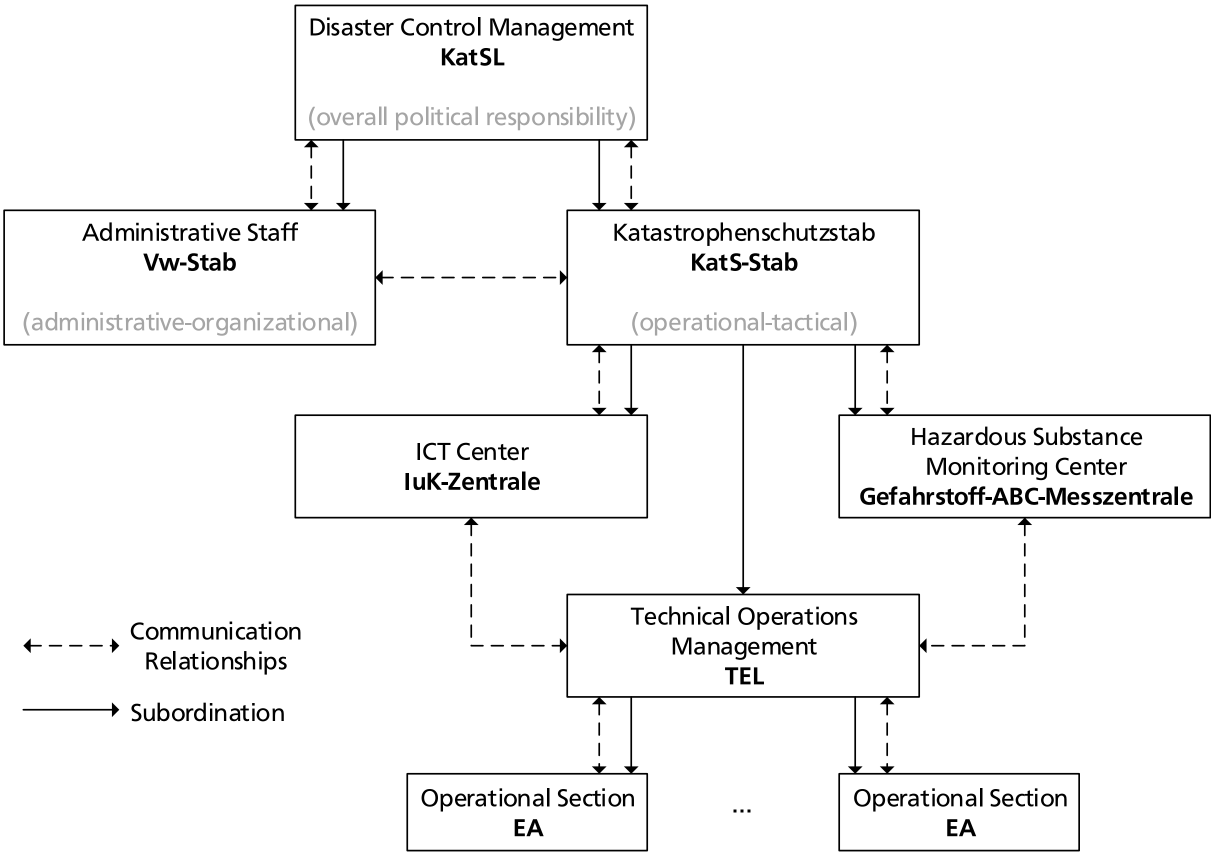


Figure 2.1: Management structures in the event of a disaster in Hessen according to HMdIS (2016b, p. 5)

2.3. “Stabsarbeit” – Staff Work in Crisis Management

Heimann and Hofinger (2016) describe a staff as a (temporary) advisory and support element that works for a leading person and uses the available information flows for this purpose. The actors in a given staff adopt specific roles so that tasks are clearly distributed. They are always used when, for example, there is an increased need for coordination due to a large number of personnel or the amount of information can no longer be processed by one person. Furthermore, in such situations special expertise for decision making must be provided and uniform leadership is required (Heimann and Hofinger, 2016).

In Hessen, the KatS-Stab and the TEL are regularly managed on a staff basis. In addition, individual administrative staffs also use this form of management. The structure of the staff in in disaster control or the fire brigade is described in FwDV 100 and can be seen in Figure 2.2. Each staff always consists of a head of staff and various subject areas. The subject areas always cover personnel, situation, deployment and supply. If required, press and media relations as well as information and communications (ICT) can also be set up. The staff is supplemented by various consultants and liaisons (see Figure 2.2) from other organizations, authorities and companies or the police. The consultants are appointed to the staff depending on the situation (AFKzV, 1999).

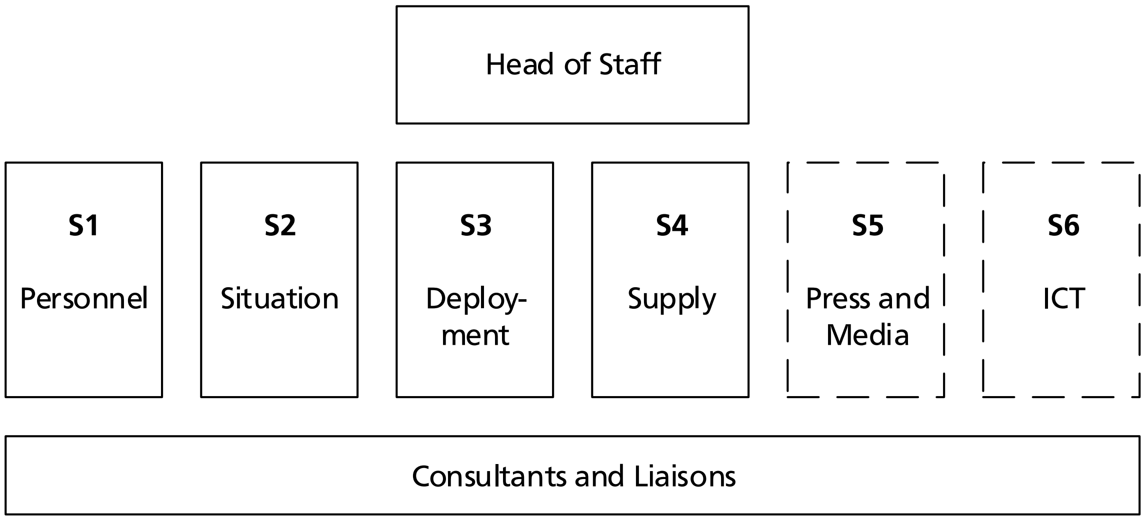


Figure 2.2: Staff structure according to AFKzV (1999, p. 13)

In order to be able to work an operation in a structured manner, clear tasks are assigned to each subject area. The S1 department is responsible for personnel matters. This includes alerting the emergency forces and calling in specialist consultants if the situation requires them. Furthermore, the department plans the reserve especially for longer missions and coordinates the required deployment areas. Another important task is the management of a force overview, which for example is relevant, when planning the supply (AFKzV, 1999).

The S2 department is responsible for determining and visualizing the situation. This includes, in particular, the continuous acquisition and evaluation of information on the deployment and the merging of it in a situation map. Furthermore, the S2 provides various deployment overviews, such as an overview of the operational sections. The department is also responsible for ensuring that information is reported to other departments as well as to the general public. The department keeps the mission diary and writes the final report on the mission (AFKzV, 1999).

The tasks of subject area S3 include, in particular, assessing the situation and deciding on the measures to be taken. They define the main areas of deployment and initiate immediate measures in the event of danger to the population. All in all, the S3 assesses the damage area and manages the responsibilities of the resulting measures. They can issue orders directly and instruct forces on the tasks to be performed, but are also responsible for monitoring said tasks. In addition, the department is responsible for conducting the situation reviews (AFKzV, 1999).

The supply during the mission is administered by the subject area S4. It organizes necessary aids and consumables such as fuel or building materials. In addition, it is responsible for the catering of the emergency forces and their accommodation as well as materials for self-protection (AFKzV, 1999).

If the subject areas S5 and S6 are represented in the staff, they are responsible for press and media relations as well as communications. Press and media work includes collecting and preparing mission information for the public and writing statements. In addition, the S5 department is responsible for the support and coordination of the press officers and involves them in the mission, for example, for warnings to the population. The S6 department is responsible for ensuring communication and passing on information. They oversee the allocation and adherence to the radio channels and transmit commands and information to the emergency forces. In addition, they ensure communication security and keep in contact with other authorities and institutions (AFKzV, 1999).

Cooperation within the staff is very important so that large-scale and complex operations requiring staff leadership can be handled efficiently. In particular, in order to assess the situation, subject areas S2 and S3 must cooperate and coordinate their actions. The subject areas must also coordinate when it comes to the additional request of task forces and the organization of provision areas (i.e. areas close to the place of action where the emergency forces gather) (S1 and S3 in both cases) as well as the planning of supplies (S4 and S1). In addition, the staff management must be involved in decisions and expert knowledge must be drawn from the specialist consultants (Lamers, 2016).

One goal of staff work is the establishment of a shared mental model. It symbolizes the common knowledge shared in the team and also includes the experiences and values of the individual actors. The aim is to ensure that all persons base their decisions on the same grounds (Lamers, 2016; Zinke and Hofinger, 2016). For example, it must be clear to each staff member who takes on which tasks and who has which skills. In order to develop a shared mental model, it is important for a staff to exchange information at regular meetings (Zinke and Hofinger, 2016).

A staff should be rather small, but with qualified personnel. Training is therefore very important for staff work. Although there are already corresponding seminars, Lamers (2016) states in his theses on future staff work that the training and further development of personnel in particular must be intensified even more. He explains that many problems can still be traced back to inadequate training and that it is important to have a pool of specialists with the appropriate key competences.

A very relevant form of training for disaster control is the exercise. For example, § 29 HBKG regulates which preparatory measures are to be implemented by the disaster control authorities in Hessen and mentions in particular the exercise which is to be used, among other things, to test the interaction of all forces and parties involved in disaster control (§ 29 *HBKG*, 2018; § 32 *HBKG*, 2018). It is precisely these exercises that the next chapter focuses on and describes their various types and their development in disaster control.

3. Exercise in Civil and Disaster Protection

Exercising plays an important role in the field of civil protection and disaster response. Glass (2012) describes the regular exercise in combination with training and operation as a coordinated system, which in its entirety guarantees the readiness of all forces in civil protection. This chapter will address this in more detail. After a brief historical overview of the fire brigade and disaster control exercise the various objectives associated with the exercise will be analyzed. Furthermore, the chapter gives an overview of the different forms of the exercise and the methodology for planning, implementation and evaluation. With the LÜKEX exercise series, a special exercise in Germany will be outlined in the following. At the end of the chapter, the situation of the exercise in practice is described and discussed.

With the foundation of the voluntary fire brigade in the 19th century, exercise assumes a role with increasing importance in fire and disaster protection. Since these areas were from then on the responsibility of the fire brigade as an organization, the approaches and measures especially in fire protection shifted from a preventative to a preparative character. The exercise was part of everyday operations and led to the forming of routines and the strengthening of preparedness among the emergency forces (Ellebrecht et al., 2013). In combination with the inherent discipline of operations the exercise became a classic feature of the fire brigade and promoted the inner calmness of its members while reducing susceptibility to errors (ibid.). In addition to this professionalization of forces, the exercise was given a further task in modern times. As such it served to increase the confidence of the population in the abilities of the fire brigade. This was achieved by staging large-scale public exercises, a procedure which is still practiced today where especially large exercises take place in the presence of representatives of the media and political leaders (ibid.).

3.1. Exercise Objectives

In addition to the confidence-building approach the exercise in civil protection and disaster response fulfils a number of other objectives. A very dominant aspect is the experience of the disaster described by Ellebrecht et al. (2013) in order to be able to prepare for crises. This incorporates the idea of uncertainty and enhances the exercise into a tool to avoid turning threatening events into a disaster. In particular, it is about mental preparation for crisis events (BBK, 2011b) or according to Anderson and Abbey (2011, p. 1093) “making affectively present a space-time [...] so that the exercise can function as a technique of equivalence, allowing future events to be rendered governable”. This objective was confirmed in an interview with the professional fire brigade Darmstadt underlining the importance of simulating and training events that rarely occur in everyday life (Interview 5, 2019, personal communication, 13 May).

A further fundamental objective of the exercise is the training of emergency forces and other actors. In the context of an exercise they will be enabled to test and validate concepts, protocols and capabilities in a low-risk environment. Actors can also familiarize themselves with their own role and related tasks in the overall system and exercising promotes interaction and communication between the different actors and organizations involved (U.S. Department of Homeland Security, 2013). Exercises will enable the emergency services, administrators and decision-makers to understand the impact of their own decisions and improve responsiveness through the routine gained (Adey and Anderson, 2012; Anderson and Adey, 2011; BSI, 2008). In an interview held on March 18th 2019 the department for crisis management and research at the State Fire Service Institute North Rhine Westphalia it was also explained that exercises give actors a sense of security in their actions (Interview 3, 2019, personal communication, 18 March). The department of fire and disaster control at the regional council of Kassel ('upper' disaster control authority) emphasized in an interview the importance of the exercise especially for non-specialist personnel of e.g. administrations. Training and repetition are often the only possibility to internalize special requirements which occur in connection with large-scale damage situations (Interview 2, 2019, personal communication, 05 March). According to Glass (2012), exercises also strengthen the motivation of the emergency forces.

The training of the personnel is directly accompanied by another objective of exercising, namely the verification and application of processes. Often only the application of specific processes and protocols shows their feasibility (Bédé and Hofinger, 2016). This includes in particular the verification of assumptions made as listed by the BSI (2008). The exercise enables all stakeholders to identify capacity gaps in the defined structures and processes and to create opportunities for improvement (O'Grady, 2016). Practitioners also attributed a high degree of relevance to this goal (Interview 3, 2019, personal communication, 18 March). Moreover, it is stated that in addition to the defined processes it is also important to obtain knowledge regarding the equipment used and the tactical approach (Interview 5, 2019, personal communication, 13 May).

One goal that is repeatedly mentioned, especially in the context of the LÜKEX exercise series, is to deal with a specific disaster scenario (Bédé and Hofinger, 2016; Haritz, 2016). Through the intensive planning, execution and evaluation of an exercise, the actors are prompted to deal with the scenario at hand and gain specific insights. From the point of view of an administrative staff, the aim is to gain an understanding of the respective situation and the actors relevant to it (Interview 2, 2019, personal communication, 05 March). This is accompanied by the belief that exercises should take place regularly in order to cover different scenarios and to recognize individual characteristics. Anderson and Adey (2011, p. 1092) take up this aspect in their brief definition of the exercise as "rehearsals of response and recovery from a range of disruptive events". This objective can be summarized by saying that the exercise is part of everyday life within the fire brigade and thus a crucial tool in everyday life and training (Interview 3, 2019, personal communication, 18 March).

Finally, a very important objective of the exercise is to improve cooperation and networking. In crisis events it is very relevant to "know your friends before you need them" (equivalent to the German "in der Krise Köpfe kennen") as Haritz (2016, p. 265) puts it. This applies on the one hand to the deepening of cooperation within the staff and the direct environment (Bédé and Hofinger, 2016), but also between the various organizations involved in the situation (Anderson and Adey, 2011). Since crisis situations are often associated with stress, it is advantageous if the actors already know each other through recurring exercises and can understand and assess each other (ibid.). This serves in particular to avoid mistakes in the field of communication and is important in cooperation in crises (Interview 5, 2019, personal communication, 13 May).

3.2. Types of Exercises

Nowadays, the organizations involved in disaster control have established various forms of practice. These differ above all in their central function, the effort involved in planning and implementation and whether they are discussion-based or operation-based. In the following, the most important forms of exercises are presented and explained.

One of the most common exercises is the drill. According to the U.S. Department of Homeland Security (2013, p. 2-5), a drill constitutes a "coordinated, supervised activity usually employed to validate a specific function or capability in a single agency or organization". The drill is used to maintain routine handling of the equipment as well as to reduce execution errors. For example, putting on respiratory protective equipment or the handling of salvage tools is practiced regularly in drills, as Ellebrecht et al. (2013) explain. In addition to the drill, function tests also apply to the frequent and regular forms of exercise. During function tests sub-processes, procedures and systems are checked for their functionality and sequences are revised (BSI, 2008). These can be for example restart protocols in factories or critical infrastructures but also a regular siren test of the fire brigade.

Another form of exercise is the table top exercise (TTX). This is a scenario-based discussion exercise in which a hypothetical emergency situation is simulated. The TTX is intended to promote general awareness and is mainly used to practice communication and the order of spatial location (Ellebrecht et al., 2013). Also concepts and procedures are played through and different ways of solving a situation are discussed (U.S. Department of Homeland Security, 2013). In the table top exercise the practitioners play their role and communicate their actions and decisions verbally. For easier understanding, common notes or graphical models can also be created (Ellebrecht et al., 2013). During the exercise, practitioners are encouraged to engage in deeper discussions. The aim is to analyze different problem-solving strategies and to achieve a deeper understanding of the scenario (U.S. Department of Homeland Security, 2013). Table top exercises can be extended by a pre-defined script and made more complex for the participants. The exercise instructor makes changes to the scenario with so-called "injects" to which the participants have to react. The injects can be introduced into the scenario in different ways, e.g. by simulated telephone calls or emails (ibid.).

A special form of TTX is the "Stabsübung" which translates to staff exercise commonly used in Germany. The focus here is on cooperation within the staff and its working methods and only staff members are trained (BSI, 2008; Hofinger et al., 2016). Table top exercises and staff exercises are particularly suitable for untrained staffs that are on technical and content level and can be used as preparation for functional or full exercises (Hofinger et al., 2016). TTX require relatively little preparation and are easy to implement as they involve less personnel in the exercise coordination (ibid.). The scenarios in a table top exercise can also be from areas not related to the subject (e.g. the control of a cruise ship). This could have the advantage that the trainees can more easily get involved in their role and the scenario (Zinke et al., 2016).

The "Stabsrahmenübung" is an extension of the staff exercise and forms a transition to the functional exercises. In addition to the staff, command posts such as the technical operations management (TEL) are also practiced, but there is no actual implementation of the orders (Bédé and Hofinger, 2016; BSI, 2008). During the exercise, the staff receives periodic injects from the exercise management or a control group and must work through these as if in an operational situation with the aid of the subordinate command levels (Hofinger et al., 2016). The Stabsrahmenübung supports the members of the staff in being able to act in complex situations (Bédé and Hofinger, 2016). Furthermore, functional exercises are used if aspects of implementation are to be trained in addition to the mental processing of the situation.

The functional exercise which corresponds to the German “Rahmenübung” (framework exercise) is an operation-based exercise. Functional exercises are designed to evaluate the participants’ capabilities and practice plans, procedures and command and control functions. Routines in the practical handling of processes and equipment will be facilitated. Functional exercises always move within the limits of a defined scenario in which they are held through the use of injects (U.S. Department of Homeland Security, 2013). They represent excerpts from possible emergency situations and vary in duration and scope. The participants can thus carry out the organizational processes and actions in a realistic time and environment. In recent years, the scope of functional exercises in Germany has increased more and more, and large-scale exercises with a large number of actors are taking place more frequently. With the help of simulations, disaster scenarios are being played out more and more frequently with functional exercises (Ellebrecht et al., 2013).

The most complex and resource-intensive form of exercise is the full-scale exercise (FSE). In this type of exercise all aspects of a scenario are practiced. Depending on the scenario, different hierarchical levels and often several organizations are involved and the exercise is carried out in real-time (BSI, 2008; Ellebrecht et al., 2013; U.S. Department of Homeland Security, 2013). To ensure that the scope of the exercise remains manageable and does not become too complex, full-scale exercises are planned in clearly defined spatial areas and with clearly defined participants (Ellebrecht et al., 2013). The FSE tries to create a stressful environment in order to depict missions as close to reality as possible and to prepare the participants ideally for corresponding situations (U.S. Department of Homeland Security, 2013).

In addition to the previously mentioned forms of exercise, seminars and workshops are also held specifically to impart theoretical knowledge (U.S. Department of Homeland Security, 2013) and create reviews aimed at discussing and evaluating previously defined plans and procedures (BSI, 2008). Regular alarming exercises should also be carried out to check the procedures and protocols as well as the technical equipment for reporting and alarming (ibid.). All these exercise types can be subdivided into categories for easier differentiation. The U.S. Department of Homeland Security (2013) differentiates between discussion-based and operations-based exercises. Using this classification the Stabsrahmenübung forms a special case. It includes both the aspects of discussion and operation, so that both categories apply to it. Another way to distinguish between exercises is whether or not they are based on scenarios. An overview of all exercises and their categories is shown in Table 3.1. In principle, the exercises never stand alone but build on each other. Both theory and practice have to be trained regularly. Therefore it often makes sense to develop a multi-year exercise and training plan that defines applicable learning goals and requirements and relates exercises to one another (BSI, 2008; U.S. Department of Homeland Security, 2013).

Table 3.1: Exercise type overview (own illustration following U.S. Department of Homeland Security (2013) and BSI (2008))

	Discussion-based	**Operations-based**
Scenario-based	▪ Table top exercise ▪ Stabsübung	▪ Functional exercise ▪ Full-scale exercise
	▪ Stabsrahmenübung	
Non scenario-based	▪ Seminar ▪ Workshop ▪ Review	▪ Drill ▪ Function test ▪ Alerting exercise

3.3. Exercise Methodology

In regard to crisis management in Germany there are hardly any regulations or guidelines on exercise methodology (Interview 3, 2019, personal communication, 18 March), especially from official regulatory bodies. Only the “Feuerwehr-Dienstvorschrift 2” (FwDV 2), which stipulates the training of voluntary fire brigades, defines the performance of practical exercises as components of various training courses. However, it does not deal with the training methodology either (AFKzV, 2012). The “BSI Standard 100-4” on emergency management provides an overview of the various types and the conduct of exercises as well as the documents required, but it is primarily aimed at businesses and public agencies (BSI, 2008). Support in the planning and implementation of crisis management exercises is offered by some fire brigade schools in Germany which are each set up by the federal states. They offer seminars and training courses for administrative districts (Landkreise) and cities (IdF NRW, n.d.; SFSG, n.d.). In the international area, more precise specifications are given in some cases. The U.S. Department of Homeland Security, for example, provides a complete guide to exercise methodology in the form of the “Homeland Security Exercise and Evaluation Program” (HSEEP) (U.S. Department of Homeland Security, 2013).

The methodology for conducting exercises is generally based on three phases: exercise planning and preparation, also known as the design and development phase, exercise conduct and exercise evaluation. Looking at the long-term development of the organization and its members of staff, improvement planning is also seen as the fourth phase (Bédé and Hofinger, 2016; BSI, 2008; U.S. Department of Homeland Security, 2013). How much time and effort is involved in the planning, conduct and evaluation of the exercise depends on the type of exercise and its boundary conditions. However, Bédé and Hofinger (2016) quote a ratio of 60% (planning) to 10% (conduct) to 30% (evaluation) as a rule of thumb for scenario-based exercises (especially the Stabsrahmenübung) (Bédé and Hofinger, 2016, p. 244). Accordingly, the planning and preparation of an exercise takes by far the most time and effort. The actual implementation on the other hand requires less effort even though it has the greatest external impact.

In the planning phase, the overall concept of the exercise is defined and personnel planning is carried out for the entire duration of the exercise, including preparation and follow-up. The type of exercise is also defined and the associated exercise objectives are discussed and established. In the case of a scenario-based exercise, the scenario is designed and the documents required are created, in particular the exercise script. For a successful evaluation of the exercise, its objectives are already defined in the planning phase and the evaluation is planned accordingly (Bédé and Hofinger, 2016; BSI, 2008; U.S. Department of Homeland Security, 2013).

The overall concept which is to be developed throughout the planning of the exercise should serve as a guideline for the control and leadership group and must be approved by the management of the organization, authority or company (Bédé and Hofinger, 2016). It includes general information and framework conditions, such as the name of the exercise and the reason why it is required. In addition, the information includes cost and expense planning and the specifics of the exercise (ibid.). These and other details, such as the type of exercise, the level of participation and the duration of the exercise, form its scope and help the exercise leader to define the correct size and complexity and to make the exercise feasible (U.S. Department of Homeland Security, 2013).

In addition to the aspects already mentioned, the overall concept also includes the exercise objectives and the scenario, if there is one. It goes into more detail about the time schedule and sets dates for the planning sessions. Another important aspect is the definition of the target group, i.e. the question of who should practice. Are different areas involved and do they come from different organizations? Should other external actors be involved in the exercise? The concept contains further information on the exercise surroundings. It lists the members of the exercise leadership team as well as the observers and describes the procedure for the documentation and evaluation of the exercise (including the evaluation goals). Last but not least, it contains the location where the exercise is to take place and what needs there are with regard to supply, security and other resources required (Bédé and Hofinger, 2016). Since this information is often not available in detail at the beginning of the planning process, a two-stage approach has been established. First, a rough concept is drawn up and only after approval a detailed planning is carried out (BSI, 2008).

For each exercise, clear exercise goals must be defined at the beginning of the planning process. These should always be measurable, realistic and achievable (Bédé and Hofinger, 2016). They should also be relevant for all actors involved in order to achieve a better identification with the exercise (U.S. Department of Homeland Security, 2013). When defining the exercise goals, the level of knowledge of the exercise participants should be considered, so that the exercise specifically promotes the participants' abilities. The goals can be process-related or content-related, or they can specifically address the team, for example, in a communication exercise (Bédé and Hofinger, 2016).

On the basis of the exercise objectives, a reference scenario is selected that provides the foundation for the exercise. The scenario must be chosen in such a way that it enables the accomplishment of the exercise objectives and challenges the participants, but does not overburden them. In addition, the reference scenario should be related to the participating organizations or the region in which the exercise is conducted (Bédé and Hofinger, 2016; U.S. Department of Homeland Security, 2013). It is therefore common for scenarios to be selected on the basis of risk analyses or past events (BBK, 2011b). In his article, Alexander (2015, p. 6) expressed it with “we plan for the last event, not the next one”. He referred in particular to the availability of resources. For an exercise to be as realistic as possible, it can only be based on resources that are actually available. This should be reflected in particular in the selection of the scenario.

In most cases, the scenario methodology is used to develop the exercise scenario (Bédé and Hofinger, 2016). As Alexander (2005) explains, this technique is particularly suitable for three areas: the development of plans and procedures, the prediction of future events and the development of hypothetical emergency situations. The scenario describes a sequence or evolution of events or provides a framework or model for the events and the related exercise (Alexander, 2015; U.S. Department of Homeland Security, 2013). It is an exploratory tool with which different consequences and outcomes can be modelled and that allows for different framework conditions to be incorporated (Alexander, 2015). The procedure for the development of scenarios is usually iterative. Based on the defined reference scenario and some input conditions, possible processes and consequences of events are assumed and formulated. Afterwards, follow-up developments are generated and the plausibility of the resulting process is checked on the basis of the reference scenario and the initial consequences. Thus, it is possible that a scenario can result in a variety of outcomes (ibid.). The sequence of events results in a narrative event timeline which forms the basis for action (U.S. Department of Homeland Security, 2013). In free-running exercises, scenarios can also develop in unplanned directions, which is why various injects are planned during the conception of the scenario to guide the participants back closer to the initial situation (Alexander, 2005). The scenario and planned injections are documented in the form of a tabular script and, in addition to the description of the content, contain information on the time of the event or the injection, the form of communication, the sender and the recipient. Furthermore, the expected reaction or required tools can be described as well (Bédé and Hofinger, 2016; BSI, 2008). An example of such a script is shown in Table 3.2.

Table 3.2: Exercise script according to BSI (2008, p. 88)

Exercise: XYZ											
No.	**Real time**	**Scenario time**	**Keyword**	**Activity**	**Goal/ Expected response**	**Injector**	**Actors**				**Auxiliaries /Tool/Type of injection**
							A	**B**	**C**	**...**	
1	...	...	...	...	...	...	...	...	...	...	...
2	10:10	5	Report to CC	Background info of situation							
3	...	...	...	...	...	...	...	...	...	...	...

After the planning phase, the exercise can be conducted. The date chosen for this is usually announced to the participants and should influence the normal course of operations as little as possible (Bédé and Hofinger, 2016; BSI, 2008). The exercise should always start with a briefing by the exercise leader. During the briefing the active participants are introduced to the scenario and their roles as well as the schedule are explained (Bédé and Hofinger, 2016; U.S. Department of Homeland Security, 2013). Also, there should be hints regarding the behavior and confidentiality of the exercise. All materials used in an exercise must be clearly identifiable as exercise materials. Furthermore, for the purpose of external communication, it must be made clear that an exercise is conducted. For genuine emergencies during an exercise, a keyword must be defined that allows a clear identification of the emergency (Bédé and Hofinger, 2016).

During the exercise, various people take on special tasks and functions in addition to the active players. The exercise leader and the steering group are central to this. They make sure that the exercise moves within the framework planned beforehand and take corrective action in the event of excessively large deviations through injects or interventions (Bédé and Hofinger, 2016; BSI, 2008; U.S. Department of Homeland Security, 2013). While doing so they still try to ensure that the development and play of the exercise is as free as possible (BSI, 2008). The formal decision-making power and responsibility is incumbent on the exercise leader. In case of unforeseeable events or external effects, he or she can also abort the exercise (Bédé and Hofinger, 2016). In addition to the input of information on the situation, the steering group also takes care of the project management and the documentation of the exercise. They answer questions from the participants and take care of logistical matters (ibid.). In addition to these functions, observers are also included, especially in larger exercises. They are not actively involved in the exercise and therefore do not participate in the communication between the participants (Bédé and Hofinger, 2016; U.S. Department of Homeland Security, 2013). Much more they observe certain areas of the exercise from the outside and document their results and assessments. In discussion-based exercises, observers can also ask questions that can be discussed in the group of participants (U.S. Department of Homeland Security, 2013). In order for the observers to consider aspects relevant to the exercise in their assessments, it is important that the exercise objectives are clearly communicated to them. It is also useful to have previously created checklists according to which observations can be made (Bédé and Hofinger, 2016).

After the contents of the script have been worked through, the exercise is finished by the exercise leader and the disassembly begins. Each exercise should be followed by a debriefing in which a summary of the exercise and the satisfaction of the leader are communicated (Bédé and Hofinger, 2016; U.S. Department of Homeland Security, 2013). Also, any problems or successes that are noticed can be expressed in the form of a pre-evaluation (BSI, 2008). In addition, the participants should be given the opportunity of direct feedback and discussion of strengths and weaknesses in the debriefing or in the final discussions of the respective areas (also called “hot wash”) (U.S. Department of Homeland Security, 2013).

The evaluation, which already begins with the debriefing after the execution, is a central component of each exercise (Bédé and Hofinger, 2016). During the evaluation the exercise should be assessed with regard to the defined objectives and form the transition to the improvement planning (U.S. Department of Homeland Security, 2013). Osarek (2016) argues that the importance of evaluation lies in obtaining reliable statements about the actors’ competences and their ability to act. The author pleads for specific expectations of the evaluation and the observers to be addressed in advance of the exercise and for evaluation concepts with checklists to be drawn up for orientation. The observations made may differ between discussion-based and operations-based exercises. While in discussions attention is often paid to the correct integration of plans and procedures, in operational exercises the focus is also on the execution and on what basis decisions have been made (U.S. Department of Homeland Security, 2013). Other topics on which observers can give estimates include how authorities or other organizations were involved in decisions and executions, whether the organizational and command structures were adhered to, how and which information was shared and how overall communication took place (ibid.).

In addition to the information provided by the observers, the exercise protocols and the assessments of the participants (active players, steering group and exercise leader) are also used for the evaluation (BSI, 2008; Osarek, 2016). In order to be able to establish a certain systematic, question and feedback sheets as well as audio and video material are partially used (Osarek, 2016). The aim of this data analysis is not only to identify what happened but why it happened, i.e. to carry out a root-cause analysis (U.S. Department of Homeland Security, 2013). The evaluation ends with the preparation of a final report for the exercise which is subsequently presented to the responsible persons of the organization, the authority or the company (Bédé and Hofinger, 2016; BSI, 2008; Osarek, 2016).

3.4. LÜKEX – An Interministerial and Interstate Crisis Management Exercise

The "Interministerial and Interstate Crisis Management Exercise" (Länderübergreifende Krisenmanagement Exercise – LÜKEX) is a special exercise in Germany. It is the only exercise that pursues an overarching societal approach and targets the strategic level, i.e. the highest decision-makers from the federal government, the states and companies (especially operators of critical infrastructures) (Haritz, 2016). The national crisis management is practiced with a "worst-case scenario" across departments and states (BBK, 2019b). The aim is to involve the entire social security system in the preparation and conduct of the exercise. This also includes the police, the German armed forces and the intelligence services as well as the actors of civil protection and the operators of critical infrastructures. Another aim of the security system is the citizens' ability to help themselves (BBK, 2019b). With its approach, LÜKEX serves to review this precautionary system and works to improve cooperation between the various levels and actors (BBK, 2011b).

LÜKEX was created after the major damage situations at the beginning of the 2000s, in particular the Elbe flood, and the recognition of the need for improvement in coping with such interstate events (BBK, 2019b; Haritz, 2016). LÜKEX was anchored in law through the "Zivil- und Katastrophenhilfegesetz" (ZSKG) in 2009 (BBK, 2019b; § 14 *ZSKG*, 2009). The first LÜKEX was carried out in 2004 and has since been conducted every two to three years with changing scenarios. The last LÜKEX took place in November 2018 where the scenario was a gas shortage in southern Germany during an extreme winter. The next LÜKEX is planned for 2021 (BBK, 2019b; Haritz, 2016). Table 3.3 gives an overview of the eight LÜKEX exercises and the respective scenarios that have been carried out so far.

An essential aspect at LÜKEX besides the implementation is the networking in all phases of the exercise. Here, LÜKEX generates a platform that enables joint work and the exchange of information independent of scenarios and the configuration of organizations and actors (Haritz, 2016). The exercise cycle at LÜKEX is comparable with the phases of other forms of exercise. First, in the planning phase (approx. 6 - 8 months) the exercise topic and a rough scenario are defined (BBK, 2019b). Furthermore, in this phase the exercise objectives are specified and it is clarified which actors are involved in the exercise and how intensive their participation is. For example, at LÜKEX 18 twelve federal states participated in the exercise, but only the states of Bavaria and Baden-Württemberg practiced intensively (ibid.). General exercise goals can include, for example, reviewing overarching cooperation, improving information management or optimizing media and public relations work (BBK, 2011b). In the subsequent preparatory phase, the scenario is further elaborated and the script is prepared. In addition, weak points and possible optimizations relating to the scenario are analyzed (BBK, 2019b). The preparation phase, which takes approx. 9 - 12 months, is pivotal for the network formation and the intensive discussion of the scenario by the preparation team of the exercise participants. The scenario is developed in an iterative and discursive process. This results in partial scenarios for the various participants, which must be linked accordingly (BBK, 2011b). The preparation is followed by the execution (approx. 2 - 3 months) of the exercise and the subsequent evaluation (approx. 4 - 6 months) (BBK, 2019b). Different methods are used for the evaluation in order to enable a comprehensive verification. Observers and questionnaires are used and various evaluation sessions are carried out. At the end an internal and a public report will be produced (ibid). The overall management of LÜKEX is the responsibility of the Federal Ministry of the Interior. The individual phases from planning to evaluation are managed by a BBK project group (ibid.). Overall, LÜKEX is regarded as a success and has contributed to an improved coordination and decision-making culture (Glass, 2012; Haritz, 2016).

Table 3.3: Overview of previous LÜKEX scenarios according to BBK (2019b, p. 9)

LÜKEX 04	Extreme winter, power failure, terror
LÜKEX 05	Terrorism in connection with the 2006 World Cup
LÜKEX 07	Worldwide influenza pandemic
LÜKEX 09/10	Terrorist threat with chemical and radioactive agents
LÜKEX 11	Threat to IT security from massive cyber attacks
LÜKEX 13	Exceptional biological threats
LÜKEX 15	Storm surge on the North Sea coast
LÜKEX 18	Gas shortage in Southern Germany

3.5. The Exercise in Practice

As Ellebrecht et al. (2013) explain, various representatives of the authorities predict an age of practice and describe it as an essential element in the security apparatus. The exercise enables a reduction of complexity and creates security in dealing with uncertainties (ibid.). It is an established and important tool of preparedness and prevention within civil protection

(Ellebrecht et al., 2013; Glass, 2012). If one looks at current practice, however, it quickly becomes clear that there is no “one” exercise. Rather, it depends on the organization or authority which role exercises play in everyday life or which objectives and structures are in the foreground. In order to be able to sketch a more distinguished picture of this, interviews and discussions with several actors on the context of exercise planning were conducted in the present work, the results of which are presented below. In order to better classify the statements, the actors are briefly introduced (cf. section 1.3).

From the point of view of the professional fire brigade in Darmstadt exercises are described as an integral part of everyday life. Exercises and other forms of training have fixed times and are scheduled weekly (Interview 5, 2019, personal communication, 13 May). This statement is also confirmed by the team of the department for crisis management and research at the State Fire Service Institute North Rhine Westphalia taking the perspective of firefighting schools (Interview 3, 2019, personal communication, 18 March). In this interview is was further explained that exercises are the decisive tool in everyday life as well as training and that they are also part of the examinations at the end of training courses. In contrast, the department of fire and disaster control at the regional council of Kassel explained from the perspective of the “upper” disaster authorities and the administrative level that exercises can, depending on the people involved, play a subordinate role in everyday life (Interview 2, 2019, personal communication, 05 March). While LÜKEX as described above inherently is not a part of everyday life, there have also been noticeable improvements in regard to processes and communication among regular participants. The focus here continues to be on networking among the exercise controllers and the planning team, as the BBK’s LÜKEX project group emphasizes (Interview 1, 2019, personal communication, 26 February).

The lack of handouts for the planning of exercises is often viewed critically. Here, one can speak of a “weakness in the system” with which the individual organizations and authorities have to struggle (Interview 3, 2019, personal communication, 18 March). Some practitioners argue that this could be remedied by checklists and experienced exercise planners and controllers (Interview 5, 2019, personal communication, 13 May). Above all, however, it is important that each actor in the exercise has a task and feels needed to perceive the exercise as a positive experience. A proper allocation of exercise control with the aim of reflecting the crisis management staff is also an important criterion for the success of the exercise (Interview 2, 2019, personal communication, 05 March). For scenario-based exercises, it is particularly important during planning to ensure that the scenario is as realistic as possible and that the documents used for the scenario look real. This is important because the scenario is often used as a vehicle for motivation and increases the acceptance of the users as long as they can relate to it (Interview 3, 2019, personal communication, 18 March).

For most exercises, planning teams are often formed in the organizations that also carry out the exercise themselves. Alternatively the exercise is developed and carried out in the context of a seminar at the state fire brigade schools or the “Academy for Crisis Management, Emergency Planning and Civil Protection” (AKNZ). In addition, there are also some concepts based on joint planning by several actors. This is the case, for example, with the LÜKEX exercises (Interview 1, 2019, personal communication, 26 February) or in a structure that is being planned for the city of Darmstadt using a working group for exercises with experts from all organizations and various consultants (Interview 5, 2019, personal communication, 13 May).

Different methods and software are used for the different phases of the exercise. In the planning and preparation phase, for example, these are mainly classic office software applications since most of the exercise material is text and list based (Interview 3, 2019, personal communication, 18 March). In the context of the methodology, the question of the exercise type is the most important, as emphasized by the department for red cross work and civil protection at the Institute for Education and Communication of the Westphalia-Lippe regional association of the German Red Cross (Interview 4, 2019, personal communication, 18 March). Similar to the scenario development within the LÜKEX group workshops, there are some iterative workshops to develop the exercise framework and the scenario (Interview 2, 2019, personal communication, 05 March). In the implementation phase, the systems employed by the respective departments in everyday life are used and practiced accordingly. These are, for example, crisis management tools (Interview 5, 2019, personal communication, 13 May) or information systems and databases (Interview 3, 2019, personal communication, 18 March). Research is developing methods for the evaluation of exercises, but these have not yet found their way into practice (Interview 4, 2019, personal communication, 18 March).

The time required for planning, carrying out and evaluating the exercises is high overall and depends on many factors. As an example, crisis and administration staffs must take into account the fact that personnel are required for two shifts and that an additional reserve must be available. This has a major impact on the exercise sessions, as the number of people to be trained is high and additional organizational aspects such as shift changes should also occur in exercises (Interview 2, 2019, personal communication, 05 March). Another factor is that even a high degree of experience can only lead to a limited reduction in the planning and preparation phase, as a certain minimum load is always present. In most cases exercises are secondary to day to day tasks, which can lead to time problems for the people involved. In some cases, this means that the follow-up to the exercises is no longer carried out under the same pressure (Interview 3, 2019, personal communication, 18 March). This is accompanied by the problem that there is no “state of the art” for uniform criteria for preparation and follow-up (Interview 4, 2019, personal communication, 18 March).

Other challenges include difficulties regarding foresighted thinking in developing the scenario as well as defining the exercise boundaries (Interview 4, 2019, personal communication, 18 March), especially with regard to the spatial and temporal aspects. The scenario is intended to introduce the players to the situation and to challenge them, but not to overwhelm them (Interview 2, 2019, personal communication, 05 March). Further difficulties in the context of the scenario are the high effort required for data collection for the respective area and the involvement of the relevant specialist groups or experts (Interview 3, 2019, personal communication, 18 March). Due to the complexity, especially with larger exercises, it is often necessary to involve several consultants in the planning process in order to make them as realistic as possible (Interview 1, 2019, personal communication, 26 February). In addition, simulations are difficult to carry out and some assumptions have to be made (Interview 4, 2019, personal communication, 18 March). In order to avoid subsequent uncertainties or missing data, assumptions are made leading to exercise artificialities. However, it can be noted that the excessive use of such exercise artificialities is to be evaluated critically, since they can lead to a dilution of the exercise results. In general, the identification of topics including the definition of the objectives of the exercise as well as the selection of the actors involved must be reflected upon and sometimes smaller module exercises, which only consider individual aspects, are better suited than highly complex scenarios in which many assumptions have to be made (Interview 5, 2019, personal communication, 13 May).

A general challenge for exercises in cities and administrative districts is scheduling, especially for larger exercises where many volunteers are involved. Here it is important to ensure that the exercises have as little impact as possible on the everyday tasks of the participants (Interview 5, 2019, personal communication, 13 May). With the strategic exercises of LÜKEX, one problem lies in finding participants, especially from different areas. In addition, it can be challenging to harmonize the actors so that the output of the individual can be maximized. Since many people are involved in LÜKEX exercises, the flow of information between the players as well as within the steering group is always a challenge that should not be underestimated and must be well organized (Interview 1, 2019, personal communication, 26 February). Public relations work which is of great importance within LÜKEX often poses a difficulty for exercises on a smaller level. This is especially applicable to the administrative staff and its actual implementation due to the lack of resources. Still, it can be emphasizes that public relations and the role of social media should be regularly addressed in exercises. Finally, in many areas it is perceived as a challenge to present and analyze the actual communications that take place. These can vary considerably, especially in the case of free-running exercises, which are generally sought out (Interview 3, 2019, personal communication, 18 March).

An essential aspect of an exercise is its evaluation. What is interesting here, however, is that systematic evaluations are exceedingly rare, as Ellebrecht et al. (2013) also note with regard to simulation exercises (Interview 2, 2019, personal communication, 05 March). Practitioners describe the evaluation of the exercise as a “major construction site” which is often neglected and where standards would both be possible and useful (Interview 5, 2019, personal communication, 13 May). In general, evaluations of the exercise are obtained by assessments of the participants in the exercise. Normally, players and observers are recorded separately, sometimes using questionnaires (Interview 3, 2019, personal communication, 18 March). The evaluations are strongly oriented towards the defined exercise objectives and their focus lies primarily on internal processes and communication (Interview 2, 2019, personal communication, 05 March). However, an explicit evaluation of communication does not take place (Interview 3 and 4, 2019, personal communication, 18 March). A final report is drawn up at the end. An exceptional case here is the LÜKEX exercise. Here, the final report is intensively coordinated in advance between all parties involved and focusses on an assessment rather than a rating. It formulates recommendations for action for the various aspects considered (Interview 1, 2019, personal communication, 26 February).

Exercises in civil protection have great potential and form an important foundation of preparedness and prevention (Ellebrecht et al., 2013; O’Grady, 2016). They can be used to sensitize actors and improve processes, communications and actions (Osarek, 2016). The planning, implementation and evaluation of exercises, however, also involve a great deal of effort and expertise, for which there have been only few standards and minimal software support so far. This applies in particular to the planning and evaluation of exercises for which a number of supporting capabilities can be identified. Methods and software tools that support the development of scenarios and reduce uncertainties appear to be particularly helpful. They should also create opportunities for a systematic evaluation and thus support a better error culture, as Lamers (2016, p. 278) outlines with one of his theses on future staff work. In order to develop such a tool, this work examines social networks and their analysis procedures that have already established themselves in many areas. Therefore, the next chapter turns to the basics of social network analysis and looks in particular at the centrality of actors in the network.

4. Social Network Analysis

As can be seen from the observation of exercises, scenarios, or the various situations from which they are constructed, are composed of dynamic chains of various interactions between different actors. These interactions can represent dependencies or causal relationships, or they can represent action sequences or processes. Interactions can also be found manifold in exercise scenarios in the form of communication. In all cases the focus is on the interaction or relationship between the actors and not on the actors themselves. For example, it is not the "storm" that is decisive in an exercise scenario, but the effect or relationship it has on a dyke due to the rising water level. Similarly, especially in complex exercises, it is not so much the individual actors, but their cooperation and communication that are relevant to the management of a situation. By this characteristic, exercises can be described as interaction or relationship networks, which offers many possibilities for analysis and interpretation.

Networks are an integral part of today's world. They can be found in almost all areas of science and technology. Newman (2018), for example, distinguishes four scientific fields in which network theory and analysis play an important role. Among these he counts technology, information, social and biological networks. Technology networks include, for example, large infrastructure networks such as road or transport networks as well as energy supply and telecommunication grids. Information networks can be citations or peer-to-peer networks for instance. Social networks usually describe relationships between entities such as friendship or links between organizations. An example of biological networks on the other hand are the branched neurons in the human brain (ibid.). This multitude of areas and applications also explains why network research is a very interdisciplinary field (Marin and Wellman, 2011). For the analysis and interpretation of networks, social network analysis has established itself as the most important approach in many research areas. Despite its widespread use in science, the concepts and methods of social network analysis have not yet been applied in practice. In order to investigate the use of networks in the context of exercises in civil protection and disaster response, this chapter first outlines the theoretical basics. The focus is on social networks and their analysis. At the beginning, a look is taken at the fundamentals of social networks and their terminology. After that, the chapter presents relevant aspects of graph theory as the mathematical representation of networks. With this background, the concept of centrality as one of the central concepts in the analysis of social networks is further discussed. The chapter ends with a description and discussion of techniques for the visualization of networks.

4.1. Social Network Fundamentals

According to Wasserman and Faust (1994, p. 3), the focus of social network analysis is on "relationships among social entities and on the patterns and implications of these relationships". This focus is based on the assumption that social life originates from and is shaped by relationships and patterns arising from these relationships (Marin and Wellman, 2011). Furthermore, the representation of these relationships in networks creates possibilities for structural and behavioral analysis, as Tavassoli (2018) explains. The origins of social network analysis in its current form go back to Jacob Moreno and Helen Jennings (1934) (Borgatti et al., 2009; Freeman, 2004), who in their work 'Who shall survive?: A new approach to the problem of human interrelations' established a technique for the graphic representation of relationships between individuals with 'sociometry' (Borgatti et al., 2009; Moreno, 1934). Sociometry made it possible to visualize abstract social structures and make them tangible (Borgatti et al., 2009). According to Wasserman and Faust, some conditions apply to the definition of social networks. For example, actors are not regarded as independent of each other and in the analysis of individual actors, the network structure is interpreted as creating opportunities or obstacles for the individual to act (Wasserman and Faust, 1994).

In network analysis, the entities whose relationship structures form the respective network are often referred to as *nodes* or *actors*. They can have different characteristics or attributes to make them distinguishable from each other (Borgatti et al., 2018). A node in a network can in principle be almost anything, including both actors capable of action and objects incapable of action (Albrecht, 2010; Borgatti et al., 2018). Furthermore, a node is not limited to a single acting entity or an individual but can also symbolize a group of actors such as an organization, a company or a country (Haas and Malang, 2010). A central problem in network analysis is the definition of the class of actors which is dependent on the relations to be investigated (Butts, 2009). Since a change in the node set can have a significant impact on the network and its implications for the analysis, it should be defined in a way that it includes all relevant entities. Relevant entities are all those that are able to form at least one of the investigated relationships (ibid.).

Relations, also referred to as *ties*, between the nodes of a network are the primary focus in network analysis whereas the attributes that a node associates with itself are subordinate to them (Wasserman and Faust, 1994). The relations can be of very different types. Borgatti et al. (2018) distinguish between two groups of relations, the relational states and the relational events. Relational states represent relationship types which are continuous, i.e. constant for their period of existence. These include similarities, relational roles and relational cognition. The three groups can be further specified. For example, Borgatti et al. (2018) list location for the group of similarities or the kinship as a relational role. An example for relational cognition is perception, which can be used to map relationships such as 'who knows whom'. Unlike relational states, relational events represent relationships that have a defined end. Here interactions like 'who talks to whom' or flows such as streams of information or resources can be categorized (ibid.).

In the social network analysis, not only the relations between node pairs are considered, but in particular the patterns of relations in different areas and the overall network (Marin and Wellman, 2011). This also reveals a great strength of the network approach, namely the effect of indirect connections (relations between actors that exist exclusively via other actors) (Borgatti et al., 2018). Network analysis also assumes that similarities between actors do not arise on the basis of their attributes and characteristics, but rather on the basis of their social structure and position in the network. The concept of positions or centrality is one of the most important concepts in social network analysis, as it provides an insight into the perceptions and possibilities of action by the actors (see also section 4.3) (Marin and Wellman, 2011; Stegbauer, 2010).

In conclusion, a social network can be described as a finite set of nodes that are connected by one or more types of relations and whose structures and patterns can provide indications of the actors' possibilities for action (Marin and Wellman, 2011; Wasserman and Faust, 1994). The description of a phenomenon in a network is characterized by assumptions about the relevant actors, the inherent relationships and interactions as well as the time period in which these take place (Butts, 2009). As Marin and Wellman (2011) put it, in social network analysis one cannot speak of a theory or a methodology, but rather of perspectives. Accordingly, the analysis of social networks does not show predictions about expected events, but instead creates opportunities to look at a problem and understand it.

4.2. Graph Theory – The Mathematical Representation of Networks

With the help of graph theory, social networks can be formalized. It forms the mathematical basis on which many tools for the analysis and representation of networks are based on. The following section describes the basic theorems for social networks from graph theory that are relevant in the next chapters. Here the standard works of Wasserman and Faust (1994), Steen (2010) and Newman (2018) are used as a basis. Most of the formulas and definitions presented in this section derive from these works on complex and social networks from the fields of mathematics, physics and sociology.

In its simplest definition, a network or graph G consists of a set of nodes or vertices V and a set of edges E, so that $G = (V, E)$ applies. For each edge e it also applies that it connects two nodes v_1, v_2 with each other and thus defines an unordered pair $e = \langle v_1, v_2 \rangle$. The number of nodes is declared with n, so the set of nodes can be described with $V(G) = \{v_1, v_2, \dots, v_n\}$. Equivalent to this is the number of edges is denoted by m and the set of edges equals $E(G) = \{e_1, e_2, \dots, e_m\}$. This form of graph is also called *undirected graph*. *Directed graphs* on the other hand are those with edges pointing from an origin to a target node. Edges in directed graphs are called *directed edges* or *arcs* and are formalized by ordered pairs $\langle \overrightarrow{v_1, v_2} \rangle$. In addition to a direction, edges in graphs can also have a weight. This is especially relevant if an edge or relation is not only dichotomous, i.e. exists or does not exist, but has a value or a strength. Weights in graphs correspond to real-valued numbers which can be both positive and negative (Newman, 2018, p. 109). A graph that has edges with weights is thus aptly called a *weighted graph*. Furthermore, if two nodes in a graph or network are connected by one edge at most and the structure contains no *self-edges*, i.e. edges which connect a node to itself, it constitute a *simple graph* or *simple network*. Otherwise, if a graph has multiple edges between two nodes (*multiedges*) or self-edges, it is called a *multigraph*. Figure 4.1 shows the different types of graphs that have been introduced. For all four types of graphs, the nodes and layout are identical and only the edges are different. Figure 4.1 (a) shows a simple undirected graph while Figure 4.1 (b) is directed. Figure 4.1 (c) corresponds to the first graph with the distinction that the edges have different weights, which is illustrated by the thickness of the edges. For example, edge $\langle v_D, v_E \rangle$ has a weight of 1 while $\langle v_B, v_D \rangle$ has a weight of 5. Finally, Figure 4.1 (d) provides an example of a directed multigraph.

Networks and graphs can also be represented mathematically in matrices. The *adjacency matrix* A of a simple undirected graph is a symmetric $n \times n$ matrix with elements a_{ij} so that:

$$a_{ij} = \begin{cases} 1 & \textit{if there is an edge between nodes i and j,} \\ 0 & \textit{otherwise.} \end{cases} \tag{4.1}$$

The adjacency matrix can also be used to formalize directed graphs. In this case, however, the matrix is not necessarily symmetrical. While they can still be mapped by a single matrix, formula 4.1 cannot be applied to define the matrix elements for simple weighted graphs or multigraphs. In the case of simple weighted graphs, the edge weight is used as matrix element whereas for multigraphs, the matrix element represents the number of edges. Accordingly, it is not possible to map weighted multigraphs using a single adjacency matrix. The matrices can be used to calculate various network properties such as density or node degree, which are discussed below.

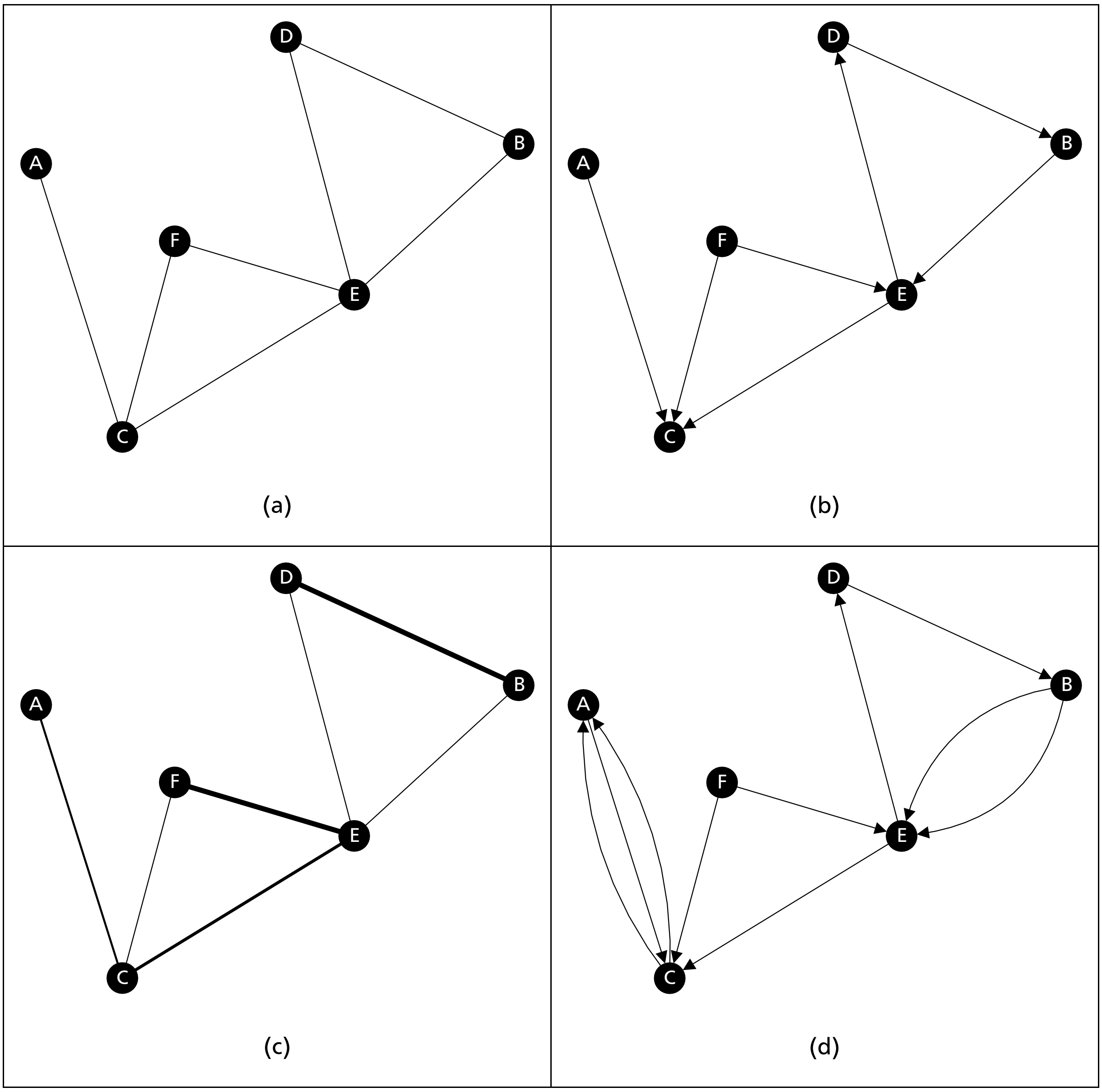


Figure 4.1: Four graphs with different edges. (a) A simple undirected graph, (b) a simple directed graph, (c) a simple weighted graph represented by edge thickness and (d) a directed multigraph

An important network property is the *degree* d of a node, i.e. the number of edges connected to it. This can be determined via the adjacency matrix. For an undirected graph, the degree of a node v is:

$$deg(v) = \sum_{j=1}^{n} a_{ij} \tag{4.2}$$

Since each edge has two ends, the sum of the degrees of all nodes in an undirected graph is $2m$. This allows the mean degree of the graph to be calculated by:

$$\overline{deg} = \frac{2m}{n} \tag{4.3}$$

With directed graphs the degree can be distinguished between incoming and outgoing edges. The *indegree* deg_{in} corresponds to the number of all incoming edges, while the *outdegree* deg_{out} measures the number of all outgoing edges of a node:

$$deg_{in}(v) = \sum_{j=1}^{n} a_{ij} \text{ and } deg_{out}(v) = \sum_{i=1}^{n} a_{ij} \tag{4.4}$$

Here, each edge is counted exactly once in the calculation of the indegree and once in that of the outdegree. Therefore, the average indegree or outdegree of a graph is:

$$\overline{deg}_{in} = \overline{deg}_{out} = \frac{m}{n} \tag{4.5}$$

Another network property is the *density* ρ of a graph. For simple graphs the density describes the ratio of the actually present edges to the maximum possible ones. In other words, the density of a graph is equivalent to the probability that two randomly selected nodes are connected by an edge (Newman, 2018, p. 128). The value of the density is in the range of $0 < \rho < 1$. For simple undirected graphs the density is calculated as:

$$\rho(G) = \frac{2m}{n(n-1)} \tag{4.6}$$

In case of a simple directed graph twice as many edges are possible, accordingly the density is given by:

$$\rho(G) = \frac{m}{n(n-1)} \tag{4.7}$$

In networks, not only the direct connections between two neighboring nodes are interesting for the structural understanding, but also the indirect connections of two nodes, i.e. those that run through other nodes (Borgatti et al., 2018). For the analysis of such connections, distance measures are used in graphs. A distinction is made between *walk*, *trail* and *path*. A *(directed) walk* $W(v_0, v_k)$ in graph G denotes an alternating sequence $[v_0, e_1, v_1, e_2, \dots, v_{k-1}, e_k, v_k]$ of nodes and edges with $e_i = \langle v_{i-1}, v_i \rangle$, or $e_i = \langle \overrightarrow{v_{i-1}, v_i} \rangle$ in case of a directed graph. It thus describes a route through the graph from a start to a target node. A walk is called a *closed walk* if $v_0 = v_k$. During a walk, nodes and edges may be visited several times. If one restricts this condition to the effect that each edge in a sequence must be distinct, it is called a *trail*. In addition, if each node may only be passed once, it then constitutes a *path* in G. The *length* of a walk, trail or path is defined as the number of edges present in the respective sequence. A path that is particularly relevant for many analyses of networks is the *shortest path* or *geodesic path*. It describes the path with the minimum length, i.e. the smallest number of edges, between two nodes. The length of the shortest path is also called *geodesic distance*. If no such path exists between two nodes in a graph, the distance is given as ∞. From all shortest paths of a graph its *diameter* can be determined. It is equal to the distance of the longest existing shortest path between two nodes in the graph.

A concept of graphs related to the paths is that of *connectivity*. Thus, two nodes in a graph are called *connected* if at least one path exists between them. If two nodes are not connected, they are located in different *components* of the graph. A component is thus defined as a subset of nodes or for which at least one path exists for each node pair within the subset. If a graph consists of only one component, it is called *connected*. Otherwise it is considered *disconnected*. With directed graphs there is a further distinction: Such a graph is called *strongly connected* if there is a *direct path* between each of its node pairs. If this is not the case, it can be called *weakly connected* if the undirected version of the graph is connected.

Multilayer and Dynamic Networks

With increasingly complex or dynamic systems, simple graphs reach their limits. Although multigraphs can be used to define several relationships between two nodes, the relationships are not easily distinguished from one another. *Multilayer* or *multidimensional networks* can be used to map systems composed of different nodes and edges. Newman (2018) describes them as “[...] a set of individual networks, each representing nodes of one particular type and their connections, plus interlinking edges between networks.” He uses the example of a transport network. This is composed, for example, of the railway and bus networks, which each have certain stops (nodes) and are connected by edges. Additionally, there are some stops where one can transition from one network to the other on foot.

A special form of multilayer networks are the so-called *multiplex networks* that are very common in social networks. Multiplex networks can be defined as networks consisting of a sequence of graphs which are also called layers L. Each layer $l^{[\alpha]}$ (where $\alpha \in \{1, \dots, M\}$) in turn consists of a set of nodes $V^{[\alpha]}$ and edges $E^{[\alpha]}$. For multiplex networks, the node sets are normally the same in all layers or at least a subset of nodes overlap. In addition, the edge set in each layer represents a different type of relation or interaction respectively (Kivelä et al., 2014; Tavassoli, 2018). The theoretically possible interlayer edges, which in multiplex networks can only be defined between two identical nodes in different layers, are often ignored in practice (Newman, 2018). Network properties such as the degree of a node are described as vectors analogous to the description of multiplex networks. So the degree of a node v in a multiplex network is given with $deg(v) = (deg(v)^{[1]}, \dots, deg(v)^{[M]})$, where $deg(v)^{[\alpha]}$ is the degree in layer α (Boccaletti et al., 2014). If the nodes are identical in all layers, multiplex networks can be transformed into *monoplex networks* for simplification. One way to do this is by using so-called *projected networks*. With these a connection between two nodes is indicated in the resulting monoplex graph if it existed in at least one of the layers of the multiplex system. The elements $\overline{a_{ij}}$ of the corresponding adjacency matrix $\bar{A}$ are defined by (Boccaletti et al., 2014):

$$\overline{a_{ij}} = \begin{cases} 1 & if\ a_{ij}^{\alpha} = 1\ for\ some\ 1 \leq \alpha \leq M, \\ 0 & otherwise. \end{cases} \tag{4.8}$$

Another customary way to simplify multiplex to monoplex networks is through aggregation (Kivelä et al., 2014). Unlike the previously defined projected networks, the edges are weighted in the aggregation if they are present in multiple layers. Battiston et al. (2014) call these aggregated or weighted edges the *edge overlap*. The elements o_{ij} of the corresponding overlap matrix O are given by:

$$o_{ij} = \sum_{\alpha=1}^{M} a_{ij}^{[\alpha]} \tag{4.9}$$

The temporal network is a special multilayer or multiplex network where aggregation is often used. Temporal networks are dynamic networks whose structures change over time (Holme and Saramäki, 2012; Newman, 2018). Here, too, social networks are typical examples, for instance when different interactions take place over time in a communication network or when different structures develop in a friendship network. In a temporal network, the layers of the network typically represent a single point in time with its actors and interactions (Holme and Saramäki, 2012). Through aggregation, static graphs for time periods can be generated, which can be more easily examined for their structure. However, when simplifying multiplex networks, it must be considered that useful information may be lost or wrong conclusions may be drawn. For example, Holme and Saramäki (2012) describe the problem that an edge $\langle v_1, v_2 \rangle$ could be defined in a temporal network at a certain point in time t_1, while there is no such edge in time t_2. Instead in time t_2, there could be an edge $\langle v_2, v_3 \rangle$. If one aggregates the two times to a static graph, one can falsely assume that there is a direct path between v_1 and v_3 via v_2, which does not exist in the underlying multiplex network. Battiston et al. (2014) also explain that information about the individual layers and the origin of an edge can be lost during projection or aggregation. To counteract this, they propose various metrics for analyzing the roles of individual layers, which reduce the loss of information. In addition to the forms of representation of multilayer networks described above, other forms of representation are discussed in the literature. Especially the representation of networks as higher-order tensors has to be mentioned (Boccaletti et al., 2014; De Domenico et al., 2013). Under the assumption of non-interconnected multiplex networks, multigraphs can also be used in combination with visualization techniques such as edge-coloring. Here, a specific color is assigned to a layer and each edge of the layer is represented in this color (Kivelä et al., 2014).

4.3. Centrality in Networks

The centrality concept is one of the most common concepts in social network analysis (Borgatti, 2005). Centrality is seen as an important structural feature of social networks and is relevant for the organization of groups (Freeman, 1978). In principle, the analysis of centrality raises the question of the relevance or importance of the nodes in a network. The aim is to identify central nodes and actors, since specific abilities such as control, influence or power are assigned to them based on their relationships in the network (Borgatti et al., 2018; Iacobucci et al., 2017). For example, nodes may have special relevance for a network if their loss results in the network no longer being connected (Borgatti et al., 2018). As Borgatti et al. (2018) point out, it is important to note that these attributions are not definitions but hypotheses about the possible consequences for the nodes (or the groups in which they are involved) according to their centrality. Mutschke (2010) summarizes three properties in the description of centrality: On the one hand, centrality is a node-related measure that does not make any direct statements about the considered network as such but only enables the localization of central actors. On the other hand, centrality describes the degree of involvement of the actors in the network and is only dependent on the network's structure. Finally, with the help of centrality, a linear order across the nodes can be achieved. With regard to exercises in civil protection, the concept of centrality offers possibilities to draw conclusions about the respective actors involved on the basis of existing relationship structures. For example, in an exercise it is possible to identify particularly well networked actors in the evaluation or potentially critical nodes in the planning.

The literature contains a multitude of different centrality measures, each representing a different interpretation. As such these measure are based on a specific basic intention regarding the structural properties of the interaction processes in the network (Freeman, 1978). Borgatti (2005, p. 56) formulates this with "[...] the formulas for these different measures make implicit assumptions about the manner in which things flow in a network". In his work 'Centrality and network flow' Borgatti (2005) further introduces a topology of different network flows and explains that the different centrality measures are not automatically meaningful for all kinds of flow and that this should be considered accordingly when choosing the analysis methodology.

On the question of choosing the 'right' centrality measure, Iacobucci et al. (2017) explain that the different methods are rather robust and that the centrality measures often correlate to a certain degree. In network research it is generally accepted that the different centrality measures are not mutually exclusive but complement each other (Mutschke, 2010). According to Mutschke (2010) and Landherr et al. (2010), centrality should be seen as a multidimensional concept that requires a variety of measures to get a clear picture of the actors in the network. In the following, some of the most common centrality measures are presented and the respective basic intentions are explained. To illustrate this, the example network in Figure 4.2 is examined for its central actors with the respective measures. The centrality is illustrated graphically by the size of the nodes. The larger the node's size, the more central the actor is.

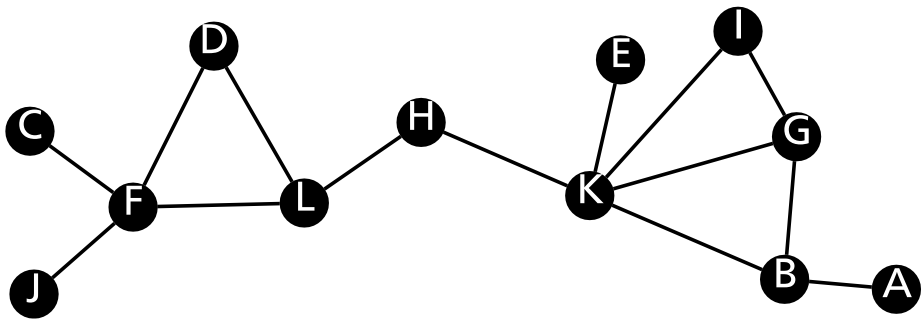


Figure 4.2: Simple undirected network without any centrality measure applied to it

Degree centrality

The simplest and most frequently used centrality measure for undirected networks is the degree, also called degree centrality, i.e. the number of direct connections of a node as defined in the last section (Borgatti et al., 2018; Iacobucci et al., 2017).

$$C_D(v) = deg(v) \tag{4.10}$$

The degree centrality can be normalized through the division by $n-1$ and thus made independent of the respective network (Wasserman and Faust, 1994). Borgatti (2005, p. 62) describes degree centrality as "[...] a measure of immediate influence - the ability to infect others directly or in one time period". In a friendship network, for example, it can be assumed that people who have many friends also have access to a lot of information and have correspondingly greater influence (Newman, 2018). Such persons can also be described as channels for information (Freeman, 1978, p. 219). Typical questions that can be answered with degree centrality are, for instance, questions about the most influential or least influential nodes. But also the question of nodes that can quickly retrieve resources can be investigated when applying the concept of degree centrality (Cambridge Intelligence, 2019a). Borgatti (2005, p. 62) explains that degree centrality is particularly suitable for walk-based transfer processes. Figure 4.3 shows the result of the degree centrality calculation for the sample network. It is clearly visible that actor K occupies the most central position in the network, having five direct connections to other nodes. Actors A, C, E and J have the least influence in the network, since they are only bound to the rest of the network via one connection.

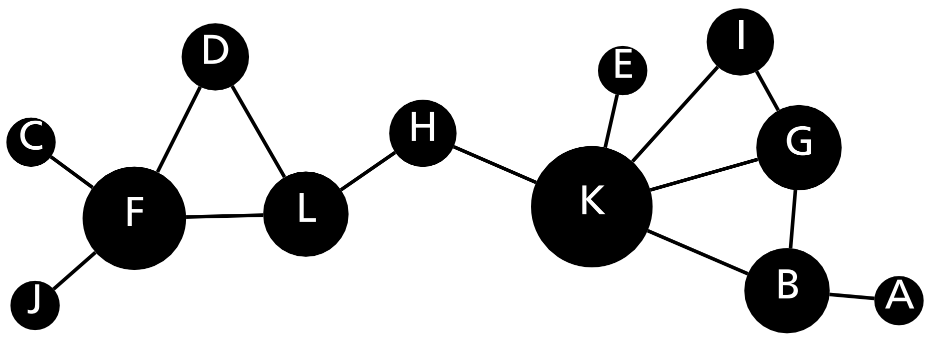


Figure 4.3: Sample network with node size corresponding to the degree centrality

Degree centrality can also be calculated for directed networks. A distinction is made here between indegree and outdegree centrality. Depending on the type of relation the two can be interpreted differently, whereby outdegree can always be seen as the initiation capacity of network flow while indegree rather describes a receiving capacity. Degree centrality can furthermore be easily extended for weighted networks. In this case not the number of edges is relevant, but their total weight. Under the assumption of multilayer networks without interlayer edges, as they are understood in the further course of this work, the degree centrality can also be extended to multilayer networks. As described by Tavassoli (2018), the calculation is performed for each layer individually.

$$C_D^{[\alpha]}(v) = deg^{[\alpha]}(v) \tag{4.11}$$

Closeness centrality

Closeness centrality is another measure of centrality. It is described as the inverse of the sum of the geodesic distances from the investigated node to all others in the network. The geodesic distance between two nodes is marked with $d(u, v)$. The closeness centrality in simple undirected networks is thus (Freeman, 1978; Iacobucci et al., 2017):

$$C_C(v) = \frac{1}{\sum_{u(\neq v)} d(v, u)} \tag{4.12}$$

Peripheral nodes receive a large value for closeness centrality, while very central nodes are given a small one (Borgatti et al., 2018). Like degree centrality, closeness centrality can be normalized dividing it by $n - 1$ (Wasserman and Faust, 1994). Looking at closeness centrality in terms of network flow, it is assumed that, for example, information flowing through a network quickly reaches central actors (Borgatti et al., 2018). Information from central actors also has a high fidelity, since it is to be expected that misunderstandings become more frequent each time information is passed on (ibid.). It is important, however, that the flow is always assumed to run along the shortest path (Borgatti, 2005). Closeness is usually most informative when the relationships in the network are not very dense, otherwise many nodes might have a similar closeness value (Cambridge Intelligence, 2019a). In general, it can be used to answer questions about the efficiency of actors in obtaining or disseminating information in the network (Cambridge Intelligence, 2019a; Freeman, 1978). Figure 4.4 illustrates closeness centrality using the example network from Figure 4.2. It can be seen that node K appears as the most central node in the network. Node H, which previously played only a marginal role in degree centrality, is also located much more centrally. In contrast, nodes A, C and J, which are located at the periphery of the network, have a very low closeness centrality.

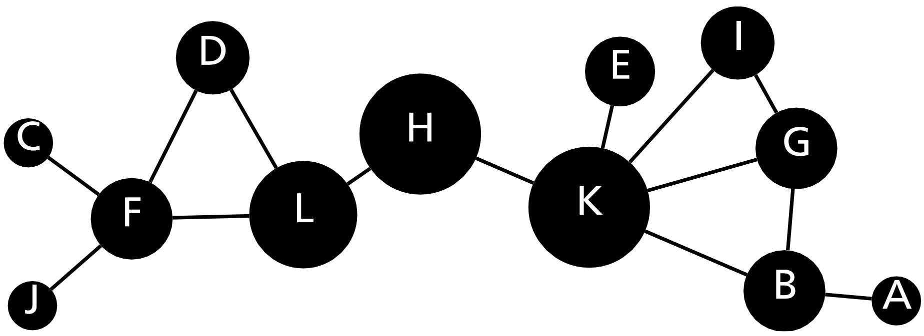


Figure 4.4: Sample network with node size corresponding to the closeness centrality

Closeness is only defined for connected networks and cannot easily be applied to directed networks (Borgatti et al., 2018). A use with weighted networks is generally possible, but in this case the optimal path between two nodes has to be defined exactly (ibid.). Similar to degree centrality, closeness centrality can also be extended for multilayer networks. The calculation is performed individually for each layer and paths are only possible within the same layer (Tavassoli, 2018).

$$C_c^{[\alpha]}(v) = \frac{1}{\sum_{u(\neq v)} d^{[\alpha]}(v, u)} \tag{4.13}$$

Betweenness centrality

Another measure is the betweenness centrality. According to Freeman (1977), betweenness describes how often an actor is on the shortest path between two other nodes in the network. With $\delta_v(s,t)$ as the number of shortest paths passing node v and $\delta(s,t)$ as the number of all shortest paths between nodes s and t with $s,t \neq v$, the betweenness centrality for simple undirected networks can be calculated as follows (Tavassoli, 2018):

$$C_B(v) = \sum\nolimits_{s,t \in V} \frac{\delta_v(s,t)}{\delta(s,t)} \tag{4.14}$$

The betweenness can be normalized by dividing it by $\frac{n^2-3n+2}{2}$ (Freeman, 1977). Unlike closeness centrality, betweenness centrality can also be calculated for disconnected networks because the number of paths between two nodes is relevant and not the path itself (Wasserman and Faust, 1994). Betweenness describes a dependency of two nodes on a third one, so that nodes with a high betweenness centrality are often referred to as brokers (Mutschke, 2010; Newman, 2018). Freeman (1977) explains that such brokers can promote, block or even change information and thus potentially cause a disruption of network flow. This ability is reduced if the broker node is not on all shortest paths of a node pair. Questions that can be investigated using betweenness centrality include those that ask for the nodes with the greatest control over information flow, or those that investigate where the network flow could fail (Cambridge Intelligence, 2019a). If the betweenness centrality is calculated for the example network from Figure 4.2 as shown in Figure 4.5, a line structure of central nodes can be seen, which is most evident in the nodes K, H and L. Any information flowing from the left to the right side of the network or the other way around must pass through these three nodes, which causes their central position.

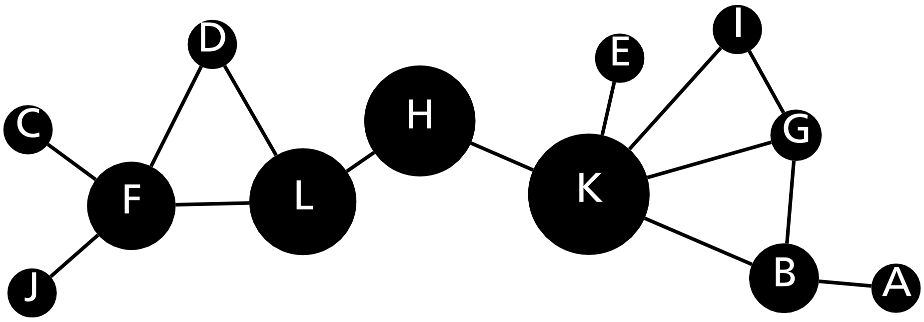


Figure 4.5: Sample network with node size corresponding to the betweenness centrality

Brandes (2008) has proposed some variants to make the betweenness centrality generalizable for directed and weighted networks. Similar to the degree and closeness centrality, the betweenness centrality can also be extended for multilayer networks as shown by Tavassoli (2018), if no interlayer connections are considered.

Eigenvector centrality and PageRank

The eigenvector centrality is an extension of the degree centrality which measures the influence of a node not only by the direct connections but also by the centrality of the connected nodes (Newman, 2018). Bonacich and Lloyd (2001) argue that the attribution of an actor as being powerful has more weight if it comes from someone who itself is perceived as powerful. The eigenvector centrality for simple undirected networks is calculated accordingly (Bonacich and Lloyd, 2001; Newman, 2018):

$$C_E(v_i) = \frac{1}{\lambda}\sum_{j \in V} a_{ji} * C_E(v_j) \tag{4.15}$$

Here, λ is the maximum eigenvalue of the adjencency matrix A (Bonacich and Lloyd, 2001; Borgatti et al., 2018; Newman, 2018). According to Mutschke, the eigenvector centrality assumes that the centrality of a node cannot be considered by itself but results from the interconnectedness in the network, which in turn affects the centrality of other nodes. Eigenvector centrality is especially suitable for influence processes (Borgatti, 2005). A node can exert a lot of influence even if it is only connected to one node, if this node itself has influence on many other nodes. The eigenvector centrality can, for example, answer questions about nodes with a far-reaching influence on the network (Cambridge Intelligence, 2019a). Figure 4.6 illustrates the calculation of the eigenvector centrality for the example network. Here, a phenomenon can be seen that occurs with eigenvector centrality when the network structure, as in the present case, resembles a 'bow-tie'. As Borgatti et al. (2018, p. 195) point out the centrality for all the nodes in the smaller subgroup (left of node H) will uniformly be lower than for the nodes in the larger subgroup (right of node H). This is an aspect that should be considered when interpreting the results. Another issue with eigenvector centrality in the case of disconnected networks is that for all nodes in the smaller components the centrality values are zero (ibid.).

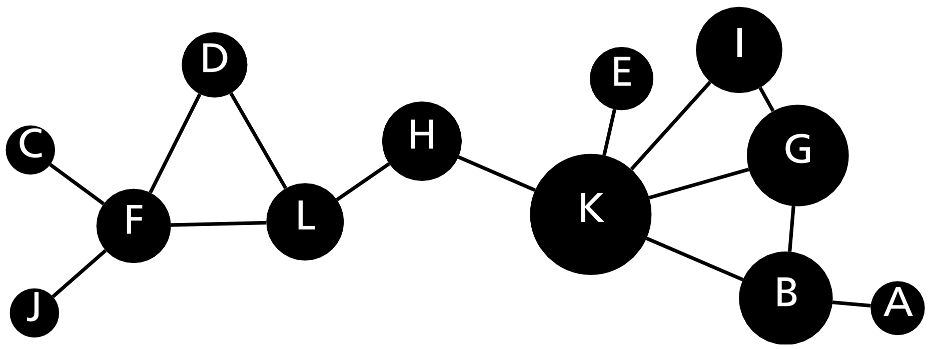


Figure 4.6: Sample network with node size corresponding to the eigenvector centrality

When generalizing from eigenvector centrality to directed networks, various difficulties arise. However, there are some variants of eigenvector centrality that address these problems (Borgatti et al., 2018; Newman, 2018). One of these variants is the PageRank centrality or PageRank (Page et al., 1999). It determines the influence of a node based on the indegree and can be calculated as shown in (Newman, 2018):

$$C_P(v_i) = \alpha \sum_{j \in V} a_{ij} \frac{C_P(v_j)}{\max(deg_{out}(v_j), 1)} + \beta \tag{4.16}$$

As Newman (2018) explains, the centrality derived on nodes v_i from its neighbors is proportional to their centrality divided by their outdegree. If the corresponding node has no out-going edges the centrality value is one. α and β are positive constants, where β is used to give nodes a minimal centrality even without indegree (ibid.). PageRank was developed to enable a ranking of websites and is part of Google's ranking algorithm (Newman, 2018; Page et al., 1999). Figure 4.7 illustrates the calculation of the PageRank for the example network. In this case, the results overlap with those of degree centrality. Both eigenvector centrality and PageRank can be used for weighted networks (Borgatti et al., 2018). Their application for multilayer networks is also possible if going layer by layer similar to the centrality measures already discussed.

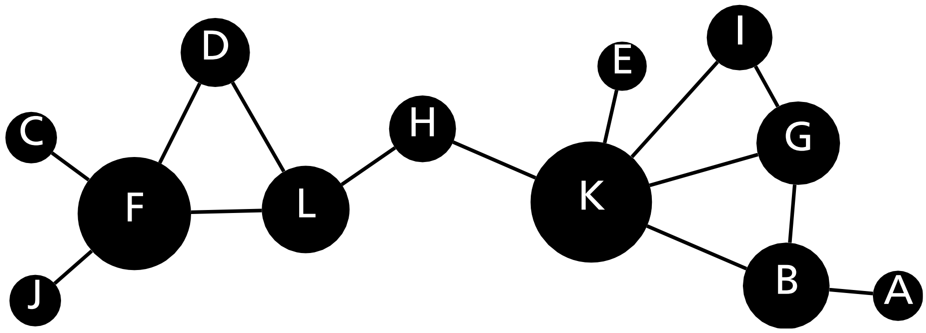


Figure 4.7: Sample network with node size corresponding to the PageRank centrality

4.4. Network Visualization

The visual representation is a central element in the analysis of graphs and networks. Graphical representations of network information can have an explanatory or understanding-enhancing effect (Stegbauer and Häußling, 2010). Borgatti et al. (2018, p. 115) describe the explanation capacity of network representations as being able to communicate a qualitative understanding which is difficult to determine quantitatively. Compared to, for example, a tabular representation of the information in a given network, the graph representation is an intuitive form of visualization that can be quickly grasped by the human mind (Cambridge Intelligence, 2019a; Devaux, 2019a). Since each network can be represented in a variety of ways and thus allows certain aspects to be highlighted and others to be pushed into the background, networks can be very flexible and insightful (Cambridge Intelligence, 2019a; Stegbauer and Häußling, 2010).

The flexibility of the network representation is provided in particular by two aspects, namely the visual properties of nodes and edges and the layout of the network. By using visual properties, it is possible to display attributes and structural features of nodes and edges. For nodes, the graphical elements include the size, color or shape of the node (Krempel, 2010). For example, as seen in the previous section for ease of illustration, the size of a node may depend on its centrality (see Figure 4.7). Also, different properties or the type of a node can be represented by its color or shape (Borgatti et al., 2018; Freeman, 1999; Krempel, 2010). Figure 4.8 illustrates this using the example network established in section 4.3. Two colors and two shapes are used to represent different categories of information and to increase the understanding of the network. The network could, for instance, represent the working relationships within a company. While the shape of the node represents the associated department, the blue color of individual nodes indicates that these actors are management personnel. As a result, the network is directly able to gain more far-reaching insights than what would have been possible without the color and shape coding. For example, it is easy to see that communication between the departments only takes place at the management level. With regard to degree centrality (see Figure 4.3) it can also be seen that with actor K in one department, the management level occupies the most central position, while in the other department this role is assigned to a normal employee with actor F. Visual properties of edges can be the thickness of the line or the line style (solid, dashed, dotted etc.) as well as its color. For example, the thickness of the line can be used to illustrate the relative weight of an edge. Especially with multilayer networks the type of relation can be described with the help of the color and the line style (Borgatti et al., 2018; Krempel, 2010).

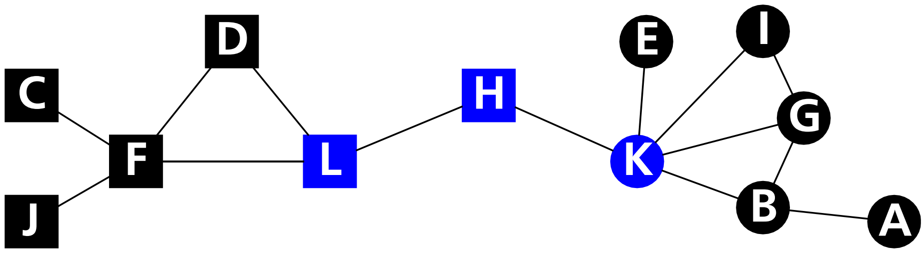


Figure 4.8: Sample network with multiple node styles

The layout describes the arrangement of the nodes in the diagram and thus their spatial configuration (Krempel, 2010). Borgatti et al. (2018, p. 116) describe it as “the most important aspect of network visualization”. It can help the viewer to understand the underlying network information or, in case of a bad layout, obscure it and lead to wrong interpretations of the situation (Borgatti et al., 2018; Huang et al., 2007). There are different approaches to creating layouts. Most common are layout algorithms. These can be characterized either by a heuristic or an optimization function (Borgatti et al., 2018). An example for layout algorithms with heuristics is the circular layout which arranges all nodes on a circular path (Huang et al., 2007). Figure 4.9 illustrates the example network from Figure 4.8 using a circular layout. The nodes can also be ranked according to one or more attributes, such as the degree. Radial layouts or centrality maps are based on a similar principle. These place the nodes on several concentric circles on the basis of various network metrics such as the centrality of the node, whereby its distance to the center, for example, corresponds to its relative centrality (Brandes et al., 2006; Huang et al., 2007; Krempel, 2010).

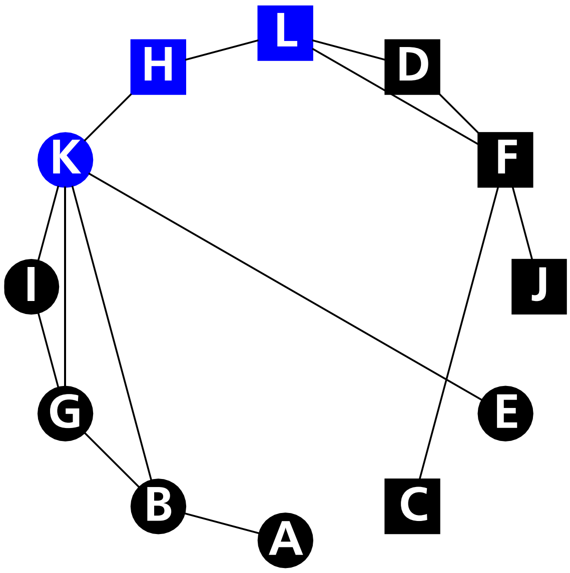


Figure 4.9: Sample network with a circular layout

Layout algorithms that place nodes on the basis of an optimization function often focus on the clarity of the network and an optimal node distribution (Fruchterman and Reingold, 1991). For example, the frequently used algorithm of Fruchterman and Reingold (1991) defines that the edge length between all nodes must be the same and that nodes that are directly connected should be placed close to each other. Furthermore, nodes should not be placed too close to each other so that they can be clearly differentiated. The algorithm belongs to the so-called force-directed algorithms, where the arrangement of the network is based on attracting and repulsive forces (Krempel, 2010). Another approach for generating layouts is the attribute-based scatter plotting (Borgatti et al., 2018). Here, the nodes are placed along axes in the diagram using continuous attributes. For example, a trading network of different countries could be represented by coordinates, with latitude and longitude representing the respective axes (ibid.). Overall the effect of layouts is more pronounced with graph novices than with experts and should always be selected depending on the user and the analysis objective (Huang et al., 2007).

Beside the described visual properties of nodes and edges as well as the network layouts there are further possibilities to support the visualization of networks. In large networks, for example, node filtering can be used to remove nodes from the network that are not relevant for analysis, thus making the network more manageable (Borgatti et al., 2018; Krempel, 2010). Overall, social network analysis offers a good opportunity to graphically represent and analytically investigate social relationships. How the methodology is used in the context of civil protection and disaster response and which possibilities arise in regard to supporting the planning and evaluation of exercises will be shown in the next chapter. In particular, the requirements for software tools that are important in this context will be discussed.

5. Social Network Analysis in Civil Protection and Disaster Response

With the help of social network analysis the structures of networked systems can be examined in a variety of ways based on their relationships. This methodology has established itself across disciplines in many areas and is used for a wide variety of problems. This chapter examines the extent to which the use of social network analysis is also appropriate in the context of exercises in civil protection and disaster response. For this purpose, approaches and studies from the related work that use network analyses as their methodology are evaluated. The areas covered include organizational research, research on disaster response and emergency management as well as risk analyses and cascades in infrastructure research. The related work is analyzed with regard to the application of social network analysis as a methodology for the planning and evaluation of exercises in civil protection and disaster response and an interim conclusion is drawn. Building on this, requirements for a possible software support system are formulated in the further course of the chapter. For this, existing software solutions as well as literature and requirements communicated in interviews with practitioners are considered.

5.1. Social Network Analysis in Organizational Research and Emergency Management

Social network analysis is a widely used method in organizational research to conceptualize, as Tichy et al. (1979) state, organizations in static and dynamic aspects. Cross et al. (2002) describe social network analysis in their work as elementarily important in the analysis of informal networks. They describe the method as particularly effective for collaboration within groups and their integration after restructuring measures. It is argued that in informal networks cooperation with central actors in the network is particularly effective for the management since the actors often do not find themselves in central positions without justification. In their work they particularly emphasize the significance of network visualizations and highlight the fact that in many cases the visualizations alone have already led to a multitude of recommendations and action strategies for decision makers. Furthermore, one of the problems identified is the fact that despite the great potential of social network analysis, its application is primarily in research and the transition into practice is not yet sufficient. They argue for a more contextualized perspective of the method in order to make it more useful for practitioners.

Many of these statements are supported by Raab (2010). He also argues that social network analysis can be used to investigate informal relationship structures and that this has established itself as a central instrument in organizational research. In particular, he identifies inter-organizational network analysis as a relevant method for analyzing the interdependencies and joint work of various organizations. The author particularly highlights the communication and coordination relationships for the analysis of organizations and argues that network visualization can lead to a direct gain in knowledge without further analysis, especially for networks with less than 50 nodes.

The methodology of network analysis is also used in a variety of ways in emergency management and disaster response research. For example, Houghton et al. (2006) conducted a study on the performance of teams and organizations in emergency trainings using the example of the fire brigade and the police. The important actors were identified with the help of centrality measures and an interpretation based on the centrality calculation and the visualization of the networks was carried out. The authors recorded the actual communications between the individual actors over the course of the exercises. Important actors were characterized as those whose centrality value was above the one sigma environment.

In their study, Choi and Brower (2006) examined the disparities between existing plans and actually practiced networks for emergency services at the municipal level. They found that network analysis is an effective tool for policy makers and provides both researchers and practitioners with a good insight into the structures of actors. In particular, according to the authors, it enables an evaluation of the effectiveness of the network. With regard to their questions, they were able to state that emergency service networks are more efficient and less prone to errors if the structure and leadership are clearly presented and visible to all participants. The authors however emphasize that a static analysis of such networks is not effective and that the static analysis of the centrality for the whole network does by itself not provide sufficient information. Rather, networks of this kind must take the inherent dynamics into account in order to be able to record changing centralities over time.

Stojmonovic and Lindgaard (2014) also used social network analysis to investigate communication failures during emergency response trainings. Through the results from two exercises they tried to show how the use of social network analysis can support the planning of future exercises. For the analysis, the number of communications between the individual actors during the training period was recorded and mapped in a weighted network. The relevance of individual actors was measured by different centrality measures. The authors argue that the method provides great added value, especially in decisions on structural development and communication leadership, and is suitable for mapping communication and coordination in real situations and exercises provided the relevant data is collected. Like Choi and Brower (2006), Stojmenovic and Lindgaard explain that the findings of network analysis are limited in a static network and argue for the consideration of temporality. They suggest to subdivide the exercise into different sections and to analyze them individually in order to illustrate the dynamics of the system. It is also argued that the methodological gain in knowledge is more substantial with a larger number of actors and therefore the data should be collected from as many participants as possible. According to the authors the method is limited in that it cannot distinguish between effective and ineffective communication and thus does not provide any insights into why miscommunications occurred.

A similar study was conducted by Mohammadfam et al. (2015). Again, social network analysis was used to investigate the effectiveness of team coordination in an emergency rescue team. In contrast to Choi and Brower (2006) and Stojmenovic and Lindgaard (2014), the data collection was carried out in the form of structured interviews in which the participants were asked about all other actors with whom they had coordinated. In addition to centrality, the authors also considered other structural network characteristics such as the density of the coordination network. The results overlap with those of the previously mentioned works. Here, too, the authors describe social network analysis as a logical and qualitative method for analyzing coordination.

In contrast to the work described above, Kapucu and Hu (2016) examined multiplex relationships between organizations in the context of emergency management. They were particularly interested in the impact of friendship relationships on collaboration networks within disaster preparedness and response. They also analyzed whether collaboration in disaster response networks can be predicted on the basis of friendship networks and disaster preparedness networks. As a data basis, the authors used questionnaires in which they asked who the respective person knew from other organizations and with whom they collaborated in disaster preparedness and response. They found out that in existing friendship relations collaborations in the preparedness and response phase were more frequent. Furthermore, the authors concluded that the analysis of multiplex relationships leads to a better understanding of interorganizational networks. With regard to collaboration between different teams, they concluded that the formation of multiplex relationships has a positive effect on future collaboration.

In their work on a corruption scandal in the Czech Republic, Diviák et al. (2019) also considered the interplay of different types of relationships and the structure of the network. They investigated a total of three different types of relationships in the network, attempting to first determine which actors make up the core network, secondly to identify how the various relationship networks overlap, thirdly to determine which actors occupy central positions and lastly to ascertain how they differ in the various relationship types. The authors first analyzed the multilayer network structure by aggregating the individual layers and then analyzed each layer individually. Diviák et al. (2019) used degree and betweenness centrality as centrality measures to identify important actors in the network. In conclusion they stated that the consideration of multilayer networks provided a variety of interesting information about the network, assuming that the corresponding data was available in the required quality.

Within a literature review, Kapucu et al. (2017) investigated how the method of social network analysis is used in public administration research. The authors state that network analysis is used to understand dynamic relationship structures and to investigate social processes using different types of relations. The data of the studies are often based on interviews or field surveys. Most studies consider the entire network and the respective network structures. The most commonly used method on the node level is centrality. The authors see particular potential in the analysis of changes in networks over time.

Jones and Faas (2017a), in their book "Social Network Analysis of Disaster Response, Recovery, and Adaptation", bring together various works from disaster research and show what possibilities network research offers for gaining an understanding of the dynamic and structural relationships and interactions in disaster response, recovery and adaptation (Jones and Faas, 2017b). As part of the book, Varda (2017) examines methodological frameworks for describing social networks in disaster settings. She presents and compares the different units of analysis as well as their methods of evaluation. Based on the dynamic nature of disaster networks, she describes the importance of dynamic observations in the analysis of networks and their visualizations. She also discusses which decisions have to be made before the analysis in order to obtain a relevant result. In particular, the author describes the importance of identifying the relevant types of relationships and the associated definition of system boundaries and research questions while proposing that this is often the greatest methodological difficulty.

5.2. Social Network Analysis within Risk and Criticality Research

In addition to the more social-scientifically oriented field of organizational and disaster research, network analysis as a methodology also plays an important role in risk and vulnerability assessment. Cadini et al. (2008), for example, researched the protection of large-scale infrastructure networks and attempted to identify critical nodes in a power transmission network with the help of social network analysis. In doing so, they drew on the concept of centrality as a descriptive analysis methodology and extended it to include the reliability of networks. They argued that an infrastructure is more 'safety-efficient' if the individual nodes are connected via more reliable paths.

Eusgeld et al. (2009) also made use of a social network approach in order to conduct an initial screening of the vulnerabilities of critical infrastructures using the shortest path between all nodes in a static network. They argued that the approach is very well suited for the first screening because it is quick to compute and easy to implement. However, they deemed the limitations of the approach problematic as the dynamic behavior of the system was not considered. Also, the topological model did not take the load distribution in the system into account.

Kröger and Zio (2011) explain that complex network analysis is a common modeling technique for vulnerability analysis in critical infrastructures. It is used to identify vulnerabilities and critical elements and can provide insights into in-depth analyses. In particular, the abstract modeling paradigms allow the simulation of cascade effects. The authors argue that network topology can have a major influence on the development of disturbances and that the analysis of cascade effects must therefore address the dynamics of the system and its complexity. In the analysis of vulnerabilities, centrality plays an important role. The degree and betweenness centrality in particular are applicable measurements for this purpose. The authors evaluate the method positively and state that it contributes to a good system understanding and allows a quantification of vulnerability indicators.

The argumentation of LaRocca and Guikema (2011) follows that of Kröger and Zio (2011) in many respects. In their literature review, they describe the benefit of network analysis in relation to infrastructures in that it allows them to be mapped even when detailed data on individual systems is not available. This makes it possible to perform simulations and to gain an understanding of the topology effects in relation to vulnerabilities. They also stated that the importance of nodes is usually determined by degree and betweenness centrality.

An approach of using network theory to assess risk interactions in large engineering projects was presented by Fang et al. (2012). The authors attempted to identify how risks in projects are interdependent and to what extent, regardless of the potential impact of one risk, risks can be triggered by other risks. For their evaluation cause-effect relationships were defined to each of which they assigned a value between 0 and 10. The topological analysis was done using the betweenness centrality. The authors concluded that the method is a good complement to classical analyses of project risks and provides valuable information for further decision making.

In his dissertation, Ongkowijoyo (2017) also investigated risk relations using social network analysis. He argued that risk and resilience analyses complement each other and should therefore be considered in a holistic approach. He presented a framework that combined different quantitative methods in one process. The methodology of network analysis was employed, specifically the concept of centrality, to investigate the dynamic risk causalities of infrastructures. He concluded that the chosen approach is useful for modeling and simulating risk interactions and that network visualization additionally helps to develop an understanding of the risks. In his findings he argued that network analysis has the ability "[...] to delve into root impact pattern of risks, to help observe the various processes of coping, and to understand which type of interventions might require coordination or integration" (Ongkowijoyo, 2017, p. 226).

The research of Clark-Ginsberg (2017) focused more on the visualization character of networks. Based on participatory data sets and the methods and tools of network analysis, he developed network maps and discussed their usefulness in planning risk mitigation strategies. The technique he presented enabled the identification of risks and an assessment of the relationships between them within a discussion-based stakeholder workshop. He explained that the visualization of networks has often been shown to be an important supporting feature in the analysis of networks. In terms of risk understanding, he explained that network visualization supports the user in understanding the causes and consequences of disaster risks. The visualization thus offers a great potential for a deeper understanding of network structures and helps in the planning of necessary measures.

The methods and techniques of social network analysis are also used in various research projects. For example, the "SIMKAS 3D" project dealt with the simulation of interactions and cascade effects of operators of critical infrastructures using the example of the city of Berlin, Germany (Bartels et al., 2014). The project partners relied on a network theoretical approach and specifically investigated the relationships that are important in the case of intersectoral cascade effects in order to better understand the effects of failures of individual infrastructures (ibid.). In the project, scenario analyses were carried out at various operators to provide a basis for the simulations (Dierich et al., 2012). As one result, a software tool in the form of an ArcGIS extension was developed in the project. This enabled a three-dimensional situation representation of the relationships and the execution of spatial analyses to identify vulnerabilities. This then made it possible to detect overlaps of infrastructures, which helped operators and other involved actors to derive decisions. The analyses results were used as a basis for exercise scenarios (Bartels et al., 2014).

Another example is the "FORTRESS" project. This project dealt with tools to predict cascading effects in crises (Hempel and Pelzer, 2019). Two software tools were designed to assist with scenario planning in the phase of crisis preparation (ibid.). The tools were created to support the cooperation of infrastructure managers and first responders and were used to identify and visualize the interdependencies of infrastructure networks (Hempel et al., 2018). The two software tools followed an approach of dynamic criticality in the analysis of cascade effects resulting from the topological relationship patterns between the systems under consideration (Hempel et al., 2018; Hempel and Pelzer, 2019). The first tool, the "FORTRESS Model Builder" is a web-based modelling tool for the creation of scenarios in the form of static, multiplex infrastructure networks (Hempel and Pelzer, 2019). Within the project, five relationship types such as the resource or the interference relation were identified as relevant. Based on these five relationship types, the criticality for possible cascade effects of individual nodes was calculated. For this purpose, measures of centrality, specifically betweenness and outdegree centrality, were applied. Changes in the criticality of individual nodes over time could be considered by the construction of the networks at different points in time (ibid.). Hempel et al. (2018) explained that the results of the analysis of criticality cannot be regarded as conclusive, but should rather lead to further discussions between the actors involved in order to obtain a common picture of the scenario or the complex dependencies it contains. The Model Builder implemented in the project supports multigraphs and enables the user to store node coordinates for geographical representation (Hempel and Pelzer, 2019). Additionally, buffer times which describe the time a relation can be maintained in case of a malfunction can be stored for the individual relations (ibid.). The developed networks can be imported in the second software tool, the "FORTRESS Incident Evolution Tool". In this tool, which is also implemented as a web application, faults or failures of individual nodes can be defined and the effects of cascades can be analyzed on the basis of the stored buffer times so that mitigation strategies can be discussed (ibid.). Hempel and Pelzer (2019) explained that the implemented tools support a joint cooperation of actors based on the developed scenarios. However, this form of crisis prevention requires specific skills, which the teams have to obtain in trainings and workshops in order to gain an understanding of the possibilities and the identified results. The authors further argued that the availability of data to adequately map scenarios is elementary.

5.3. Social Network Analysis in Exercise Planning and Evaluation

The presented works and projects give an overview of the areas of application and issues that can be investigated with the help of social network analysis. In summary, the methods of network analysis are assessed positively overall. In particular, the usefulness for analyses of the topology or structure of the relationship networks is pointed out. On the one hand, the abstract representation in networks as well as the different network visualizations promote a better structural understanding of the systems under consideration and their inherent relationships and interactions; on the other hand, network analysis with its different measures of centrality offers the potential to identify central or well-positioned actors and makes it possible to compare actors in the same network with each other. In the case of the centrality measures, the works considered show that there is no one right approach. While degree and betweenness centrality are often used as relevant measures in risk and vulnerability analyses, a combination of different centrality measures is commonly positively assessed in the analysis of communication or interaction networks.

In general, it is emphasized that for the analysis of the structures of dynamic systems such as teams and organizations or technical systems such as infrastructures, an assessment of static networks can provide initial conclusions but quickly reaches its limits. Rather, a dynamic analysis should be carried out when the appropriate data is available. This can show the changes over time and allows for more sensitive statements to be made. Previous research also indicates that by taking multilayer networks into account, more in-depth analyses can be carried out and correlations can be revealed. Network analysis is seen as a powerful tool for practitioners and policy makers. Nevertheless, the studies point out that analyses of this kind have so far been carried out almost exclusively by researchers, thus confirming the assessment from practice (see section 3.5). Some authors, such as Cross et al. (2002), argue that in order for the methodology to become more relevant to practitioners, it needs to be designed and specified for the respective context. Hempel and Pelzer (2019) also move in this direction in their description of the project results, arguing that for social network analysis to be used profitably, hands-on training is needed and expertise must be developed through growing experience.

In the literature it is seen as problematic, especially regarding the analysis of communication networks, that social network analysis does not differentiate between effective and ineffective communication. For example, the results of the centrality of different actors may be distorted due to 'wrong' communication. Furthermore, in the context of risk and vulnerability analyses for e.g. infrastructure networks one has to be aware of the limitations of network analysis. For example, in addition to the consideration of the relationships and dependencies factors such as load management, which would be useful for more in-depth analyses, are not taken into account here. In conclusion, the literature for the considered areas states that the methodology of social network analysis is particularly suitable for two main purposes. On the one hand, it enables the user to obtain a first impression or a basic understanding of the structures and the relevant actors. Here, network visualizations can take on a supporting and expanding function. On the other hand, the network analysis can be used very well for specific questions, which are based on the interrelationships of the actors in the network. For example, as Kapucu and Hu (2016) showed, it can be examined to what extent existing friendship relationships affect cooperation in a crisis. For this case, Varda (2017) identifies the definition of the relevant relationship types and the resulting system boundaries as the greatest difficulties in applying the method.

With regard to the question of what potential the methodology of social network analysis holds for exercises in civil protection and disaster response, the analysis of the examined work can provide important insights. First of all, three types of networks can be characterized based on previous research that seem to be useful for the exercise context: communication networks, dependency networks and scenario networks. In communication networks, all communications that have occurred between the actors involved during an exercise are recorded. By using multilayer networks, different forms of communication such as questions or information transfer can be mapped. Since communication during an exercise has not yet been recorded according to the statements made in the interviews on the current exercise situation (see section 3.5), these networks can create added value because they offer possibilities for visualizing and evaluating communication. An example of dependency networks are infrastructure networks such as those used by Eusgeld et al. (2009) or Ongkowijoyo (2017) in the context of risk analysis. These networks can be used to model systems relevant for an exercise scenario. For example, in a planned blackout scenario, the regional power supply can be modeled in a network to get a better picture of the dependencies and to provide support in defining the exercise boundaries. The scenario networks are a hybrid of the two above mentioned. They are used to model and map the entire scenario or specific areas of it including all relevant actors and interactions. In this way, an abstract overall picture of the scenario or a section of it can be generated and analyzed. This form of network, which is for instance used by Hempel and Pelzer (2019), enables to visualize and analyze dependencies between technical systems and organizational structures as well as training procedures. In all three network variants, the definition of multiple relationship types is possible in order to enable a more in-depth analysis, if the data basis is available. All the forms described are also suitable for both static and dynamic networks.

According to the statements made in the interviews (see section 3.5), the methodology of social network analysis is particularly interesting for the planning and evaluation phases of the exercise. In the planning of exercises, the potential of social network analysis lies in the possibility of developing an abstract picture of the exercise to be planned. For example, systems belonging to the scenario as well as their dependencies can be modeled and illustrated or the scenario can be thought through with visual and analytical support. In particular, the method can support the definition of exercise boundaries and the development of the scenario and the associated injects. As a tool for scenario development, the methodology offers the possibility to define expectation values, i.e. network representations or sociograms that reflect an ideal or expected pattern of relationships and interactions of a certain situation in the scenario. This way, exercise goals can be evaluated or it can be examined in advance whether actors could be potentially overwhelmed by too many interactions. It can be assumed that the method is well suited for combination with the practices used so far. For example, the scenario script can also be used as a data basis for the network to be modeled, or conversely, sociograms can be created for injects to provide visual support for the planners. By modeling and analyzing networks as a support in exercise planning, further difficulties mentioned by practitioners can be taken on. For example, it can facilitate the work with a common mental model if an abstract model with corresponding visualizations exists. Furthermore, such a network can be used to carry out further simulations, if they are relevant to the scenario.

For exercise evaluation, the use of network analysis also reveals some potential. For example, by analyzing the network structure and the positions of the actors in the network via e.g. centrality, it offers a possibility for systematic evaluation which has not been common in practice so far. Based on the results of the related work, it can be assumed that the visualization of the exercise structures in a network supports the participants through an intuitive way of presentation. Furthermore, depending on the data collected, different possibilities for evaluation are given. For example, the communication that took place during the exercise can be analyzed and evaluated with regard to the intended command structure. It is also possible to review dependencies and processes retrospectively and compare them with the expected value. If multilayer relationships were recorded during the exercise, these can be related to each other and changes in the course of the exercise may also be considered. The social network analysis can be combined well with previously used evaluation methods. For example, deficiencies that have arisen in evaluation questionnaires can be compared with the data in the network and, if applicable, network analysis can help to better understand and justify them. It is also feasible to use networks as visual support in the debriefing following the exercise.

A particularly relevant aspect for the use of social network analysis in the context of the exercise is the possibility of collaboratively developing scenarios as networks both in the planning and in the exercise follow-up. On the one hand, it is possible to work out common scenarios in the planning of the exercise and to check the exercise goals through simulation and discussion, on the other hand, the exercise or the scenario can be collaboratively reflected upon in the evaluation. Based on the analysis, it can be assumed that the use of social network analysis for the planning and evaluation of exercises in civil protection provides manifold added value and can contribute to a standardization and a better comparability in the exercise operation. The added value for the exercises is particularly evident when social network analysis is used as a tool in combination with the methods already established in practice for planning and evaluation. This leads to the main idea of this thesis to use social network analysis as a methodology and tool for creating interpretation possibilities for exercises in civil protection and disaster control. It serves as a tool to visualize and explain different situations from the exercise, either planned or experienced. Network analysis enables different perspectives or focus points regarding the exercise or specific situations from it by means of different visualization possibilities and structural analyses. It further helps in understanding the complex relationship structures and their temporal dynamics. With reference to the limitations described in the literature, such as the inability to differentiate between relevant and irrelevant communication, network analysis is seen as a tool in the sense of a preliminary examination or screening. In the planning phase, it offers support in the execution of simulations and the definition of expected values and exercise boundaries and thus supports the planner in the development of a realistic scenario. Furthermore, it creates possibilities for the visualization of mental models and can serve as a basis for discussion. In evaluation, it enables an assessment and analysis of the structures both for communication and for the exercise itself. Individual actors are given the opportunity to review their situation from the outside and to classify their role in the overall network.

5.4. Requirements and Existing Software

In order for practitioners to derive added value from utilizing social network analysis as a methodology for planning and evaluating exercises, software systems need to be created that meet the specific requirements for that particular use case. In the context of this thesis, these requirements were determined by interviews with experts from the practice and the analysis of the relevant literature. General requirements regarding systems for planning and exercise support are described by Pottebaum and Schäfer (2018) in their work on IT systems in crisis management. They suggest that the processing of information contributes significantly to mastering tasks in crisis situations and that units and decision makers must be enabled by software to interpret information and events. Therefore, they listed specifically the possibility of integrating all relevant data, the simulation of possible hazards or processes and the visualization of past events and exercise scenarios for incorporation into planning as specific requirements for planning support systems. They explained that the goal of exercises is to ensure experience-based learning and that decision makers and trainers must be enabled to estimate events, resource movements and interactions within the exercise during the planning process. Software systems must be able to create scenarios and run simulations with little effort. With regard to the evaluation of exercises, the authors consider it crucial that visualizations of situations in the exercise are already available to the persons involved during the debriefing. These should be goal-oriented and offer the participants an opportunity to illustrate the effects of certain actions.

An important requirement from practice is that the software offers support during the entire planning process, and in particular during scenario development (Interview 2, 2019, personal communication, 05 March). The visualization of the scenario as a network should be in the foreground and the software should be able to map dynamic actors and relationships, so that the user can work intuitively. Analogous to the work with exercise scripts processes, measures and information should always be presented with a temporal reference and possibilities should be given to assign relationships to specific situations or processes (Interview 4, 2019, personal communication, 18 March). In addition to these relationship associations it should be possible to filter individual processes to display path dependencies. With these features the software would offer to verify individual processes (Interview 2, 2019, personal communication, 05 March) and to trace communication flows (Interview 1, 2019, personal communication, 26 February). Depending on the scenario at hand different actors and relationship types must be able to be modeled by the software. In particular, it must be able to define communication and resource relationships and to perform simulations to represent functional failures and cascade effects (Interview 2, 2019, personal communication, 05 March). The software must also be able to map multiple relationships between two actors. To reduce the time required for modelling the scenario, the application should allow the creation and import of templates (Interview 2, 2019, personal communication, 05 March). This way, fixed constellations of actors and relationships such as local infrastructure networks or fixed organizational structures can be created once and then be reused in different scenarios. For the representation of exercises with actors on several levels or different sub-scenarios, the software should provide possibilities for linking (Interview 1, 2019, personal communication, 26 February).

With regard to exercise evaluation, one requirement for the software is that it should provide functions for filtering and highlighting individual actors (Interview 4, 2019, personal communication, 18 March). In doing so, both a detailed view of the relations and interactions of the individuals and their roles in the scenario can be reflected. Visualizations provided by the application should be simple and not overload the user (Interview 1, 2019, personal communication, 26 February). In order for the application to be used by personnel not familiar with social network analysis, the application should have documentation on all features and their usage (Interview 4, 2019, personal communication, 18 March).

Today, a large number of software applications and software libraries providing functions and common algorithms for network analysis are available (Newman, 2018). One example is *UCINET*, a standard application for the analysis of social networks, which offers a multitude of functions and is mainly used in research (Borgatti et al., 2002). *UCINET* is a menu-based Windows software that offers a variety of functions for the analysis of networks and integrates the software *NetDraw* for visualization (Borgatti, 2002). An example of a software library is the Python package *NetworkX* which provides a large number of methods for modeling complex networks and calculating network properties and structures (Hagberg et al., 2008). Although *NetworkX* also offers possibilities for network visualization, the focus of the available functions lies on the analysis. By using common data formats such as *GraphML*, *CSV* or *GEXF* it is possible to port network data between different applications. *NetworkX* also offers this export option so that users can visualize the data in programs specifically developed for this purpose. Besides the mentioned applications there are a lot of other tools available. A comparison and in-depth review with regard to social network analysis is given in Huisman and van Duijn (2014).

Most of the software applications available on the market for both analysis and visualization are generic solutions that can be used for different problems and contexts. However, there are also some solutions for specific use cases such as the analysis of crime networks (Devaux, 2019a). One problem Newman (2018) describes with regard to the use of existing software is that researchers tend to only answer questions that can be answered with existing solutions, neglecting potentially interesting questions. He argues that software should be oriented towards the application context and the questions and not vice versa. This argument is supported by Cross et al. (2002) with reference to the use of social network analysis as a methodology in practice. They argue that tools must be more oriented towards the requirements of the end users or approach them contextually so that the methodology can establish itself in practice.

As can be seen from the requirements mentioned above, visualization is a central aspect to obtain a deeper understanding of networks for the application of exercises in civil protection and disaster response. Therefore, for a software application to be relevant for users in practice, network visualization should always be in the foreground and also all analyses should be supported by it. As Devaux (2019b, 2019c) shows in her listing of software applications and libraries, there are also many applications that focus on the visualization of networks, many of which also provide algorithms for analysis. Up to now there is no software that offers network analysis functionalities specifically for exercises in civil protection and disaster response with their specific requirements for a support tool. Therefore, this thesis pursues the conception and development of a corresponding application. As a basis for the software concept, the three existing software applications *Gephi*, *KeyLines* and the *FORTRESS Model Builder* are briefly described below with respect to their usefulness in the planning and evaluation of exercises and their strengths and limitations are explained.

Gephi is an open source visualization software for the analysis of graphs and networks (Bastian et al., 2009). It offers a variety of possibilities for the interactive visualization of networks and includes many common algorithms for analysis, especially for the determination of centrality (ibid.). The software provides different layouts and filters with the possibility to configure them. Furthermore, nodes and edges can be adjusted in their color and size among other things (ibid.). Thereby the software allows an adjustment based on a specific metric. For example, the size of the nodes can be displayed in relation to their centrality, thus enabling a direct visual analysis. *Gephi* also supports the visualization of dynamic networks using network slices, which can be displayed as movie sequences in a timeline (ibid.). The biggest limitations of *Gephi* as a software tool for exercise operations lie in the lack of multiplexity, simulation and the enhancement of nodes with additional data. For instance, the software does not allow multiedges and does not differentiate between different types of relationships. Additionally, no simulations based on existing relationships can be performed using *Gephi*, as the software primarily focuses on visualization. Although it is possible to create and delete nodes and edges directly in the drawing area, no additional information can be attached to the elements. Therefore, it is always necessary to change the view to the datasheet. In the graphical display, individual nodes can be distinguished only on the basis of their label.

KeyLines is a commercial JavaScript library for the visualization of networks (Cambridge Intelligence, 2019a). *KeyLines* also implements common algorithms especially for the analysis for the centrality of the different nodes. The software package offers different layouts with corresponding information (ibid.). In order to further promote the understanding of the networks, the software provides various possibilities for manipulating the data (ibid.). For example, nodes can be adjusted in size and color or represented by images. In addition, filters can be defined that, for example, hide nodes below a certain centrality value from the interactive visualization. Nodes can also be combined into groups and the centrality values can be determined based on these groups. Users can be presented with additional information through optional animations of nodes or fade-ins. *KeyLines* has a time bar function which allows the visualization of dynamic network data and the ability to display selected data sets (Cambridge Intelligence, 2019b). Here, too, there are possibilities to visualize the network dynamics by means of a movie sequence (ibid.). Similar to *Gephi*, *KeyLines* does not support network simulations nor does it offer functions for the visually supported setup and editing of nodes and edges. Instead, the software is designed to be linked to existing graph databases and to map the data from these databases. These limitations, as well as the limited possibilities for displaying multiplex relationships, do not facilitate a direct use for the exercise context.

The *FORTRESS Model Builder* is a web-based application for cooperative scenario development in crisis preparation and planning (Hempel and Pelzer, 2019). The tool was developed within the EU project *FORTRESS*. It enables the modeling and analysis of cascade effects using predefined multiplex relationships (ibid.). With the help of the software, users can develop the scenario with visual support and, by calculating the centrality, analyze and discuss the structural dependencies (ibid.). Unlike the two solutions mentioned above, the *Model Builder* focuses more specifically on the scenario development and simulation. However, its use in the context of the exercise is limited, since the software cannot model dynamic scenarios natively and the visualization of the networks is not supported by the use of layouts, filters or grouping functionalities.

The software solutions presented already include some analysis functions and visualization techniques relevant for the planning and evaluation of exercises in civil protection and disaster response. However, the specific requirements for the context are not completely fulfilled by any software, so that over the course of this work a software concept for an exemplary tool was developed. The concept will be explained in the following chapter and the different functions for visualization, simulation and analysis will be discussed.

6. Software Concept for the ScenarioBuilder BOS – A Network-based Tool for Exercise Planning and Evaluation

After discussing the potentials of social network analysis as a methodology for the planning and evaluation phase of the exercise in civil protection and disaster response in the last chapter, this chapter will develop a concept for a corresponding software application. The concept takes up the previously described practical requirements as well as practices and functions from existing software and extends them for the relevant use cases in order to support the user as best as possible. First of all, this chapter addresses the objectives of the software and the use cases that are to be implemented with the application. The functions and conditions for the development of scenarios are then explained, followed by those for the scenario analysis. Special emphasis is given to the simulation and structural network analysis by means of centrality calculation. At the end of the chapter an exemplary use of the application in a discussion-based and an operation-based exercise is outlined and possible conceptual extensions are discussed.

6.1. Software Objectives and Use Cases

The aim of the conceptualized application, which is called *ScenarioBuilder BOS*, is to develop, model and analyze exercises scenarios on the basis of multilayer graph networks and their analyses. The visualization and analysis of these exercise or scenario networks are intended to show the user various possibilities of interpretation of the entire scenario or individual sequences thereof, thus making them more tangible. In other words, the user should be able to view a scenario or certain situations from different perspectives and to examine and evaluate them on the basis of different questions. The software thus makes it possible to anticipate the characteristics and processes of an exercise as early as during the planning phase or to simulate events and reactions that have occurred in the course of the evaluation.

The *ScenarioBuilder BOS* is intended to support users from practice in the exercise operation and therefore considers all people involved in the exercise, but especially the exercise planners and controllers, as its central stakeholders. Based on the previously defined requirements, the concept provides a number of design criteria for the application. In particular, the aspect of visualization is to be mentioned here, which is the focus of the application. Thus, the software is used to model and depict exercises in the form of graph networks which represent the relationships between different actors within an exercise. The basic elements used are nodes and edges or relations (see also section 4.1). Nodes usually represent individual actors, groups or organizations, but can also represent material things such as vehicles or infrastructures. It is also possible for a node to describe a phenomenon such as a thunderstorm in order to be able to map scenarios as flexibly as possible. The relations between two nodes are represented by their edges. Different types of relationships can also be represented here. Communication and interaction relationships, resource relationships and responsibility relationships are particularly relevant for the exercise context.

Another design criterion is the assumption of dynamic systems. Thus, following the practical exercise, the concept assumes that every graph network modeled is a dynamic one. This implies that nodes and relations can change over time and therefore different network structures can be formed. In this concept and application, these dynamic networks are referred to as 'scenarios'. With regard to exercises in civil protection and disaster response, they can be categorized into three different types of scenarios as described in section 5.3 that are relevant for the software. These are communication scenarios focusing on the different interactions of the exercise participants, dependency scenarios which mainly involve resource relationships to represent interdependencies as well as scenarios that represent the actual exercise scenario. In the latter case, the number of different types of relationships can be significantly larger, depending on the scope of the scenario. Here, the sequences of actions specified in the script are modelled with the interactions required both for them and the underlying dependencies. The decision which form of the scenario is used is left to the user and should be based on the requirements of the exercise.

The objective of the software application to provide the user with interpretation possibilities for situations or aspects within an exercise requires a further aspect that is incorporated into the software concept, namely a high degree of flexibility and adaptability. This includes in particular adaptability regarding the visualization but also flexibility in the analysis as well as in the use and working with the tool. The intention of the *ScenarioBuilder BOS* is not to deliver absolute results for a scenario as in the case of expert systems, for example. Rather, the application is intended to enable a reflective and discursive approach to a scenario and thus functions as an exercise support tool in the planning and evaluation phase. The necessary process of classification and evaluation of the results further enables collaborative work. Flexibility in the analysis ensures that a scenario can not only be evaluated as a whole but that certain aspects can be prioritized and individual situations can be examined in a targeted manner.

The software is based on the two main use cases scenario development and scenario analysis, each of which is enhanced by different software functionalities. An overview of these two superordinate use cases as well as their subordinate use cases can be seen in the UML diagram in Figure 6.1. If the user wants to develop a new scenario (see section 6.2) the specific boundary conditions as well as the relationship types and types of nodes to be used must first be defined. Once this has been done the user must create nodes and relations that are the basic elements through which a scenario may be described. These can be further described by defining specific capacities and requirements. The user may also load predefined scenario templates to aid with development and external events extending the scenario may be defined. Scenario development can also take place with an existing scenario. In this case, the user loads the scenario and creates additional nodes, relationships and events as required. Existing elements can be edited using different manipulation options. Furthermore, scenarios can be linked to each other in order to differentiate between different levels for example.

If the user wants to analyze an existing scenario (see section 6.3) he/she has various options available after loading the scenario from the database. The user can combine these analysis options as he/she wishes and draw conclusions from them. This includes visualizing the scenario through combinations of relationship types and variations of time horizons as well as calculating the centrality of the individual nodes in different ways. Furthermore, he/she can view the scenario network in different layouts and investigate specific path dependencies. If capacities and requirements are defined in the scenario, the user has the possibility to investigate cascading effects and malfunctions over time by simulating the scenario. It is also possible for the user to filter individual nodes from the view or to combine them into groups. Finally, the user can play the scenario as a film sequence to get an insight into its dynamics.

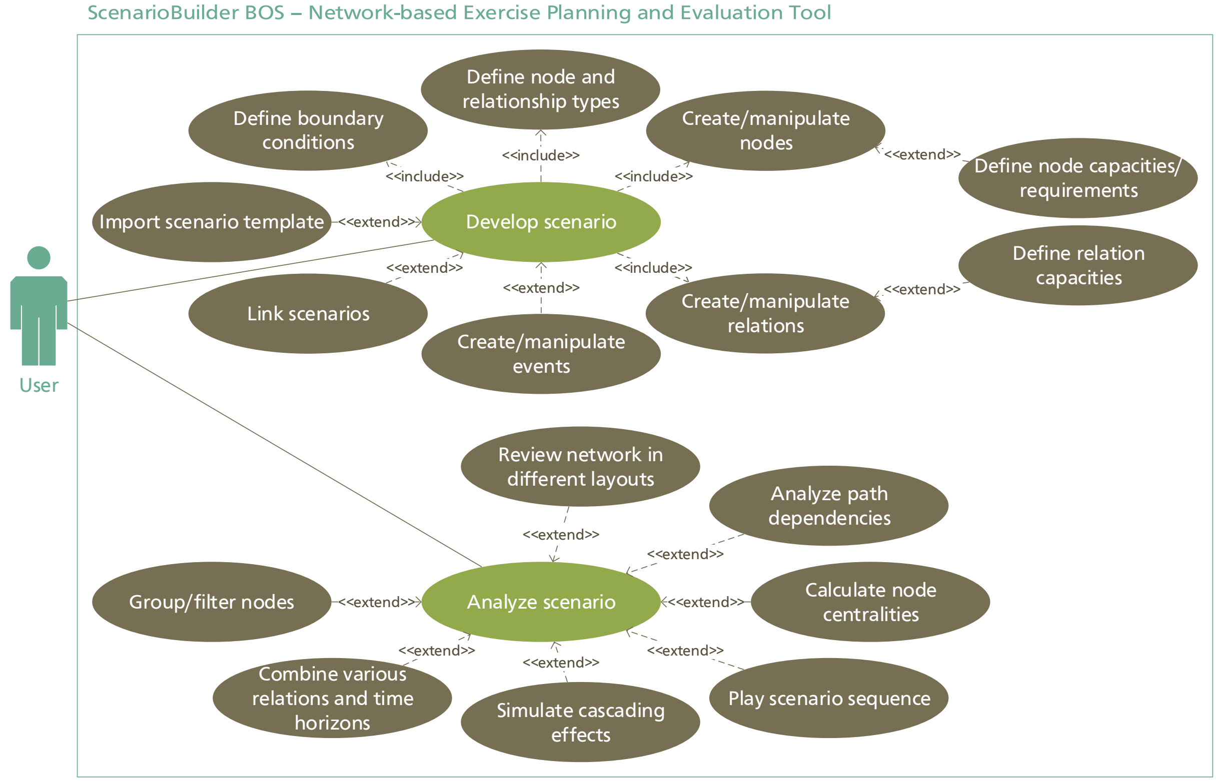


Figure 6.1: Use case diagram according to UML notation for the network-based tool to support the planning and evaluation of exercises

The user has the possibility to switch back and forth between the two use cases. For example, incomplete scenarios can be analyzed while still in development and errors identified during analysis may be corrected at any time by switching to development mode. In the following sections the functions and approaches defined here for the two superordinate use cases are described in detail and their implications are explained.

6.2. Scenario Development

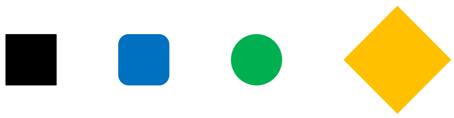
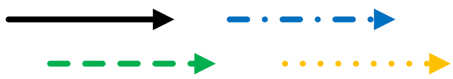
Defining Boundary Conditions

Before a scenario can be analyzed, it must first be created or developed with the *ScenarioBuilder BOS* application. This is independent of the question of whether the application is intended to support the actual development of an exercise scenario in the planning phase or whether it is used in the context of evaluation. In both cases, the scenario must first be modeled before further analyses and discussions for interpretation can follow. At the beginning of the scenario development there is always the definition of the boundary conditions. This includes the definition of the exercise objectives, the time frame and the name of the exercise. For the use of the application, it must also be specified which form of scenario is to be modeled (see section 6.1). For example, should the scenario model the communication or the actual exercise scenario to be practiced with the relevant action sequences. Based on this question it must be decided whether the relationships to be depicted are directed or undirected relationships. For most exercises directed relations are used because they enable a clear assignment of sender and receiver of for example information, which is usually important for the investigation, especially in communication networks. In cases in which the sole interest is in knowing between which actors a relationship existed and not from whom it originated, these can be represented by undirected relationships (although it is also possible to work with two oppositely directed relationships in such cases).

Defining Node and Relationship Types

In addition to the definition of the boundary conditions, the user must also decide which data is to be collected for the scenario and how it should be visualized at the beginning of the scenario development. Here, one has to distinguish between the considered actors and the considered relationships. With regard to the actors, the user must specify which actors or nodes are relevant for the scenario and how they can be categorized. By assigning them to a category different groups of actors can be visualized in the same way, thus allowing the user to directly assign individual nodes and actors to each other without overloading the scenario visually. Moreover, a layered categorization with superordinate and subcategories is often useful. A power plant node may serve as an example. For a power plant, ‘infrastructure’ can be defined as a top category, while a corresponding subcategory could be ‘energy infrastructure’ and underneath that a more detailed description such as ‘energy infrastructure for production’ would be appropriate. Another example would be an S1 from the crisis management staff of the fire department (see section 2.3). As a superordinate category one could specify a ‘unit’. A more precise categorization could be given by the organization ‘fire brigade’ and the assignment to the ‘crisis management staff’. The visualization of different categories in the *ScenarioBuilder BOS* is done by varying the color, shape and size of the nodes (see section 4.4). Examples for different nodes are shown in Table 6.1.

Table 6.1: Examples of different representations of node and relationship types

	Styles	**Examples**
Nodes		▪ Infrastructures → box-shaped nodes (energy → yellow, water → blue) ▪ Units → cirle-shaped nodes (fire brigade → red, ems → green)
Relations		▪ Resources → solid line (people → black, water → blue) ▪ Communication → dashed line (command → blue, question → orange)

A visualization in case of a layered categorization as described in the examples mentioned above is made possible by the combination of, for example, shape and color. For instance, the user can define that infrastructures are always displayed as box-shaped nodes. Different colors are used depending on the infrastructure in question. For example, energy infrastructures could be represented as yellow box-shaped nodes while water infrastructure is displayed using blue color coding. Furthermore, actors that are particularly relevant for a scenario can be displayed larger than the remaining actors to allow for further visual differentiation.

In addition to deciding which actors are relevant for the scenario and under which categories they can be grouped, the user must also decide which types of relationships should be mapped within the scenario. Through this process the user determines the degree of multiplexity of the scenario and defines the system boundaries. Similar to the categorization of nodes, it can also be useful to categorize relationships in order to enable a more detailed view if required. Categories of relationships that are of interest for the civil protection and disaster response exercise are mainly communication or resource relationships. A distinction within the group of communication relationships can be made, for example, with regard to operational reports. Here, communications are differentiated between general information or messages, commands, requests and questions. Resource relationships can be differentiated according to the type of resource, for example. Possible subcategories include but are not limited to water, electricity, or human resources (e.g. task forces or man-power). In the software application, different categories of relationships are visualized by different colors and shapes of arrows (see section 4.4). Examples are shown in Table 6.1. As with the nodes, layered categories can be achieved for relationships by a combination of shape and color. Using the example of communication relations, all corresponding relations could be shown with a dotted line. Depending on the type of communication, the color could be varied. For example, a command relationship would be represented by a blue dotted line, while a communicated request would be represented by a black dotted line. This enables the user to see at first glance which relationships correspond to the types depicted in the scenario and allows for easy deduction of first qualitative findings from the perception of the scenario network.

When defining the node and relationship types, it must be taken into account that the complexity of the scenario increases with increasing multiplexity and depth of detail. On the one hand this enables a more detailed examination of the modeled scenario network, but on the other hand it also increases the effort required for data collection. Furthermore, it must be remembered that a too large number of different visualizations can also lead to confusion. However, this can be alleviated during the evaluation phase by using filters or grouping nodes and relationships. In general, the definition of the relevant node and relationship types should always be based on the exercise objectives and the questions of interest to the user. If the software is used several times across different exercises, it makes sense to develop a uniform definition of types and categories to achieve better comparability between different scenarios.

Creating and Manipulating Nodes and Relations

After the boundary conditions for the scenario and the categories of nodes and relationships used have been defined the dynamic scenario can be developed step by step. The underlying dynamics are displayed in the *ScenarioBuilder BOS* in the form of a relative time scale where the time $t = 0$ corresponds to the start time of the exercise defined in the boundary conditions. Which real time span is covered with one time step depends on the needs of the user and should be defined in the course of the determination of the boundary conditions. Since most exercises last less than five to six hours, time steps in the lower minute range are usually sufficient (1-15 minutes). During scenario development, the application always visualizes the currently selected time of the scenario. All elements that are defined for that time are displayed. For a better overview, the user can switch between different time steps at any time, which updates the displayed scenario network. An example of an imaginary scenario at different times is shown in Figure 6.2. The diagram lists five time steps ($t = 0$ to $t = 4$). In the last part of the figure (bottom left), the individual time steps were merged and displayed in a single static network.

When developing and modeling the scenario with the application, the user usually starts with the description of the initial situation ($t = 0$). For each newly created node, a unique name must be defined and assigned to a predefined node type. The name serves as an identifier and label at the same time and is intended to prevent the user from having to work with numerical IDs and to ensure a uniform name throughout the entire work with the scenario. Next to the name, the specification of a start and end time ensures that the node is only visualized in the time period of the scenario for which it is relevant. Users can also link additional attributes to a node. For example, it can be useful to store coordinates to give the node a geographical reference.

The conditions for creating relationships are similar to those for nodes. They must also have unique names and be assigned to a specific relationship type. In communications networks, for example, relationships can be initiated by one actor to several receiving actors at the same time. This means, however, that more flexibility is required here with regard to naming and labels than is the case with nodes. With the *ScenarioBuilder BOS*, the user has the option of flexibly adjusting the labels of relationships or deactivating them completely. It is also possible to duplicate relationships with all their properties whereby the application provides the previously mentioned name with an additional index in order to guarantee unambiguousness in naming. Analogous to the creation of nodes relations must also have a defined period of time for which they are valid. The time period of relations can sometimes vary greatly in a scenario depending on their relationship type. While communication relationships often only have a very short activity phase resource relationships between two nodes, for example, tend to have a longer-term effect. When creating a relationship a reference to the origin and target nodes is required in addition to the attributes mentioned above. Furthermore, references to relationships that have already been created can be stored in a relationship for the later display of path dependencies. Figure 6.2 again serves as an example. If one assumes that the shown communication scenario describes a path dependency, the reference relation is the command relationship (blue dotted line) from time step $t = 0$. All relations from time step $t = 1$ refer to just this command and would not have been established without it. The same applies equivalently for all the further time steps.

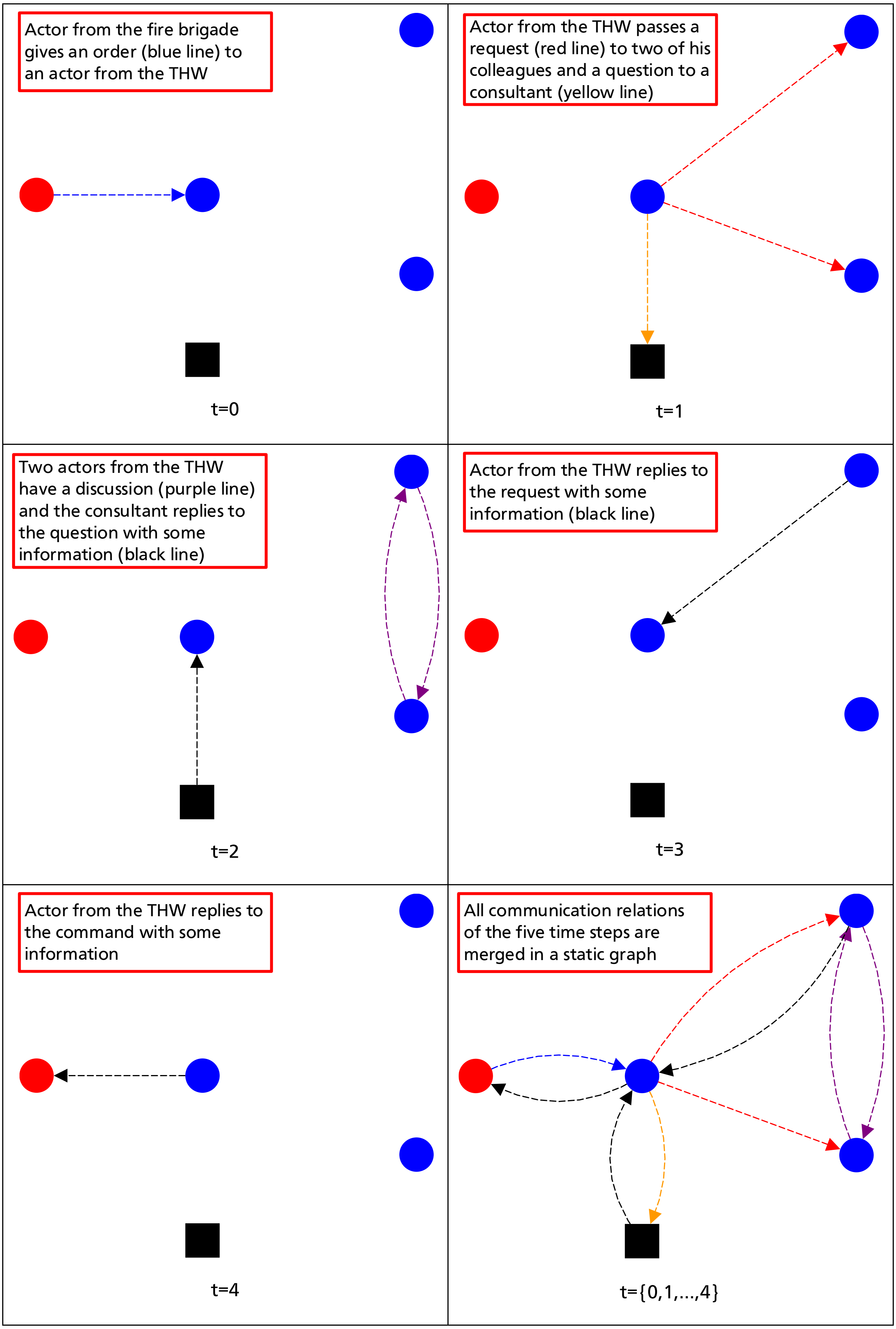


Figure 6.2: Example of an imaginary dynamic communication scenario for the times t=0 (top left) to t=4 (bottom left) and merged for the time range t={0,1,...,4} (bottom right)

In the event that changes occur in already modeled nodes or edges during the development of the scenario, the *ScenarioBuilder BOS* provides functions for editing and manipulation. Individual relationships can be deleted or changed. In particular, start and end times can be edited or a reference to other relationships can be created or removed. It is also possible to assign a relationship to another relationship type. The manipulation of a node is possible in the same way as for relationships. Here too, its start and end time or other attributes can be updated. Since relationships are always assigned to an origin and a target node, they are automatically deleted when a node is removed from the scenario, provided they are linked to it. For data storage and handling the application uses an integrated database that stores all changes made by the user and makes them available again when loading the application at a later time. Furthermore, the *ScenarioBuilder BOS* provides functionality to export and import both the database as well as individual data from it. This enables the user to work with applications he is familiar with. For example, they can also define node and relationship types outside the application using spreadsheet programs for instance.

Defining Capacities and Requirements for the Scenario

Especially in the planning phase of exercises, the possible effects of events are not so easy to assess for the planners and make the development of the scenario more difficult (see section 3.5). This is especially true for scenarios that should include cascade events in socio-technical systems such as infrastructures. Here it is helpful for users if they can use simulation approaches to calculate and simulate the effects of these systems on the overall scenario and derive consequences for the development. In this way, more realistic exercises can be achieved, which leads to an increase in motivation and acceptance of said exercises (see section 3.5 and section 5.4). In order to enable the user to develop such scenarios, the *ScenarioBuilder BOS* provides concepts for extending a scenario so that possible problems and consequences can be simulated. The approach taken by the application assumes that nodes may have specific capacities, load limits and requirements. These in turn can change depending on the time and the situation in which the node is in. Under the assumption that the types of capacities and requirements always correspond to the relationship types defined in the respective scenario and that the scenario is a one build upon directed relationships, the approach further assumes that the relationships (especially resource relationships) in the scenario act as carriers of such capacities. This approach can be illustrated using two examples:

- A city hospital (node) has a patient capacity of 200 people during normal operation, that it can provide for as long as sufficient staff and the necessary infrastructure are available. Here, each admission of patients (incoming relationship) leads to a reduction of the available capacity while a discharge of patients (outgoing relationship) results in an increase. A change in the situation might mean that normal operation can no longer be guaranteed. For example, in the event of a power failure, it can be assumed that patient capacity will decrease because the hospital can only provide emergency care.
- A forest fire scenario requires a certain amount of extinguishing water that can be provided in different ways. For example, a fire truck (node) has a limited capacity with a water tank of 2000 liters. If on the other hand a fire pond or hydrants are available in the immediate vicinity, the water availability is much greater. In both cases, the capacity attribute of the

relationship specifies how much water can be transported per time step from the source node to the target node.

In order to implement such scenarios and to allow for simulation later on, the applied approach assumes that nodes can be in different states, i.e. different conditions of a system. Each of these states is linked to specific capacities and requirements that can be defined individually. The *ScenarioBuilder BOS* enables the user to specify multiple states for each node and their corresponding attributes such as output capacities, i.e. functions that can be performed by the node, intake capacities or load limits and requirements. This can be illustrated via the hospital example mentioned above. Two different states can be identified, namely the 'normal state' and the 'emergency state'. No output capacities are described for the normal state, but there is an intake capacity of 200 persons to be treated. There are also some requirements for the hospital to function in the normal state. In particular, there is a requirement for the resource electricity. For the emergency state there is also no output capacity defined and here too there is an intake capacity for persons to be treated, but it will be considerably smaller than in the normal state. In order to maintain hospital operation in the emergency state, i.e. diesel generators are required for emergency power generation and thus the resource diesel is a requirement.

Since relationships in the context of simulation map the transport of resources and other relationship types from one node to another, the user needs to define exactly one capacity for each relation to be used for this purpose. This shows the 'flow' that exists between the origin and the target node, meaning in particular, the type of relationship that exists between the two nodes and the quantity that the relationship transfers per time step. With the *ScenarioBuilder BOS* it is also possible to edit or remove individual capacities and requirements as well as entire states. While yes/no relationships are possible and will appear in rare cases, the above examples have shown that capacities and requirements are almost always more complex. Especially in the case of resource dependencies such as electricity or water quantity-specific information is required that can also take dynamic changes into account. Therefore, the application stipulates that for capacities and requirements based on resource relationships a mathematical function is specified for the user to describe the corresponding quantity and dynamics. Different function types are available to the user. The application distinguishes between constant, linear and non-linear operations. An overview of the available functions including an example is given in Table 6.2. While the parameter t represents the current time step the scenario is in, p_1 and p_2 are parameters that the user has to select to describe the functions in more detail. In some cases, the start time t_{start} of the respective node or relationship is relevant as well in order to reflect the true value of the function.

Table 6.2: Overview of the types of functions used by the ScenarioBuilder BOS to describe capacities and requirements

Type of Function	Formula	Example
Constant	$f(t) = p_1$	A water tank has a specific, constant capacity of e.g. 2000 litres, regardless of the time.
Infinite	$f(t) = \infty$	A special form of a constant capacity where the quantity is in any case sufficient or unlimited, e.g. a hydrant.
Linear	$f(t) = p_1(t - t_{start}) + p_2$	A linear rise in the water level at a dike due to constant rain.
Exponential	$f(t) = p_1 e^{(p_2(t - t_{start}))}$	The availability of volunteers in the initial phase of an emergency after the alert or the spread of an epidemic.
Logarithmic	$f(t) = p_1 \ln(p_2(t - t_{start}))$	The pump capacity or the amount of water delivered during the pump start-up phase.

Creating and Manipulating Events

In addition to the nodes and relationships, *events* are introduced as a further basic element in the *ScenarioBuilder BOS* to support the development and analysis of scenarios. Events describe external occurrences that can have a negative effect on the entire system described in the scenario or individual nodes from it. An example of events are disasters such as floods or earthquakes. Events like these can have a direct effect on nodes within their temporal and spatial scope of influence and can limit or completely destroy their functionality. For example, a gas station damaged in an earthquake may not be able to operate at all or only to a very limited extent. In the application, events are indirectly visualized through the nodes affected by them. As soon as a node is restricted in its function or completely destroyed by an event, it and all relationships originating from it are outlined with a red frame as demonstrated on the left side of Figure 6.3. The application supports the creation, manipulation and deletion of events. When creating an event, the user must define a name for identification purposes, a period of time within which the event will affect the respective nodes as well as the affected nodes themselves. Furthermore, for each node it must be specified if its function is impacted only during the active time of the event or whether or not the effects linger afterwards. Different events can exist within the same time frame and also affect the same nodes.

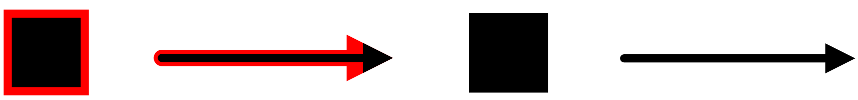


Figure 6.3: Functional (right) and non-functional (red outlined) nodes and relationships (left)

Linking Scenarios to Each Other

When planning exercises it is not uncommon for there to be a request to involve various organizations and hierarchical levels in the exercise and to develop an appropriate scenario. Since these different stakeholders sometimes define different goals for their own teams and may have very different procedures, the development of an overall scenario is very complex and time-consuming. An example of such an exercise is the regularly held LÜKEX (see section 3.4). This exercise, which takes place under one central scenario, contains a multitude of smaller subordinate scenarios involving a subset of the participating organizations, authorities and companies. For example, at LÜKEX 18 which simulated a gas shortage situation in Germany as a central exercise scenario (BBK, 2019b) different sub-scenarios were developed and processed by the participating states and authorities that more specifically reflected their own needs and exercise objectives. This can make the analysis of the scenarios more complicated since each sub-scenario is an independent scenario but while being influenced by the higher-level one. On the other hand, incidents in a sub-scenario can also have an impact on a higher level.

Another example intending to illustrate how the *ScenarioBuilder BOS* deals with such linked scenarios is visualized in Figure 6.4. The figure shows an excerpt from a disaster scenario of an urban damage event in which communication is to be examined on two levels. On the superordinate level (top part of the figure) the interactions between different urban actors are shown. The bottom part of the figure specifically considers the interactions within the disaster management staff (KatS-Stab) and thus represents the subordinate level of the scenario. The difference to an unlinked scenario is the node “External”. This is, so to speak, a mirror image of the node “KatS-Stab” and its relationships from the superordinate level. Incoming relationships in the superordinate level are displayed as outgoing relationships in the subordinate level and vice versa. With the possibility of linking scenarios, the application can be used to reduce the complexity of such scenarios and map multi-layered scenarios. However, it is necessary that the boundary conditions, especially the time reference, are the same for the different scenarios. If a node within a scenario refers to a higher-level or lower-level network, the user can recognize this by the extension ‘Linked’ in the node label. Switching between the different scenarios can be done via the nodes “KatS-Stab” and “External”.

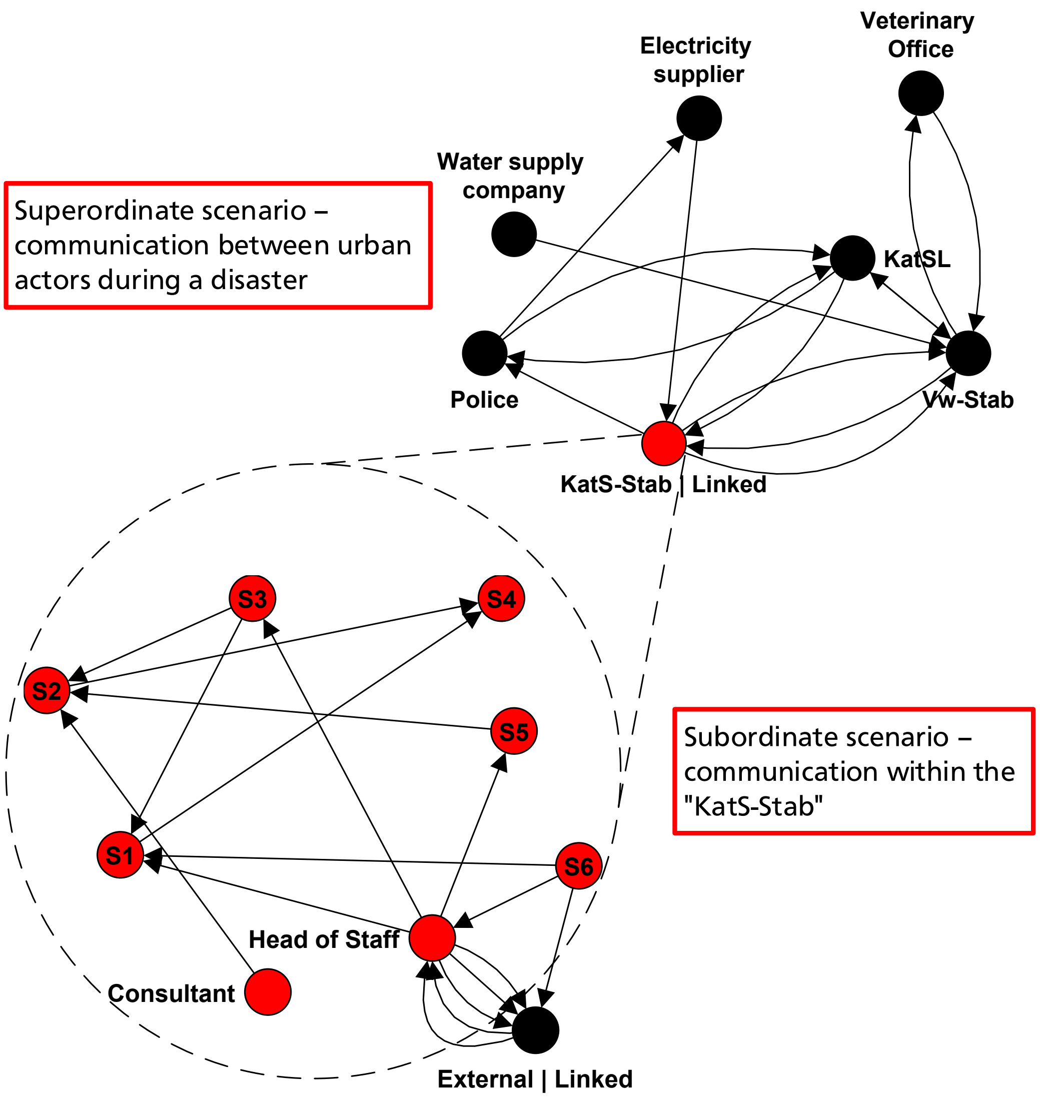


Figure 6.4: Example of a linked disaster scenario visualizing the communication relationships between the urban actors (black nodes) in the superordinate scenario (top) and within the disaster management staff (red nodes) in the subordinate scenario (bottom)

Importing Scenario Templates

The planning of exercises and especially the development of scenarios is a very time-consuming process for the exercise planners. In order to reduce this time expenditure, many organizations collect exercises that have been planned previously so that they can be reused in a similar or modified form at a later date. The *ScenarioBuilder BOS* picks up this concept and gives the user the possibility to save already developed scenarios as templates and reuse them in later exercises. In particular, it enables the import of one or multiple templates in a scenario and thus supports an efficient design of the relevant situation. When importing, all nodes and their relationship structures are transferred to the new scenario so that they can be directly reused and known dependencies do not have to be created again in order to be included in the analysis. Templates are particularly suitable for static systems and structures that do not vary greatly, such as the energy network of a district or the units of the supra-regionally deployed Medical Task Force (MTF) (BBK, 2018). When using templates attention must be paid to the temporal boundary conditions. Although the start and end times are irrelevant for a template, the definition of the time span per time step must be consistent between the scenarios so that there is no distortion of relationships and capacities.

6.3. Scenario Analysis

As soon as a first version of a given scenario is developed, the user can switch back and forth between the scenario development and its analysis. The *ScenarioBuilder BOS* offers different options for analyzing the scenario that may be utilized by the user depending on the defined exercise objectives and the phase in which the application was used. For example, the scenario can only be simulated if the required data has been stored. Also grouping or filtering of nodes is especially interesting for complex scenarios with many nodes. Since the application always saves all created scenarios, the analysis can be performed temporally independent and a comparison of different scenarios can be carried out at any time.

Reviewing the Network in Different Layouts

A central goal of the software is to enable the user to view the scenario from different perspectives. This should aid in obtaining a better overall picture of the scenario or exercise and in grasping connections that have not yet been considered. One way in which the *ScenarioBuilder BOS* allows the user to view the scenario from different perspectives is to analyze the scenario through different layouts. These are one of the most important elements of network visualization (see section 4.4) and support the user's understanding of structural relationships. The application provides the user with a number of layouts that offer advantages for different use cases. These include but are not limited to:

Auto-generated layout: With the auto-generated layout, a dynamic force-directed layout such as the Fruchterman and Reingold (1991) algorithm is used by the application to support the user, especially in scenario development (see section 4.4). Since the algorithm determines the placement of the nodes with the aim of achieving the greatest possible clarity, newly generated nodes are distributed sensibly in the user's field of view and a minimization of edge crossings is aimed at. In this way, even with a large number of nodes a uniform picture of the situation is possible and the user can identify groups or clusters of well-networked actors more easily. The layout is disadvantageous in networks with several components (see section 4.2), especially when components consist of only one node because they repel each other and thus components tend to be focused on the corners of the drawing area. Figure 6.5 (a) illustrates the auto-generated layout using an example scenario.

Sociograms: Sociograms form a group of layouts that serve to support human perception in understanding network or scenario information. This is made possible by positioning the nodes according to defined criteria such as the node centrality or the category to which a node belongs. For the exercise context in civil protection and disaster response three types of sociograms are of particular interest, namely the *circular layout*, the *radial layout* and the *group layout*, that are all supported by the *ScenarioBuilder BOS* (see section 4.4). The circular layout can be used very well for comparisons. By arranging all nodes in a circle, the user can easily identify what the direct outreach of a node is and which neighbors it has (see Figure 6.5 (b)). In addition, the nodes are sorted according to a selected criterion so that comparisons between two nodes can be made quickly. For example, the relevance of two nodes can be compared using the degree centrality (see section 4.3) as shown in Figure 6.5 (c).). With the radial layout it is just as easy to compare different nodes based on a selected criterion such as centrality. In particular, the specific arrangement of nodes in concentric circles makes it possible to identify properties that are of similar or even equal value for the associated nodes in a given circle. The group layout offers another possibility of representation for questions concerning, for example, the relationship structures within and between teams. Here, nodes are placed according to their node type, or in other words, their category. Each category forms a cluster of nodes which are positioned close to each other while the distance to other clusters is as large as possible. The focus of the display is therefore on the interaction between node types or actor groups which is illustrated in Figure 6.5 (d) (actors are grouped within their team).

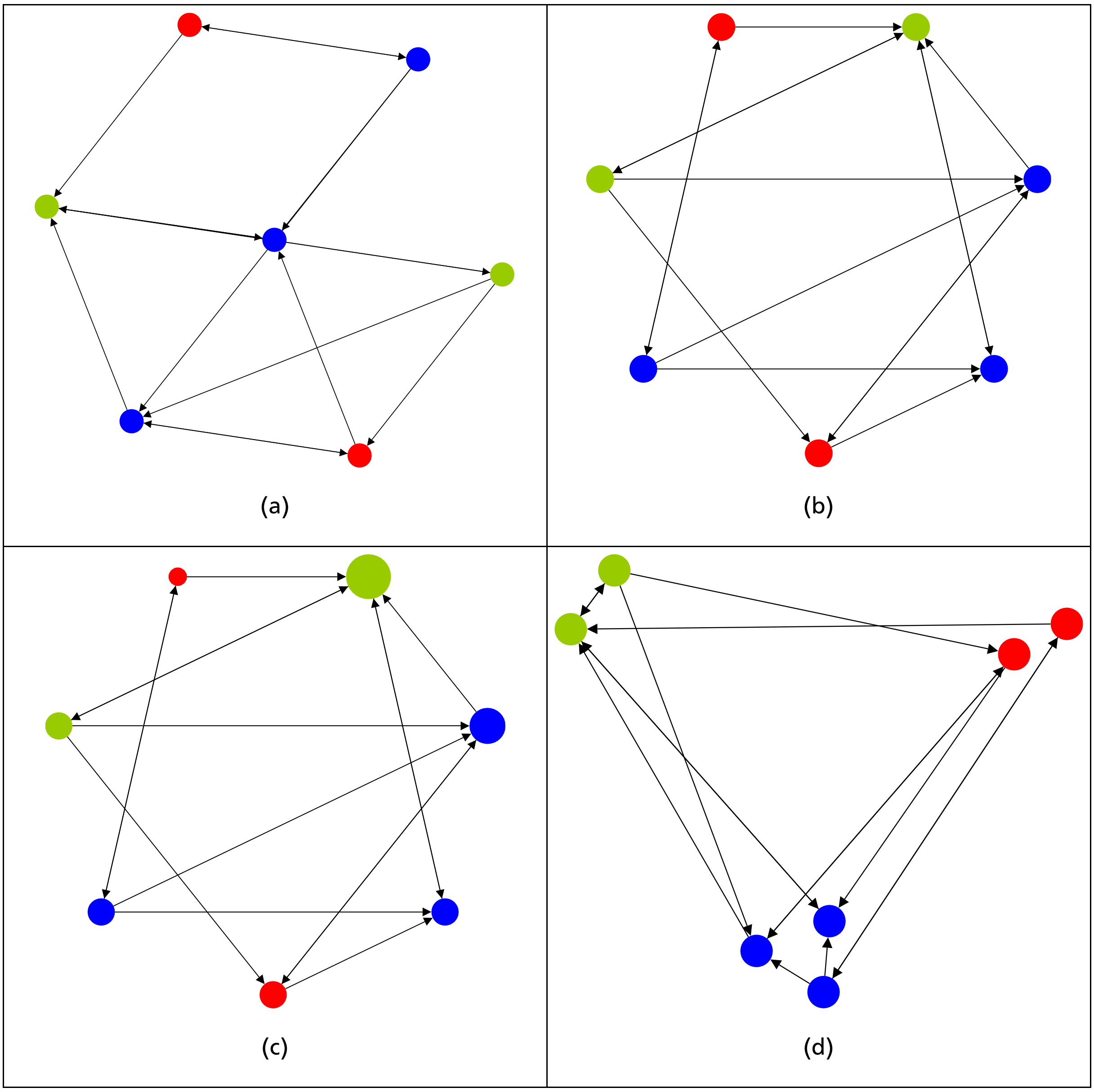


Figure 6.5: Example network with seven actors (nodes) from three different teams (each color represents one team) in different layouts: (a) auto-generated layout, (b) circular layout, (c) circular layout with degree dependent node size and (d) group layout (grouping according to team membership)

Geo-layout: The Geo-layout or situation layout is based on the principle of the situation map and places nodes according to their coordinates on a background map view. To use the layout, the coordinates must be stored as attributes in the nodes and a geo-referenced map with the area of the scenario must be available. The advantages of the layout are its spatial arrangement directly reflecting a real-world situation and the associated clarity about the distribution of the nodes in the exercise area. This makes it interesting for questions that relate to the spatial distribution of, for example, operational forces within the scenario. For instance, one could look into the question of whether or not there are more interactions with nearby actors than with those located further away in a scenario.

User-specified layout: With the user-specified layout, the *ScenarioBuilder BOS* offers a layout that does not follow a special algorithm or a fixed arrangement of nodes but instead flexibly responds to the needs of the user. The layout is initially based on a random layout that places the nodes randomly in the drawing area. Starting from this configuration, the user can vary the position of the nodes as required. The application saves the position changes made so that the user can return to his selected configuration even when changing the layout. The user-specified layout is suitable, for example, for displaying and checking the chains of command in a communication network of a fire brigade. In this case the free arrangement makes it possible to display the nodes in the defined hierarchy levels and to get an immediate understanding of the communication paths between all levels.

Playing Scenario Sequences and Analyzing Path Dependencies

The application enables the user to move within the dynamic scenario network by changing the time step. If a different time step is selected, the *ScenarioBuilder BOS* updates the visual representation of the network graph with all nodes and relationships defined for this point in time. The previously selected layout is also adopted, so that the display remains the same when time steps change. To make it easier for the user to understand the perception of the scenario's temporality, the application further provides the possibility to 'play' the scenario as a sequence. In this case, the *ScenarioBuilder BOS* automatically runs through the individual time steps with a delay defined by the user so that he or she can view the scenario as a film and examine it for its changes. The application supports two different procedures, namely the playback of time steps or of combined time periods. While the former starts with the time step $t = 0$ and iterates over each individual time step, the latter uses a time span defined by the user. In this case, all nodes and relationships defined in the time span are combined into a static network and the application iterates over them. For example, if the user has defined 15 time steps as the span to be examined, the first network of the sequence is composed of the nodes and relationships of the scenario from $t = \{0,1,\ldots,14\}$, the second of those from $t = \{15,16,\ldots,29\}$, and so on. Using a time span is especially useful if only a few relationships between nodes are defined per time step.

A special form of analysis over time provided by the *ScenarioBuilder BOS* is that of path dependencies. When analyzing these path dependencies, the user can examine how the scenario has developed in relation to a specific interaction between two nodes. This can be interesting, for example, if the user wants to investigate how and at what point in time information was communicated between certain members of a team and what reactions this information triggered. Here, questions such as if the information had reached the relevant actors and if the reactions to it where in accordance with the corresponding expectations can be answered. Path dependency analysis can also be used to evaluate the efficiency of processes. For example, is a process completed by three interactions or was a longer path necessary and how much time elapsed until completion? Using the *ScenarioBuilder BOS*, the user can obtain an overview of the paths defined during the scenario development and select them. The corresponding path is then filtered out of the scenario and visualized. For each time step in which a relation to the path exists, a network representation is generated and presented to the user in form of a sequence (see Figure 6.2). In addition, a summary of that sequence is provided by visualizing a merged static network consisting of all nodes and relationships involved in the path as shown in the lower right part of Figure 6.2. This gives the user an overview of the nodes involved in the path as well as the amount of relationships.

Simulating Cascading Effects

As shown in section 5.2, the network-based representation of technical systems is very well suited for the simulation of cascade effects as well as risk analysis. These capabilities also represent an important quality for exercises in civil protection and disaster response when working with scenarios. Especially in planning, scenario simulations can support the user in defining system boundaries or in identifying potential problematic areas or situations. The application's approach to scenario simulation is based on the definition of capacities and requirements that can then be assigned to nodes in order to map their specific capabilities and functions but also their limits and resource demands (see section 6.2). It is also assumed that relationships symbolize the exchange of resources and information and also have a capacity that characterizes the amount of exchange per time step. Since the systems considered in exercises are often dynamic and sometimes vary significantly the approach further assumes that nodes have different states in which their capacities and requirements can deviate. Capacities and requirements are specified by mathematical functions to represent time dependencies adequately.

The *ScenarioBuilder BOS* provides an algorithm for an iterative simulation calculation for each time step in the scenario which includes the capacities and requirements stored in the nodes and relationships as well as the defined events. The algorithm calculates whether a node can fulfill its function taking into account all conditions relevant to the scenario network at that time or whether it is damaged. As the basis for the calculation the user first has to provide information about the conditions defined for each node. In every case, a node has a 'default' state which describes its standard conditions. Furthermore, a 'damaged' state should also be defined for each node that covers the minimum capacities that the node can provide even in a defective condition. An example for this can be a water utility plant: In its regular or default state it provides a certain amount of water. However, if the water utility plant is damaged, it may not be possible to provide any more water yet the employees can still act as experts and provide information to other locations. If no 'damaged' state is defined in a node it is considered to be completely inoperative as long as the node is affected by an event. Defective or fully non-functional nodes and relationships are visualized with a red border as shown in the left part of Figure 6.3 and can have an effect on the rest of the network since no more services can be transmitted by outgoing relationships. Besides the 'default' and the 'damaged' state any number of further states with corresponding capacities and requirements can be defined by the user.

The iterative algorithm used in the *ScenarioBuilder BOS* distinguishes between three levels, the network level (Figure 6.6), the node level (Figure 6.7) and the state level (Figure 6.8), whose functions are further explained in the following.

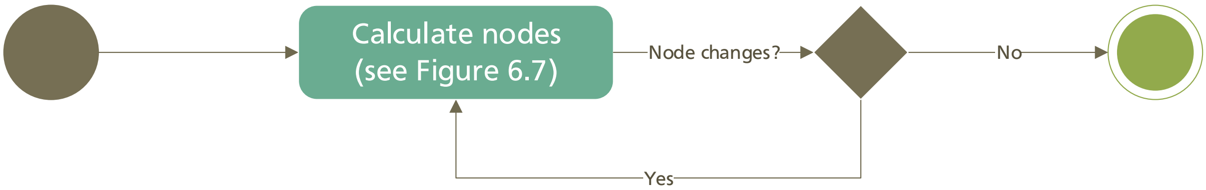


Figure 6.6: Activity diagram for the calculation of the scenario network simulation (network level)

A simulation calculation is performed by the *ScenarioBuilder BOS* each time the scenario network is changed. This includes adding or editing an element (node, relationship or event) and changing the time step. As shown in Figure 6.6, at least one iteration is performed at the network level for the simulation calculation. Each node defined at the current point in time of the scenario is calculated individually based on its stored capacities and requirements, the relationships connected to it and the existing events. The simulation checks whether there is a change to the previous situation of the node. If this is the case for at least one node a new iteration is triggered since the change that is now present can in turn affect other nodes in the scenario. If there is no change in any of the nodes the calculation for the time step is finished and the network visualization can be updated.

At node level, as shown in Figure 6.7, the situation of the node, i.e. values such as its functional readiness, are first stored so that at the end of the calculation they can be compared with the new situation and checked to see if there has been a change in the node. Afterwards it is checked whether the current node is already completely defective (or marked as 'totally failing') in the time step in which the scenario is currently in. In this case, no further calculations are necessary and the node's attributes are set to 'not functioning'. This implies that all outgoing relationships must also be declared as 'inactive' and cannot transfer any more capacities.

If a total failure was not already present, it is subsequently checked whether the node is affected by one or more events in the current time step. If this is the case, it is then examined whether at least one of the events affecting the node leads to its complete failure. If this check is affirmative the attributes of the corresponding node are marked as 'totally failing' and the calculation for the node in the current iteration is finished. Since in this case a change in the node has taken place another iteration of calculations at network level is triggered after computing the remaining nodes of the current iteration (see Figure 6.6).

If the node is neither affected by an event nor does any of the events affecting it lead to a complete failure of its function a calculation on the state level is necessary, provided that states are stored in the node (see Figure 6.8). It is differentiated whether the node is affected by at least one event. If this is the case, the node is transferred to the 'damaged' state and the associated effects of capacities and requirements on the scenario are calculated at state level. Otherwise, if no events affect the node, the calculations are performed for all states, the best possible state is selected and the node is transferred to it. In case of several possible options, the best possible state is selected according to an order defined by the user when creating the states, whereby the 'default' state is always preferred.

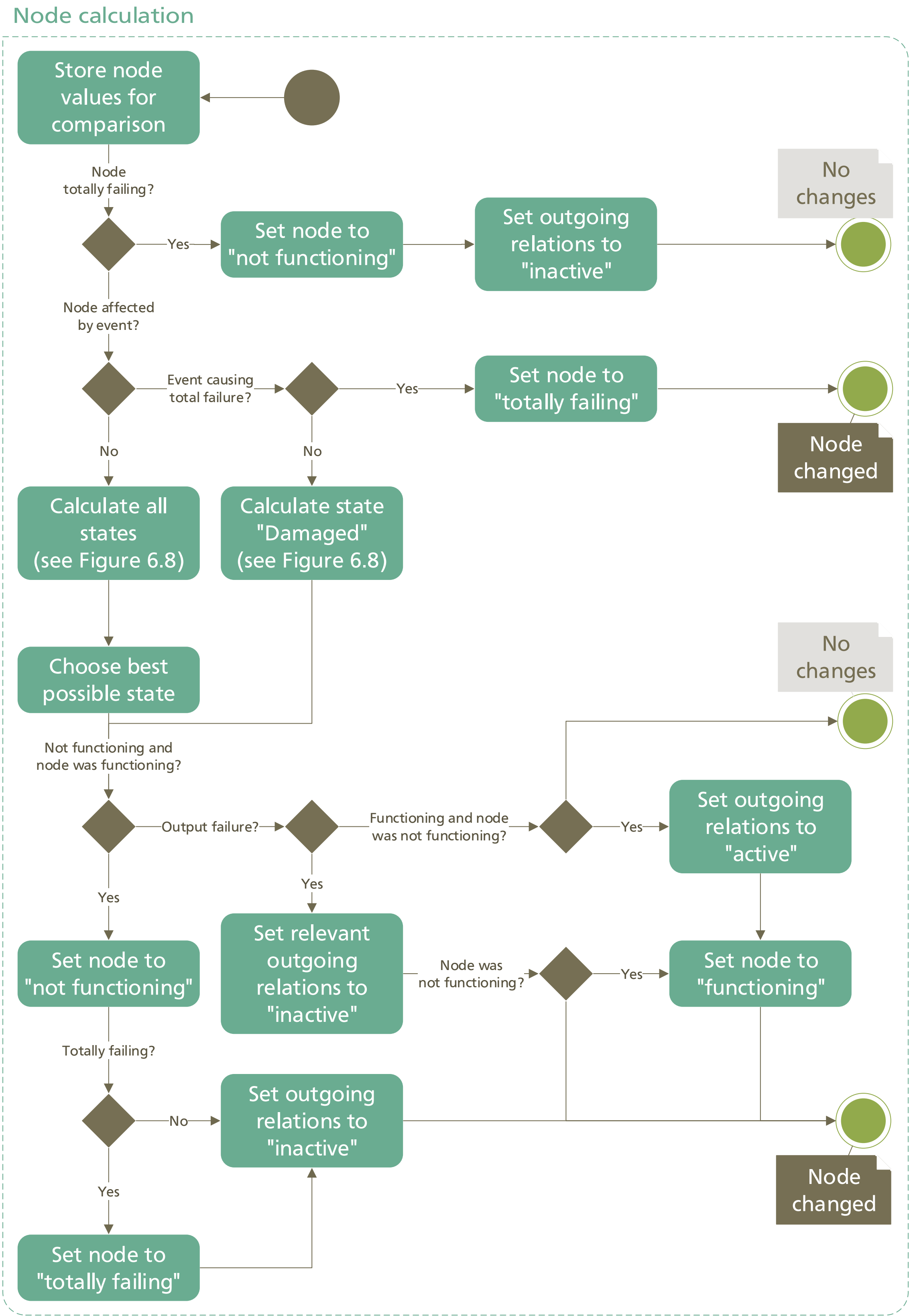


Figure 6.7: Activity diagram for the calculation of the scenario network simulation (node level)

After the state calculation, the situation of the node must be compared with the situation stored at the beginning of the node calculation. If the node was functioning before and is no longer functional it is updated and in case of a total failure the nodes attributes are marked accordingly. All outgoing relationships are marked as 'inactive' and a new iteration of the calculation is required. In the event of an output failure, only the affected outgoing relationships are set to 'inactive' and, if the node was not previously functional, it is updated. In any case, there is a node change. For nodes that are functional after the state calculation, it is checked whether they were also functional before. If this is the case, there are no changes for the node. Otherwise, its outgoing relationships must first be activated and its attributes need to be updated.

At state level, the effects of capacities and requirements on the nodes in the respective state are calculated as shown in Figure 6.8. The existing capacities and requirements given for the state are compared with the incoming and outgoing quantities in the relationships. This is done individually for each relationship type. After that, the verification takes place sequentially checking for exceedance of the intake capacity, fulfillment of the requirement and exceedance of the output capacity. A distinction is made between flow-based relationship types (especially resource relationships such as water, energy, etc.) and others. While with flow-based relationships the actual quantities are added up, all others are only recorded categorically. For example, an information that is passed from a node by an outgoing relationship can be passed on an unlimited number of times, even if it has only been transmitted once to the node. On the other hand, a node can only provide an output of water, for example, in the quantity that it has at its disposal or that was made available to it via incoming relationships.

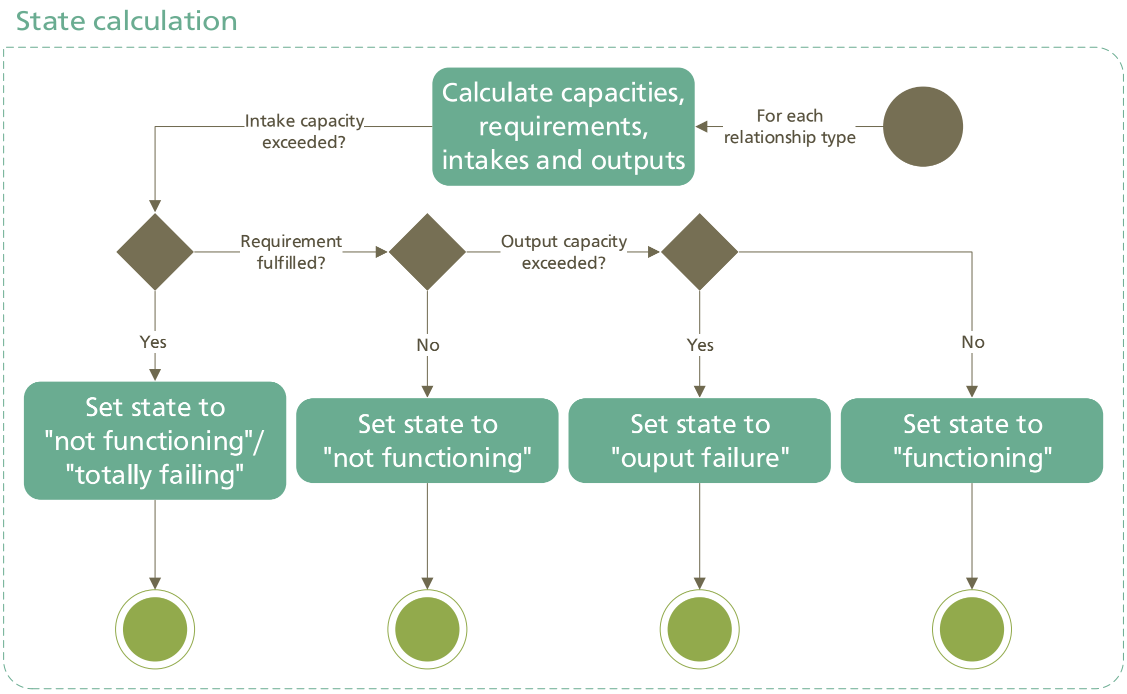


Figure 6.8: Activity diagram for the calculation of the scenario network simulation (state level)

The intake capacity for a specific relationship type is exceeded if there is a maximum capacity defined and the following condition can be applied:

$$intake_x - output_x > C_x^{intake} \tag{6.1}$$

where:

$intake_x: The\ sum\ of\ all\ intakes\ given\ by\ relationships\ of\ type\ x$
$output_x: The\ sum\ of\ all\ outputs\ given\ by\ relationships\ of\ type\ x$
$C_x^{intake}: Maximum\ possible\ intake\ capacity\ of\ the\ relationship\ type\ x$

If in the state under consideration there is at least one intake capacity of a relationship type that has been exceeded and which was not declared reversible by the user when it was created, the node in this state is considered completely non-functional and the state is updated accordingly. If this is not the case, but there are one or more exceeded intake capacities that are reversible, the node for this state is only declared as 'not functioning' and not as 'totally failing'. If both of these cases do not apply and no intake capacity has been exceeded, the system checks whether all requirements have been fulfilled. A requirement is not fulfilled if:

$$intake_x < R_x \tag{6.2}$$

where:

$intake_x: The\ sum\ of\ all\ intakes\ given\ by\ relationships\ of\ type\ x$
$R_x: The\ minimum\ intake\ of\ the\ relationship\ type\ x\ that\ is\ required$

If a requirement defined in the state under consideration is not fulfilled and there is no buffer capacity for it, the node cannot perform its function in this state and the state is declared as 'not functioning'. Finally, the algorithm checks whether an output capacity for a relationship type has been defined and exceeded. For this the following condition is used:

$$C_x^{output} < output_x \tag{6.3}$$

where:

$output_x: The\ sum\ of\ all\ outputs\ given\ by\ relationships\ of\ type\ x$
$C_x^{output}: Maximum\ possible\ output\ capacity\ of\ the\ relationship\ type\ x$

If the output capacity for at least one relationship type is exceeded, the status for the node in the currently considered state is updated accordingly. Otherwise, all checks are successful and the state is marked with the attribute 'functioning'.

As soon as there are no more changes in any node the simulation calculation for the current time step is completed and the visualization of the scenario network can be updated. In addition to the general simulation calculation, which takes into account the capacities and requirements described in states as well as the events existing in the scenario, the user has the option of running a partial simulation. Depending on one's preference, this only includes one of the two aspects mentioned above in the simulation. Thus, the user can deactivate the simulation of events, which means that the calculation of states follows directly after the check of a complete failure of the node. The simulation of states can also be deactivated. In this case, a node that is affected by an event and thus not completely disabled will be declared as 'not functioning'. Likewise, if no event affects the node it is considered functional. In case the simulation of states is activated but a node does not have a damaged state, the algorithm assumes that the node has no capacities when it is damaged and directly declares it as 'not functioning' without further calculations.

Furthermore, in order to enable the simulation being compatible with the user's ability to switch between any two time steps (even if they are not consecutive) of the scenario a special consideration has to be made: Since this incurs the need to differentiate between a 'damaged' and a 'totally failing' node, the application performs a one-time simulation calculation for all time steps within the time range of the scenario defined in the boundary conditions. In this calculation the *ScenarioBuilder BOS* determines the respective time step for which each node is affected by a total failure for the first time, considering that the nodes are affected by an irreversible intake capacity and/or an event. In the course of this calculation, these time steps are stored in the corresponding nodes and are included in the general simulation calculations for a single time step when checking the occurrence of a total failure (see Figure 6.7). To further take into account cases where the failure of a requirement may be compensated for a certain time by appropriate buffer capacities, the application enables the user to specify a buffer time when creating requirements within a state. An example for such a buffer capacity can be the already mentioned hospital example. Here, it can generally be assumed that the hospital can only treat patients if a power source is available. However, if the hospital has an emergency power supply it can guarantee the treatment for a certain time even in case of a power failure. The *ScenarioBuilder BOS* assumes that a defined buffer is only used once and calculates the respective times when a node is no longer functioning accordingly during the one-time simulation through all time steps.

Combining different relationship types in varying time horizons

Exercise scenarios often extend over periods of several hours and include a large number of independent and/or interrelated procedures and processes, some of which are carried out in parallel, e.g. by different teams, while others are carried out in a consecutive manner. For the analysis of specific questions within a scenario this results in very different time horizons that have to be considered. For example, if the analysis is focused on the consecutive steps of a process, individual time steps considered one after the other or replaying the time range as a sequence can already enable initial understanding and interpretation approaches. If, however, questions are to be answered that relate to specific time periods such as the question of the interconnectedness of the actors within a given situation, it is necessary to obtain a combined representation of the relevant relations within that time period. To meet this requirement the *ScenarioBuilder BOS* offers the user the possibility to select different time horizons, visualize them in a bundled way and analyze them further. For the visualization of these time horizons the user can choose between different display formats which are illustrated in Figure 6.9. It shows an example communication scenario with six actors from two different teams (one team represented by blue box-shaped nodes and the other by red circle-shaped nodes). All relations describe information relationships. While Figure 6.9 (a) shows the relationships from the individual time step $t = 0$ and thus the very beginning of the scenario, Figure 6.9 (b) to (d) illustrate the communication within the first twenty minutes of the scenario ($t = \{0,1,\ldots,19\}$). Here, the resulting network graph contains all nodes and relationships of the scenario for which the following applies:

$$start\ time \leq t_{end} \vee end\ time > t_{start} \quad (6.4)$$

where:

$start\ time$: $The\ start\ time\ defined\ in\ the\ respective\ element\ (node\ or\ relationship)$
$end\ time$: $The\ end\ time\ defined\ in\ the\ respective\ element\ (node\ or\ relationship)$
t_{start}: $The\ first\ time\ step\ in\ the\ time\ range$
t_{end}: $The\ last\ time\ step\ in\ the\ time\ range$

The representation of nodes and relationships for the time domain can be in the form of a multigraph (Figure 6.9 (b)), an overlap network (Figure 6.9 (c)) or a projected network (Figure 6.9 (d)) (see section 4.2) and should be selected according to the questions and needs of the users.

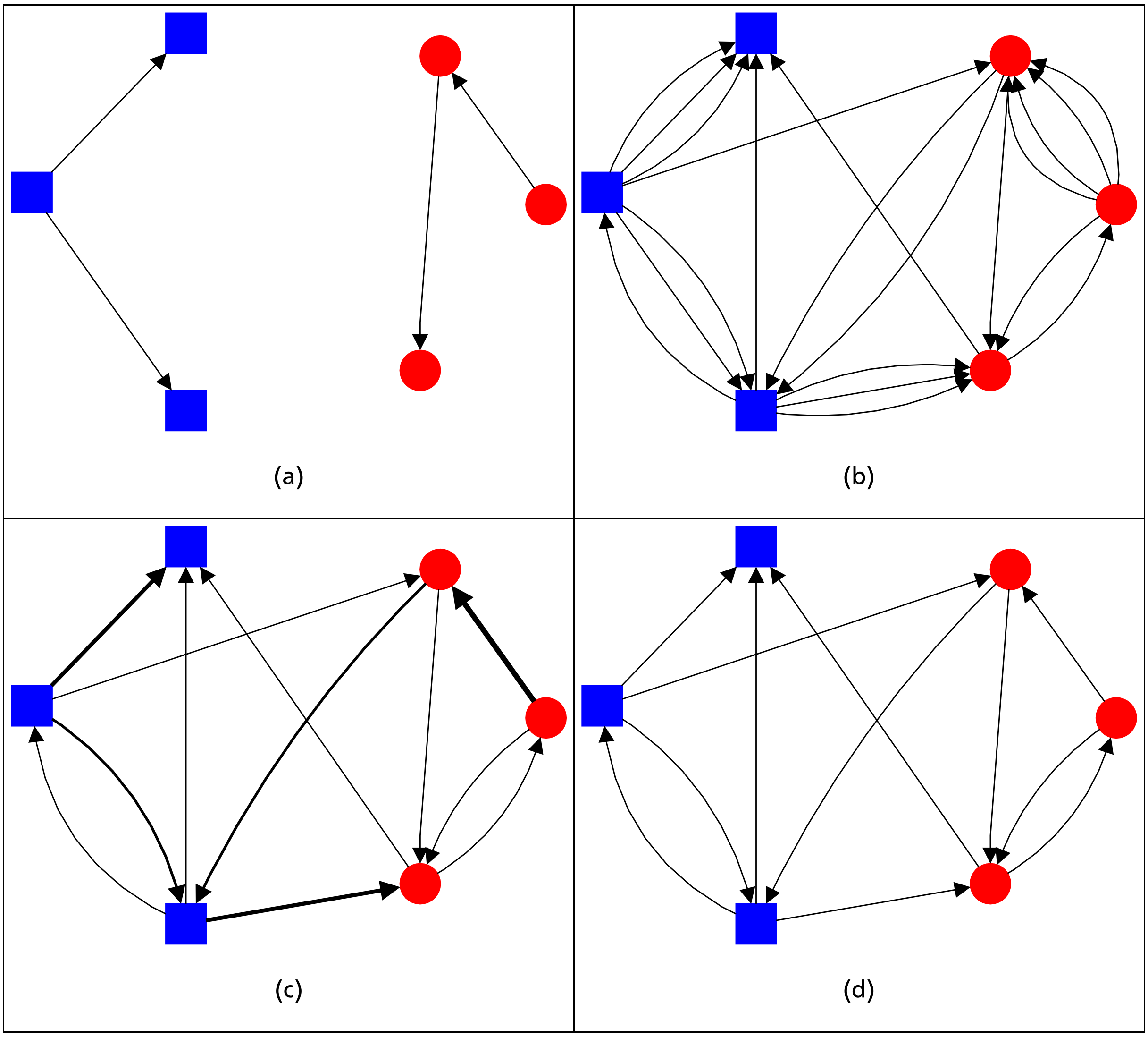


Figure 6.9: Example scenario for visualizing the communication of actors from two teams (blue box-shaped nodes and red circle-shaped nodes) in different time horizons; information relationships in (a) a single time step t=0 and for the time range t={0,1,...,19} represented by (b) a multigraph network, (c) an overlap network and (d) a projected network

As can be seen in the illustration, all three variants have their strengths and weaknesses, which must be weighed up when selecting the form of presentation. The representation as a multigraph makes it possible to identify all relationships individually and, if necessary, to assign them easily to the respective situations of the exercise or to the times in which they occurred by means of additional information in the label. The representation can promote the interpretability of the scenario through meta information. A disadvantage of the display in multigraphs is that it is not easy to understand and the user may be overwhelmed, especially when a large number of interactions occur. Secondly, the advantages of the presentation in an overlap network on the other hand are the greater clarity of the visualization and the possibility to easily compare interactions between actors. Here, the thickness of a relationship makes it easy to identify how often an actor has interacted with another actor without the user having to count the corresponding relationships. The user can be supported by additional information like the interaction frequency, which can be added as a label. A disadvantage in comparison to the multigraph is that individual relationships including their detailed information can no longer be allocated. As a third option, the representation in a projected network offers a very reduced and clear presentation, which is well suited for the investigation of questions such as the aforementioned interconnectedness of the actors or the outreach an individual situation may have in a scenario. A particular disadvantage here is that information on both individual relationships as well as their frequency is lost (see section 4.2).

In addition to the knowledge gained from the temporality of the scenario and the resulting possibilities for analyzing different time horizons, multiplexity is also an important criterion for the analysis of the scenario. Thus, each relationship type can have different implications for the situations in the scenario and a parallel representation of different types of relationships can provide the user with a detailed overall picture. Multiplex scenarios allow a more in-depth analysis of the exercise as they provide different perspectives on the situations they contain. In a communication network, for example, it is possible to not only determine which actors were involved in a situation, but also to draw conclusions about their roles in the team. More specific questions can also be examined. For example, it is possible to distinguish whether a situation was clearly understandable to all actors and only a general exchange of information took place, or whether a situation led to discussions within the team. Basically, it depends on the question under investigation which types of relationships have to be considered in the analysis and whether they should be evaluated separately or in combination. Here, too, the *ScenarioBuilder BOS* offers the user various options for analysis.

As illustrated in Figure 6.10 (a) to (c), individual relationship types can be viewed and analyzed separately or they can be combined in one network graph for the analysis as shown in Figure 6.10 (d). The figure uses the time range $t = \{0,1,\dots,9\}$ from the exemplary communication network for better clarity and distinguishes between three types of communication relationships, namely general information exchange represented by black lines (Figure 6.10 (a)), discussions represented by orange lines (Figure 6.10 (b)) and questions represented by purple lines (Figure 6.10 (c)). If one looks exclusively at the information relationships, it becomes clear that here all six actors are linked with each other and information is well distributed in the network. This is different when looking at the discussion relationships: Here, two groups that discuss the situation separately from each other can be identified in the time period. The combination of the two in conjunction with the question relationships provides an overview of the entire communication during the observed time period (Figure 6.10 (d)).

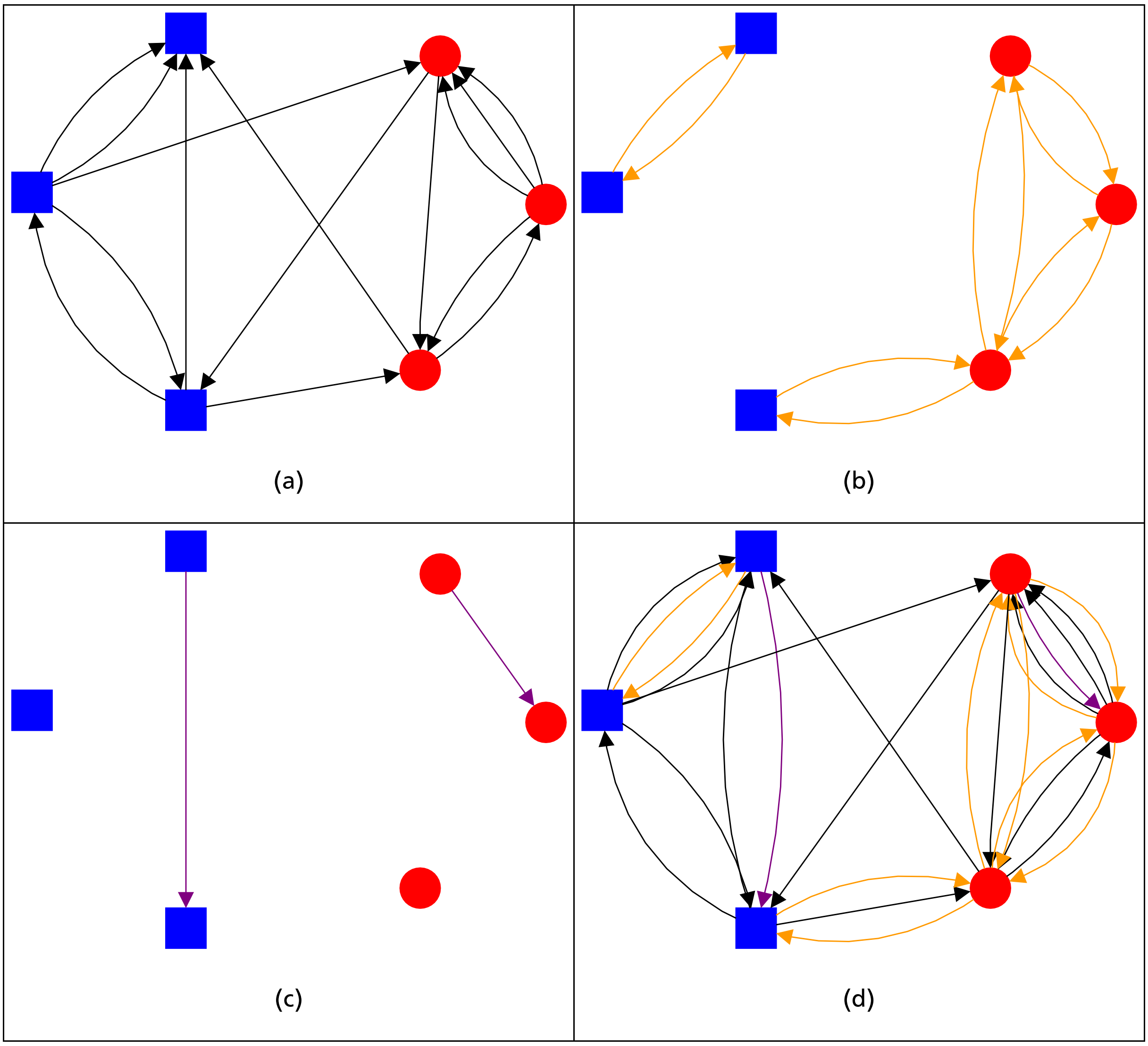


Figure 6.10: Example scenario for visualizing the multiplex communication of actors from two teams (blue box-shaped nodes and red circle-shaped nodes) for the time range t={0,1,...,9} including (a) information relations (black lines), (b) discussions (orange lines), (c) questions (purple) and (d) a multigraph representation of all communication relationships

The combination of different relationship types can be flexibly selected by the user. In addition to the explicit selection of individual types or the combination of all types used in the scenario, two or more relationship types can also be combined via the application in order to investigate specific questions. Their superordinate categories are often suitable for combining relationship types. For example, questions often refer to all communication relationships in an exercise scenario, or a deeper look at the entirety of resource relationships is required to understand the existing dependencies. As with the representation of different time horizons when considering individual relationship types, the *ScenarioBuilder BOS* also offers the user various options for the representation of multilayer networks that contain relationships of different types as well as of multiple time steps. Among these is the representation in a multigraph as used in Figure 6.10 (d). With this form of representation all interactions and the information derived from them are directly presented to the user. Since that might, however, have a negative effect on the clarity of the representation the user can also use one of the display formats shown in Figure 6.11 for the same example scenario as before, which each combine individual relationships in order to increase clarity. The graph network can be represented in a weighted multigraph (Figure 6.11 (a)), in which all relationships of the same type and the same direction between two nodes are merged and weighted depending on the number of relations. Furthermore, analogous to the visualization options for monoplex networks, there is also an option to display the relationships as overlap networks (Figure 6.11 (b)) or projected networks (Figure 6.11 (c)). In both cases, relationships are visualized as a bundle (using grey lines) regardless of their type.

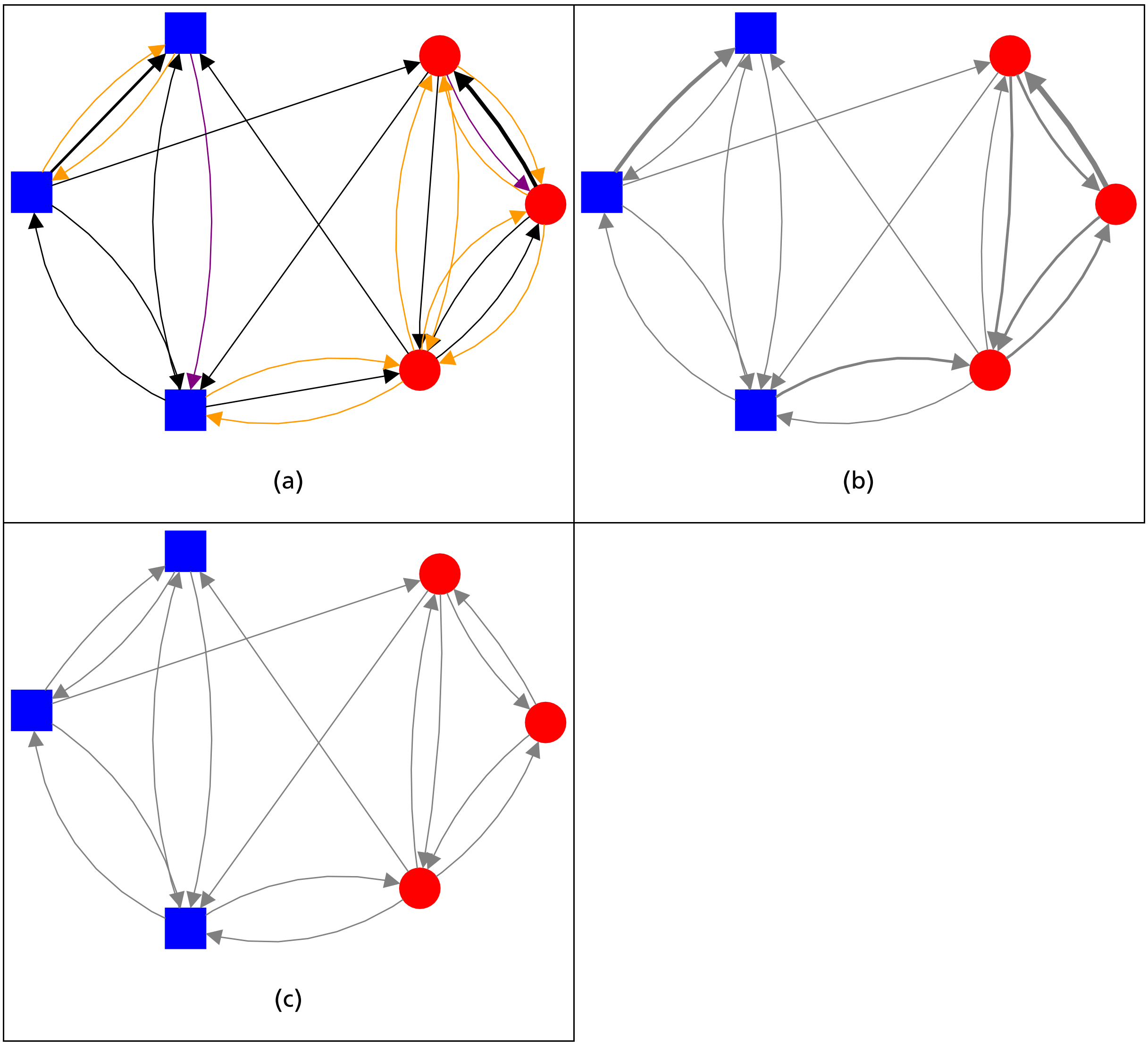


Figure 6.11: Different options for visualizing combined relationship types in a multilayer communication scenario with actors from two teams (blue box-shaped nodes and red circle-shaped nodes) for the time range t={0,1,...,9}; (a) weighted multigraph (relationship types can be differentiated by color: general information – black, discussions – orange and questions – purple), (b) overlap network and (c) projected network (bundled relations of differnet types are represented with grey lines)

While the analysis of combinations of different types of relationships can be very useful for the understanding of exercises in civil protection and disaster response, it is important that the user develops an understanding of the possible analysis errors. This can be well explained using the example of communication networks. In these networks, the distinction between different types of relationships can be very helpful, because, for example, connections between discussions and information relationships can be established. Another example is the combination of request and command relationships, which can be used to check the communication structures in an organization and determine if they are correct and if certain actors obtain a specific role. However, if one combines communication relationships such as information interactions with resource relationships, conclusions cannot be generalized to the same extent. For example, it cannot automatically be assumed that the network promotes a distribution of information between actors simply because it has multiple resource relationships. Therefore, for the analysis of scenarios, the combinations of relationship types should be chosen sensibly and interpretations should be questioned and, if necessary, verified by other combinations or the analysis of individual relationship types. In this way, the *ScenarioBuilder BOS* allows the scenario networks to be examined from different perspectives.

Calculating node centralities

A central function of the application, which in most cases is performed in combination with the analysis of temporality and multiplexity, is the calculation and evaluation of the centrality of the nodes or actors in the scenario network. As explained in section 4.3, centrality is one of the most frequently used concepts for the analysis of social networks. With its help, the relevance of different actors within a scenario can be examined and compared to other actors. By being able to carry out the calculation for specific time horizons and likewise consider different multiplex relationship structures, the user can use the application to investigate centralities including dynamic centralities that have been classified as particularly relevant in the research literature (see sections 5.1 and 5.2). The *ScenarioBuilder BOS* supports many common centrality measures such as degree, closeness, betweenness and eigenvector centrality as well as derivatives such as the PageRank (see section 4.3).

The degree centrality can be used to highlight and examine nodes that are particularly well connected or have a lot of activity on a local level. When analyzing exercise scenarios it can be used, for example, to examine the relevance of the crisis team in operational planning and implementation and thereby check the correctness of predefined hierarchical structures. It is also suitable for identifying actors that may potentially be challenged too much or too little. For example, if an actor is only rarely involved in a scenario and due to that has few interactions with other actors, this can have a negative effect on his exercise experience. In addition to this, degree centrality can also be used to identify initiators and recipients of relationships by differentiating between indegree and outdegree centrality. This in turn can be helpful for questions such as command and control. If the scenario has a large number of nodes or if the user wants to identify which actors have acted as superior decision-makers or initiators, centrality concepts such as the eigenvector centrality or the PageRank can be used. These examine the relevance of actors not only on the basis of direct (local) relationships, but also include indirect relationships and thus the extended network. Crisis teams again provide a good example for exercises in civil protection and disaster response. Especially in large exercises such as functional exercises or framework exercises (see section 3.2) staff structures and their integration into the various crisis concepts should be practiced. In order to assess their functionality and structural position the centrality calculation based on eigenvector centrality and PageRank offer a feasible approach.

Closeness centrality, which considers a node to be relevant if it has the shortest possible path to all other nodes, is a good indicator for actors in a scenario who have a good overview of the network under consideration. For the exercise context it is therefore suitable for determining positions for exercise observers, for example. In communication networks, closeness centrality can further be used in the analysis of miscommunication. Here it is assumed that miscommunication occurs when the recipient of a message understands it differently than the sender intended and subsequently passes it on incorrectly. Therefore, the probability of miscommunication increases with increasing intermediate stations at which the message is shared. In addition to communication networks the topic of cascade effects, i.e. the consequential damage or failure of systems starting from a failure or damage of another connected system, is repeatedly addressed in exercises. For the analysis of such cascade effects, betweenness centrality is a good choice. It measures how strongly actors in a network connect different network areas with each other. Thus, it can support the user in identifying bottlenecks or show him critical intersections and transitions between well connected areas. In communication networks, actors with a high betweenness centrality take over important functions in the transfer of information between local clusters. For example, in crisis teams it can be examined which subject areas bring others together in the processing of tasks and are correspondingly strongly involved themselves.

The examples given for the respective centrality measures provide a small overview of possible questions that can be analyzed in the course of an exercise. The user should bear in mind that when analyzing centrality on the basis of a single measure, it is not always possible to make a definitive statement. Instead, interpretation approaches should be developed on the basis of different measures and the relevance of individual actors should always be evaluated with regard to different perspectives. By additionally considering multilayer graph networks with diverse temporal aspects as well as different combinations of types of relationships, the user can gain specific insights from the situations of the scenario and compare them with his/her own experiences from previous exercises as well as with what he/she has witnessed during the scenario. This can be illustrated using an imaginary example: During the analysis of an exercise, it is noted that a group of actors were not well integrated into the general exercise structure and that this resulted in that group not feeling challenged. The integration should have happened via an actor A, who connects the group with the rest of the network. The analysis of betweenness centrality confirms that A has a bridge function in the network but does not yet explain why no integration took place. Only the additional analysis of degree centrality shows that A was involved in a large number of interactions in the network and was potentially overwhelmed by the number of tasks assigned to him. This can be confirmed by the comparison of his indegree and outdegree. While many interactions were addressed to A, some of which should have been passed on to the group, only a few of them actually go out to the group.

For the calculation of centrality, the *ScenarioBuilder BOS* uses the currently examined scenario network with the defined time horizon and the relationship types selected by the user. Furthermore, the calculation also takes the selected display format into account. The results are subsequently visualized by the size of the respective nodes and an additional representation of the centrality value in the node label. This presentation format can be easily understood by the user and supports his/her ability to develop interpretations of the data. In order to avoid challenges caused by nodes that are too large, the application defines a maximum and minimum value for the size and adjusts each node depending on its centrality value. As an example, Figure

6.12 shows the results of the degree centrality calculation using the previously introduced communication network with the relationship types information, discussion and questions. The values shown in the labels are normalized so that they all have values between 0.0 and 1.0. Looking at the four different forms of presentation, some differences can be seen in the results. For example, node E is much less prominent in the representation of the scenario as a multigraph than it is in the representation using the overlay network. This is due to the fact that the calculation of the degree centrality in the present case is based exclusively on the number of incoming and outgoing relationships and no edge weights (which in this case represent occurrences) are included in the calculation. If the degree centrality is calculated in such a way that it integrates not only the number but also the weight of the relationships (as shown in Table 6.3), the results are the same for multigraphs, weighted multigraphs and overlay networks. Only the representation in a projected network is different, which is logical considering the nature of this representation format because it allows at most one relationship between two nodes in the same direction and the relationship always has the weight of 1.0.

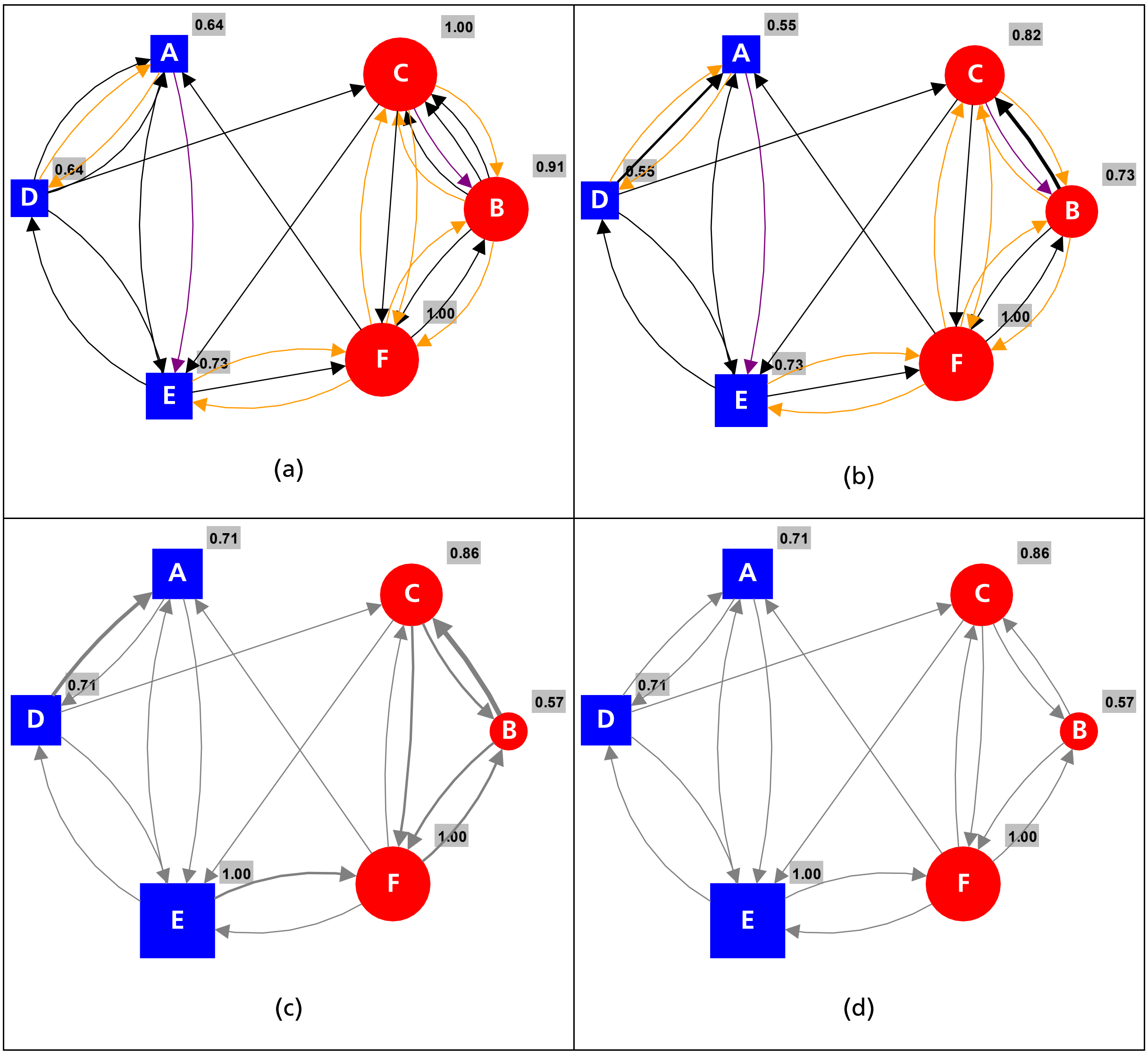


Figure 6.12: Different options for visualizing (degree) centrality calculations of a multilayer communication scenario with actors from two teams (blue box-shaped nodes and red circle-shaped nodes) and node size depending on the centrality value for the time range t={0,1,...,9}; (a) multigraph, (b) weighted multigraph (relationship types can be

differentiated by color: general information – black, discussions – orange and questions – purple), (c) overlap network and (d) projected network (bundled relations of differnet types are represented with grey lines)

Table 6.3: Degree centrality calculations (including relationship weights) of a multilayer communication scenario for the time range t={0,1,...,9} and different forms of representation

	A	B	C	D	E	F
Multigraph	0.64	0.91	1.00	0.64	0.73	1.00
Weighted Multigraph	0.64	0.91	1.00	0.64	0.73	1.00
Overlay Network	0.64	0.91	1.00	0.64	0.73	1.00
Projected Network	0.71	0.57	0.86	0.71	1.00	1.00

In addition to the degree centrality, other measures of centrality can also produce different results when looking at the different forms of presentation, as illustrated in Table 6.4 and Table 6.5 using betweenness centrality as an example. While Table 6.4 includes the weight of the relationships in the calculation of betweenness, Table 6.5 uses an algorithm that excludes the weight. Comparing the two tables it can be seen that in Table 6.5 the approximate relationship or order of centrality of the nodes remains the same throughout all forms of representation although some of the values are different. In Table 6.4, different centrality values for the same node in different forms of representation can also be seen but what is particularly striking here is the high relevance of Node D in the overlay network compared to the other forms of representation, which can be attributed to the consideration of the weight. The problem that arises is that the question regarding the meaning of the weight is determined by the implemented algorithm. As it is the case in the *ScenarioBuilder BOS*, the weight can represent the frequency of a relationship and therefore be evaluated positively (higher weight means that the node has more connections within the network). However, if the weight of a relationship represents, for example, the distance between two nodes, as is often the case when calculating the shortest routes in logistics, then the weight is assigned a negative attribution. This negative attribution is again reflected in the calculation of centrality as shown in the example of Table 6.4.

Table 6.4: Betweenness centrality calculations including relationship weights of a multilayer communication scenario for the time range t={0,1,...,9} and different forms of representation

	A	B	C	D	E	F
Multigraph	0.16	0.00	0.62	0.34	0.98	1.00
Weighted Multigraph	0.16	0.00	0.52	0.32	0.97	1.00
Overlay Network	0.18	0.00	0.55	0.64	1.00	0.82
Projected Network	0.18	0.00	0.61	0.43	1.00	1.00

Table 6.5: Betweenness centrality calculations of a multilayer communication scenario for the time range t={0,1,...,9} and different forms of representation

	A	B	C	D	E	F
Multigraph	0.16	0.00	0.62	0.34	0.98	1.00
Weighted Multigraph	0.16	0.00	0.52	0.32	0.90	1.00
Overlay Network	0.18	0.00	0.61	0.43	1.00	1.00
Projected Network	0.18	0.00	0.61	0.43	1.00	1.00

As it is not necessarily clear to the user which underlying view of the networks represented is considered by an algorithm when using the centrality as analysis paradigm, it is recommended to use different forms of representation and measures when analyzing them for scenarios. In order to further reduce uncertainties regarding the meaning of weights, interpretations should be based on the representation as a multigraph or, for some questions, on that of the projected network. As described in section 4.3, the interpretation of the centrality calculation results should be directed at the network under consideration. The results of centrality are always dimensionless and should only be used in comparison with other results of the same network and not considered individually. With normalized results as in Figure 6.12 or in Table 6.3, Table 6.4 and Table 6.5, the centrality values are always between 0.0 and 1.0. Without normalization, they take values from positive real numbers. In the literature, the mean value and the standard deviation are often used to assess the centrality of individual actors or nodes. Nodes whose centrality is above the mean value of all nodes in the considered network or above the 1-sigma environment (mean value plus simple standard deviation) are considered to be central (Diviák et al., 2019; Houghton et al., 2006). Often several measures of centrality are used together to interpret the relevance of nodes in the network. Furthermore, centrality can be used to make statements about dynamic changes in the network. For example, it can be analyzed whether the centrality of a node changes over time or whether the number of relationships in the overall network increases or decreases. For the example network from the figures and table above, node F in particular can be identified as very central. Due to its high degree-value, this node shows a strong local networking capability (see Figure 6.12) and continues to function as a mediator or bridge in the overall network, which is shown by its high betweenness-value (see Table 6.5). Nodes B, C and E also occupy special positions in the network, but these are not as prominent as those of node F.

In addition to selecting the centrality measure in the *ScenarioBuilder BOS*, the user can choose whether the results should be normalized to be interpreted more easily. Furthermore, the user can determine that nodes and their associated relationships should not be included in the calculation if they are affected by an event or otherwise not functioning. To provide the user with a possibility to use and further investigate the centrality data of the scenario in other software besides the graphical analysis within the application, it is possible to export the results of the centrality calculation for the current scenario network as a CSV file. This is especially useful for creating analysis reports during the evaluation of exercises or in the context of planning. During the export, the centrality calculation is performed for all display formats (multigraph, weighted multigraph, overlay network and projected network) and written to the CSV file one after the other. In addition, if the currently considered scenario network contains several relationship types, the centrality vectors (see section 4.3) of all nodes are calculated and also written to the CSV file. For the calculation, the *ScenarioBuilder BOS* creates a monoplex network in the background for each relationship type and performs the different centrality calculations on it. Thus, the user receives the centrality results for the combined scenario network as well as for its individual monoplex parts when exporting. The considered time range always remains the same and no further combinations of relationship types are included.

Grouping and filtering nodes

The analysis functions described so far always referred to the entire scenario network or to all nodes and relationships within the selected time horizon and the specified relationship types. In some situations, however, specific areas of the network may be of particular interest to the user or additional information on individual nodes may be required. To support the user in these situations, the *ScenarioBuilder BOS* provides a number of additional help functions. For example, the user can display all relevant information on individual nodes in an overview at any time. The information listed includes status information such as:

- the name and type of the node,
- the time period for which it is defined
- and a list of incoming and outgoing relationships.

In addition, information relevant to the simulation or centrality calculation, if available and relevant, is displayed. These include:

- the current state and condition of the node,
- a list of its available capacities and the necessary requirements at the current time
- and its centrality and the node degree.

Furthermore, the user can interact with individual nodes using filter and grouping functions (see section 4.4). The filtering of nodes is provided through two approaches. Firstly, nodes can be activated and deactivated individually. This can be used to increase clarity in complex scenario networks or to quickly check how the network would behave and develop if the node would not work or not exist at all. This can be used, for example, to question if required information would still be transmitted or if it would be missing entirely in a given situation. In the latter case, the problem could be taken up during the planning phase and solutions may be developed. The second way of filtering nodes is the extraction of so-called 'ego networks'. The application displays only the direct relationships and the corresponding neighbors of a selected node (the 'ego'). In addition, the relationships between the displayed neighbors are also mapped. Ego networks can be used, for example, in the evaluation of exercises to make individual participants aware of their local (communication) relationships and the associated role/position in the scenario. The visualization of ego networks also enables the user to compare different actors and their interactions in a situation.

Grouping can be used to combine different nodes into one. This increases the clarity of the scenario network and/or highlights specific aspects. For example, all actors of a team can be combined into one node in order to examine the interactions and the related role of the team in comparison to the rest of the scenario. When grouping, the user selects all nodes he wants to combine and defines a name for the group. All relationships between one of the nodes involved and an external one are then reassigned by the application. With the defined groups, further analyses can then be performed, such as calculating the centrality.

6.4. Practical Use of the ScenarioBuilder BOS and Possibilities for Enhancement

The designed application is intended to support the user in modeling and analyzing scenario-based exercises and to give him/her possibilities to understand and interpret individual occurrences or entire scenarios. The concept follows a generalized approach to make the *ScenarioBuilder BOS* usable for a variety of exercises. In the foreground are the analysis of relationship structures based on centralities and path dependencies as well as the simulation of states and capacities of individual nodes caused by dependencies defined by relationships and resulting cascade effects. Not all modeling and analysis functions are relevant and practical for all exercises. Generally, it can be assumed that the simulation functions are more suitable for the representation and analysis of technical systems, for example in exercises that deal with infrastructure failures. Simulations can also be beneficial for exercises where the scenario is composed of several situations with different dependencies and where strategic aspects or the implementation of predefined processes are in the foreground. The analysis of centralities on the other hand is particularly interesting for exercises in which communication is to be examined. This is especially true for exercises that practice the establishment and operation of staffs or in which a large number of different groups and teams work together and the communication structures in the team and beyond are of interest.

The use of the *ScenarioBuilder BOS* can be interesting for both discussion-based and operation-based exercises. The actual use and the functions applied depend on the orientation of the exercise and the phase in which the application is used. For example, it could be used to conduct a discussion-based exercise such as the table top exercise (see also section 3.2). For example, a scenario could be outlined to the participants from which they are supposed to extract the critical situations as well as their implications and develop solutions and strategies for action. The participants could use the application to model the outlined scenario and run simulations based on defined dependencies. This form of visualization can support the development of a common mental model and promote discussions during the exercise. The *ScenarioBuilder BOS* can also provide support in the evaluation of such exercises. For example, an observer or the exercise controller can record the communication of the participants during the exercise and subsequently evaluate the communication structures created together with the participants.

In the case of operation-based exercises, the application can support the development of the scenario, for example. The use of simulations can help planners to overcome difficulties regarding foresighted thinking and the definition of system boundaries. In addition, the analysis of the centrality can be used to evaluate how involved individual actors are. As with discussion-based exercises, the conceptualized application can also support the evaluation of operation-based exercises. In particular, communication or scenario networks can be evaluated using the recorded data of exercise observers, from used staff software or from transmitted messages. In these cases, the analysis of path dependencies and relationship structures as well as their visualization are of primary interest.

In comparison to the current situation in practice, *ScenarioBuilder BOS* offers the opportunity to bundle all dependencies and interactions that occur in the context of an exercise scenario. In doing so, the application can fall back on many already existing systems and structures and thus enables a condensation of the actual state in a network graph, especially in the context of exercise evaluation. Among the data that can be used for an automatic creation of the scenario are software systems for communication like digital radio, telephone, fax or e-mail as well as various staff software. These systems are often used to transmit messages with general information, requirements and orders or questions, which can be transferred to the application through corresponding interfaces in the form of communication relationships. These data can be supplemented by hand-recorded relationships, for example of exercise observers or planners. In addition to the automatic recording of communication relationships, dependencies within technical systems can also be recorded automatically through interfaces to corresponding software applications or digitized network plans. In addition to existing software systems, the application can also benefit from predefined processes and structures. For example, the alarm and emergency regulations of the local authorities and states contain a preset configuration of emergency forces that are used for certain operations. These predefined structures can be particularly helpful to exercise planners during scenario development. There are also fixed command structures or networks specifically for communication, which are well suited for comparison with the actual situation from the exercise and can therefore be used to support both the planning and evaluation of the exercise.

The presented software concept offers a basis for enabling the user to have different perspectives on a scenario. However, the concept and the corresponding application are not limited to the functions described here but can be adapted and extended according to the needs of the user. For example, further centrality measures or specific layout algorithms can be added, which can further enhance interpretations of individual situations. As the concept is based on social network theory and consequently on graph theory, the concepts and algorithms used in these areas could easily be added to the application. Examples that should provide added value are alternative grouping functions such as ‘k-cores’ or the integration of algorithms for comparing different networks (Newman, 2018).

In addition to these extensions based on the theoretical foundation, those that are more related to systems already in use by the user are also of interest. For example, it is possible to integrate interfaces to personnel and material databases and corresponding software to facilitate scenario creation and the definition of specific node capacities and requirements. Also, the inclusion of functionalities for documentation and logging could furthermore support the creation of reports and subsequent post-processing. In order to apply and evaluate the concept and the social network analysis as a methodology in the context of the exercise in civil protection and disaster response, an exemplary demonstrator application was implemented in this work, which will be discussed in the next chapter. In particular, the user interface and the underlying data model are described.

7. Android-based Implementation of the ScenarioBuilder BOS

In the last chapter a conceptual design for the *ScenarioBuilder BOS*, a software application that serves as a support tool for scenario-based exercises in civil protection and disaster response, was presented. The concept is based on social network theory and provides functions for the modeling and analysis of exercise scenarios using multilayer graph networks. With the help of the designed application, users from the practice are to be enabled to develop interpretation approaches for exercises that are in the planning stage or have already been carried out. In the context of this work the concept was implemented in the form of a demonstrator application for validation and evaluation purposes, which will be discussed further in this chapter. First of all, the general implementation decisions as well as the choice for a mobile application are explained. Furthermore, the system requirements and the libraries used are described. Subsequently, the chapter addresses the data structure on which the application is based. Finally, the structure in conjunction with the user interface are explained.

7.1. General Implementation Decisions

In order to technically verify the concept for the *ScenarioBuilder BOS* described in the previous chapter and to test it in real exercises, it was implemented in an exemplary demonstrator application. It was decided to realize the concept as an Android-based mobile application so that the software could be presented and used in interviews and informal discussions with practitioners as well as during various exercises. Since it could not be assumed that a connection to the Internet could be established during an exercise it was also decided to implement the software as a native application with local data storage and internal data analysis.

The implementation was done in the programming language Java using the integrated development environment *Android Studio*[1]. To ensure a high code quality and readability, various naming conventions and implementation standards were defined at the beginning of the development. For example, constants are always written in capital letters and with an underscore for word separation and XML files used to define layouts always start with a type description followed by a unique name such as “fragment_add_event_dialog.xml”. Furthermore, a uniform project package structure was introduced where the packages are arranged hierarchically by functional groups. For example, all classes that contain code for the user interface are located in the package “ui”, which in turn is divided into functional sub-packages such as the package “node” for user interface classes related to nodes. Lastly, class names were chosen so that the basic functionalities associated with the class can be directly derived from them on top of all classes following a uniform structure.

The standard programming paradigm used in the application is object-oriented programming. In addition, functional programming concepts (for example, for filter or sorting functions) are used for objects from the group of collections or maps, which the application uses to represent graph and network structures. For this purpose, the application uses the Java *Stream API* which

[1] https://developer.android.com/studio

was introduced in Java 8 and results in Java 8 being a prerequisite for the application (Oracle Corp., n.d.). The architecture of the application strictly follows the principle of separation of concerns. Thus, all activity and fragment classes contain only the program logic required for handling user interface components. Calculations and database access are done in specially designed classes. For data storage, the application uses the relational database *SQLite* which is integrated in Android. The database is accessed using the *Room Persistence Library* as an abstraction layer (Google Inc., 2020). To ensure a good user experience a non-blocking user interface design approach was chosen in the application, where all long running calculations and analyzes are processed in asynchronous worker threads. The *GraphStream* library was utilized and extended to represent and visualize scenario networks. *GraphStream* is a Java-based library for the representation of dynamic graphs which will be further introduced in the following sub-section (Dutot et al., 2007).

GraphStream – A Dynamic Graph Library

GraphStream is a Java library for the generation and manipulation of dynamic graphs with the goal to make them analyzable and use them in simulations (Dutot et al., 2007). The main underlying assumption is that graphs and networks can change over time. Changes in the graph are considered to be a changing set of nodes, through means of deletion and generation, but also changed node characteristics. Equivalent to this, changes in the set of edges or changing edge characteristics are also considered as changes in the graph (ibid). *GraphStream* contains packages for representing networks, their automated generation and analysis using common algorithms of graph theory, the possibility of importing and exporting networks in file formats, and possibilities for visualizing networks (ibid).

The *GraphStream* library uses a pipeline approach to represent and visualize graphs and networks (Dutot et al., n.d.). A component is considered a *source* if it can generate graph events and a *sink* if it receives these graph events. *GraphStream* always uses two components, the graph object and the viewer (Dutot et al., n.d.). The graph object component on the one hand reflects the actual representation of the network with its nodes and edges that is used for calculations and runs in the main thread of the application. The viewer component on the other hand is used for the pure graphical representation (or graph drawing) of the network and runs in its own thread to enable a non-blocking user interface design (ibid.). Once a network created with the library is supposed to be visualized, the viewer component is automatically added to the graph object as a sink, whereby the inter-thread communication between the two components is done via so called *pipes*. In order to ensure that interactions within the graphical representation of the network in the viewer component, such as changes in the position of nodes due to touch or drag interactions of the user, are also represented in the graph object, *GraphStream* can be used to define a second pipe with the viewer as source and the graph object as sink (ibid.).

GraphStream offers several ways to visualize networks. For example, the shape, size or color of nodes or edges can be changed or labels can be displayed in different ways (Dutot et al., 2007). For the visualization the library uses a principle that is similar to the cascading style sheets for HTML. Hereby, specific styles can either be defined via a stylesheet or set as attributes in nodes and edges (Dutot et al., n.d.). In addition to these display properties, *GraphStream* provides a force-based standard layout that automatically aligns nodes and edges in a way that minimizes edge crossings (Dutot et al., 2007). This automated layout can be disabled so that other layouts can be implemented and applied. In addition to visualization, the library provides implementations of various graph theory algorithms that can either be used directly or in newly implemented procedures (ibid.). With respect to the concept of centrality (see section 4.3) an implementation for the measures degree, closeness, betweenness, eigenvector and PageRank is already available. However, it must be taken into account that not every algorithm is suitable for all use cases of the *ScenarioBuilder BOS* application. For example, the implementation of betweenness centrality available in the library does not support multigraphs or directed networks (Dutot et al., n.d.). In order to implement an appropriate algorithm, inbuilt methods such as determining the shortest path between two nodes can be utilized.

7.2. Data Structure

In order to implement the functions described in the concept chapter for modeling and analyzing scenario networks in the *ScenarioBuilder BOS* application, a data structure with a total of 12 entities was defined. The structure was described in classes within the application and transferred to a local SQLite database using the Android *Room Persistency Library*. To be able to save the data and exchange it between different devices functions for importing and exporting both the entire database as well as individual tables were implemented. The entity-relationship model of the defined database is shown in Figure 7.1 and is explained below.

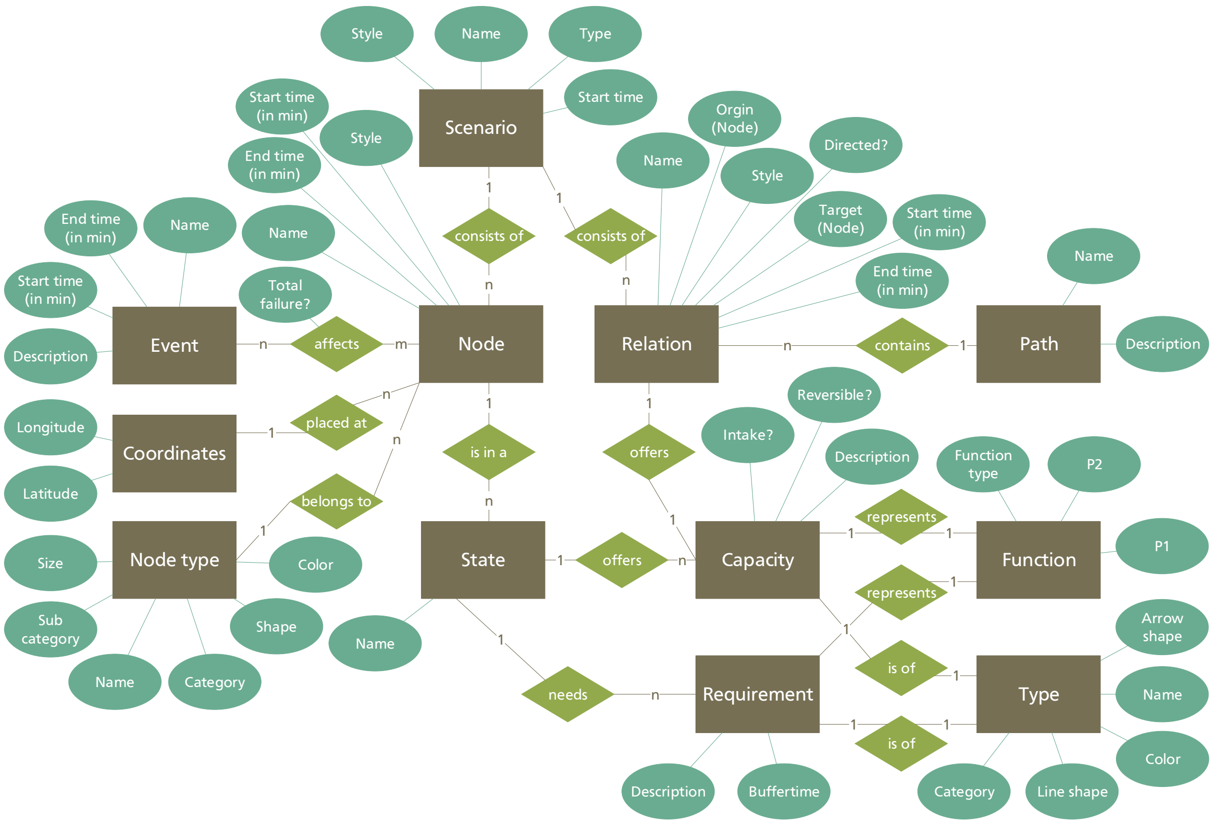


Figure 7.1: Entity-relationship model of the database structure for the ScenarioBuilder BOS

The root entity of the data structure is the *scenario*. It contains all relevant information for the general exercise scenario including its name and a timestamp that provides information regarding the starting time of the exercise. The style as well as the type attributes are relevant for the network representation using *GraphStream*. If a specific style for the visualized scenario network (e.g. the background color or the color scheme for the different elements) is required, a text-based stylesheet can be added. By further providing a network type, it can be specified whether a multigraph or any other form of graph representation should be used. The default type is always a multigraph. Each scenario consists of several *nodes* and *relations* that further describe the situations within the exercise.

As described in section 6.2, a node represents actors, objects or phenomena that are able to enter into relationships with other actors, objects or phenomena. Similar to the scenario, each node is identified by its name and has a start time as well as an end time defined. A node can further be located at a specific location described by *coordinates* (latitude and longitude). In the application, the coordinates of the center point are used for simplification and the spatial extension is not specified more precisely. In addition to the aforementioned attributes, each node is assigned with a *node type* that further categorizes it. For this categorization the node type differentiates between a category, a subcategory and a name. For each node type certain style characteristics are defined for visualization with the *GraphStream* library. These include the size, color and shape of all nodes of that type. If an individual node has a specific requirement regarding its appearance, then this can be stored in the style attribute of that node. An example of this would be special forces that have a dedicated operational symbol which should be used as a display format.

During its lifecycle in a scenario a node can be in multiple *states*. Each state is defined by a name. Whenever a node is created, the application automatically adds a 'Default' state so that a node always consists of at least one state. Within each of those states a node can have varying capabilities or needs (see subsection 'Defining Capacities and Requirements for the Scenario' within section 6.2). Both capacities and requirements have a *type* that further describes them and optionally a *function* and/or description. In addition to that, each capacity has a necessary Boolean value indicating if it is an intake capacity (e.g. a dike has a limit in how much water it can hold back) or an output capacity (e.g. a power plant has a limit in the amount of energy it can provide). If a capacity represents an intake capacity it must further be declared if a failure caused by the exceedance of the capacity limit is reversible. With the definition of a buffer time, requirements also have another mandatory attribute that indicates how long a node in its current state can still provide its function even if the specific requirement is not fulfilled. Similar to the node type, capacity and requirement types also differentiate between a category and a name to describe capabilities and needs more precisely. For each type further style information needs to be provided for the visualization through *GraphStream*. This includes line attributes such as color and style as well as the arrow shape. If a function is used to describe dynamics in capacities and requirements a function type and two parameter values p1 and p2 have to be provided.

Relations describe how one node affects or relates to another and are an equivalent to edges in graph theory. Next to a name each relation is expected to have a reference to an origin and a target node as well as a Boolean value representing whether or not the relation is directed, meaning only valid in the defined direction, which is the default for most relations in a scenario in civil protection and disaster response. Like the nodes all relations also have indications for the time period for which they are relevant in the scenario (stated by the start and end times). Similar to nodes, specific requirements for the visualization can be defined for relations through the style attribute. Since a relation by definition maps the effect of one node on another, it can only exist if this effect is described in more detail using a corresponding capacity. This capacity is always an output capacity, since it reflects "how much" of a resource, information or similar is passed from one node to another. To examine path dependencies in scenarios, a relation can be assigned to a *path*. Each path is defined by a name and a description.

Finally, in order to model external *events* in a scenario, information about the name of the event and period of time when the event is effective have to be provided. Events can further be specified by a description and must have a reference to the nodes that are affected by them. Multiple nodes can be damaged by the same event and a given node may be affected by multiple events. The effect on a node can either be a partial or a total failure. In order for a node to represent that an event has caused a partial failure of its function, a corresponding state with possibly changed capacities and dependencies should be defined within the application.

7.3. User Interface

The user interface of the *ScenarioBuilder BOS* focuses on the visualization of the scenario network. This means that the selected scenario is always in the user's view and takes up most of the screen area. This provides the necessary space for the clearest possible presentation, even in complex scenarios. The user interface of the application is based on the *Material Design*[2], a flat and uniformly clear design that works with different layout levels and is applied throughout the entire application. After starting the app, the user is first prompted to select the scenario to be processed or analyzed. This can be done by selecting an existing scenario from the database or by creating a new one. Furthermore, the user has the possibility to import a database stored as a file on the device. In particular, this can be interesting, for example, if a base scenario for an exercise was created on one device and observations are recorded during the exercise with several devices that use the base scenario.

As soon as a scenario has been selected or a new one has been created, the user is taken to the main view of the *ScenarioBuilder BOS* application (see Figure 7.2). The main view displays the scenario network for a specific time range selected by the user. In the initial view after loading or creating a scenario, it is first visualized for the time step $t = 0$. The network view is interactive and responds to user actions. For example, the user can move nodes as required to change the layout according to his or her needs. Further possibilities for interaction with the scenario are provided at the bottom of the screen. For example, the user can play the scenario as a dynamic sequence using the "play" button (left) or simply switch between different time steps using the

[2] https://material.io/design/

slider or the “next” and “previous” buttons (see section 6.3). With the “add” button (right) new elements such as nodes, relations or events can be added. In addition to the interaction options, further information on the scenario network is displayed to the user in the main view below the app bar. Both the current scenario time and a list of effective events are displayed here, provided the events are defined in the time under consideration.

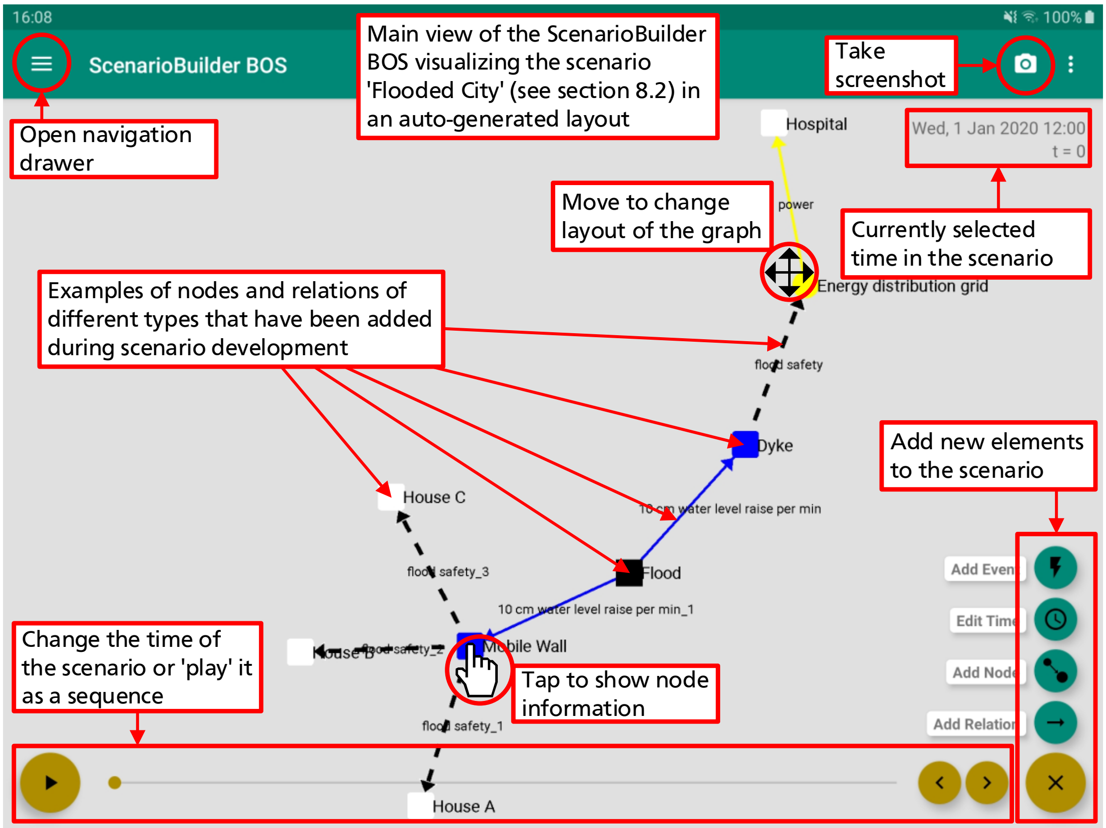
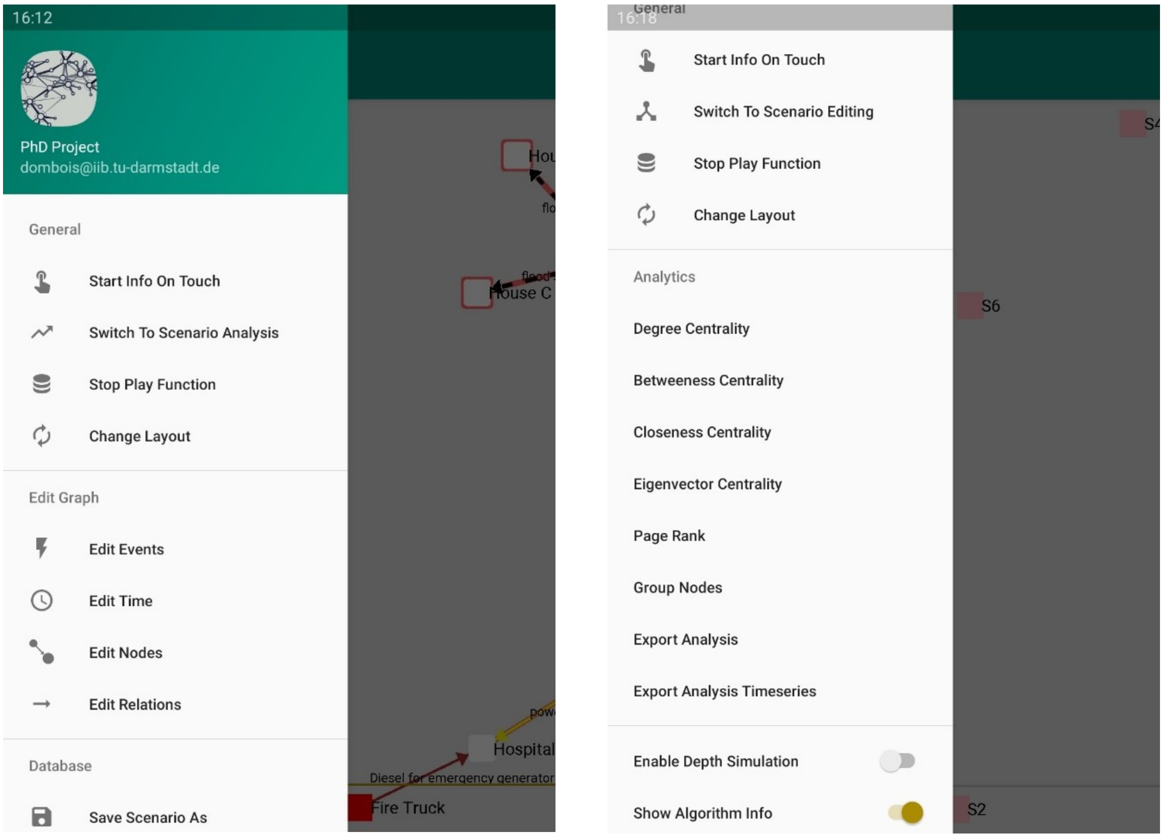


Figure 7.2: Main view of the ScenarioBuilder BOS application

The application has a navigation menu that can be accessed from the left-hand side in the main view and may be used to start various functions for editing and analyzing the scenario as can be seen in Figure 7.3. The menu is visually divided into different sections for a better overview. The upper section contains general functions that may be relevant for the user in any phase of the scenario. For example, different layouts can be selected for the scenario representation or the touch feedback for nodes can be activated and deactivated to display an information dialog with all relevant information about a node when it is touched. Furthermore, the user can switch between the functions for developing or editing the scenario and those for analysis. During scenario development, the focus is on creating and editing the scenario elements, especially the nodes or actors, the relationships between them as well as the external events. Likewise, data can be imported and exported or scenarios can be saved as templates for future use. For the analysis, the focus shifts towards the functions for viewing different time periods and dimensions of the scenario as well as the calculation of centrality. Nodes can also be combined into groups and analysis tables can be exported. In the lower area of the navigation menu, the user has various settings available which are particularly relevant for the simulation of the scenario. For example, events or the simulation of capacities and requirements (in-depth simulation) can be activated and deactivated.



(a) (b)

Figure 7.3: User interface of the ScenarioBuilder BOS navigation drawer (a) in editing mode and (b) in analysis mode

The scenario simulation, which was explained in the sub-section “Simulating Cascading Effects” within section 6.3, is implemented in the *ScenarioBuilder BOS* in such a way that it is always calculated during the scenario development as well as the analysis, provided it has been activated in the settings. Thus, the user receives direct feedback on plausibility during the development of the scenario and can experiment with different scenario variations. Furthermore, the simulation results can be considered in the further analysis of the centralities. Here, non-functional nodes and inactive relationships are not included in the calculation of the centrality, thus allowing a statement on the relevance of only functional actors. Through further settings in the navigation menu, the user can decide whether the simulation calculation should only refer to the current time step or to all previous time steps and whether non-functional nodes and inactive relationships should be grayed out or not be visualized at all in the analysis. For the analysis of multilayer networks with varying time horizons and multiplex relationship structures as well as for the analysis of centrality, the *ScenarioBuilder BOS* uses multigraphs as representation form by default. This is illustrated in Figure 7.4 using an example of the “Wesersturm” exercise (see section 8.5).

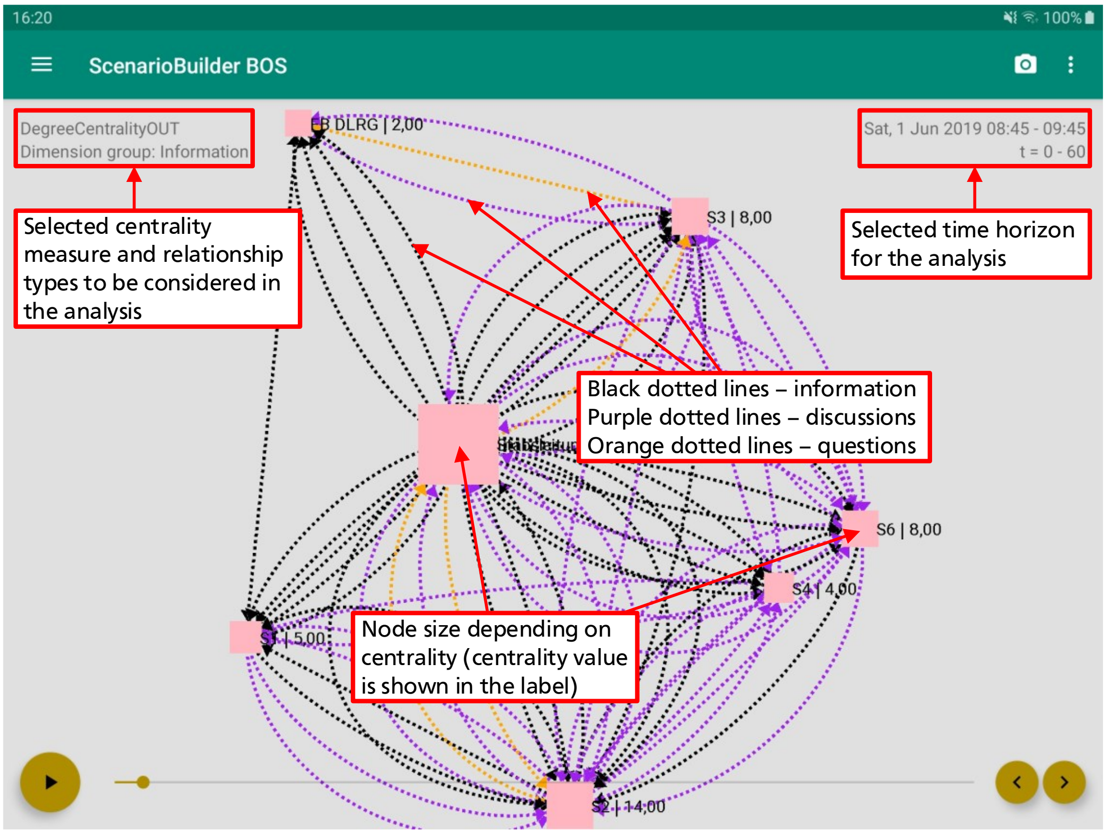


Figure 7.4: User interface when analyzing multilayer networks and centrality with the ScenarioBuilder BOS

For user entries, as in the above example for selecting the scenario when starting the application, the *ScenarioBuilder BOS* follows a workflow concept based on dialogs. This concept attempts to divide the potentially large amount of information that the user has to provide for creating or editing an element as well as for specifying a function into small individual queries and display them clearly. Depending on the input or selection, the user thus receives a series of consecutive dialogs that guide him/her step-by-step through the inputs needed for the given process. The concept is presented below using two examples from the application. First, as shown in the workflow diagram in Figure 7.5 (a), the process for editing a node with input of capacities and requirements within the scenario development is explained. Next, the process for calculating centrality is given as an example of scenario analysis, which the workflow shown in Figure 7.5 (b) illustrates.

To edit a node from the scenario, the user first selects it from the list of all nodes available in the dialog (see Figure 7.6 (a)) or by tapping it in the visualized network if touch feedback is activated. After selecting the node, the user has to specify whether the node type or one of the states of the node is to be edited, the end time of the node is to be defined or the node is to be deleted entirely (see Figure 7.6 (b)). In case the node should not be edited, another dialog is displayed where the user selects the delete action to be performed. It should be noted that deleting the node from the scenario will also delete all relationships it is involved in and other information based on the node. Specifying the end time is particularly relevant if the node no longer participates in the scenario starting with the currently selected time step and should therefore not be visualized anymore. Since the exact end time is not always necessarily known when the node is created, it is initially set automatically by the application until the end of the scenario and may later be set, for example, to the currently selected time step using the workflow described here. When the end time is changed, all relationships that are connected to the respective node are also adjusted since they cannot exist beyond the life span of the node. If the user chooses to edit the node, the following dialog, which is also the initial dialog when creating a new node, offers the possibility to define or check a name and to specify the node type (see Figure 7.6 (c)). It is not possible to change the name when editing the node because it is used as an identifier in the database. To support the user, for example in choosing the correct node type, text fields with autocomplete functionality are used throughout the application (see Figure 7.6 (d)). They filter the data from the database and make appropriate suggestions to the user based on the input.

After defining the name and type of the node, the user is asked to select the state to be edited (see Figure 7.7 (a)) or to create a new state (see Figure 7.7 (b)). Following that, the user is presented with three dialogs in sequence, each with an overview list of already defined output capacities, intake capacities and requirements (see Figure 7.7 (c)). Furthermore, the user can delete previously defined capacities or requirements or create new ones (see Figure 7.7 (d)). If he or she does not want to make any further changes, the system switches to the next overview. If no more changes are to be made to the requirements, the editing process of the node is finished and the changes are stored in the database and applied to the visualization.

In order to perform and display a centrality calculation (see section 4.3) for the scenario network, the user first selects the appropriate method for the problem or question at hand. In case the chosen method is degree centrality, it has to be further specified which degree measure should be applied (indegree, outdegree or degree). Following the selection, the user is presented with a dialogue with the most important information in order to gain a better understanding of the chosen procedure. Afterwards the user has to further specify which relations should be considered in the calculation. To do this, the user first selects whether the analysis should refer to a single type of relationship (monoplex network analysis) or a combination of several types (multiplex network analysis). Depending on the decision, the application lists either all relationship types used in the scenario or the corresponding categories of types. This leaves the user with three options to choose from: analyze exactly one type, a group of types such as all communication relationships or all types of relationships used in the scenario. After selecting the relationship types, the user is required to also further specify the time that the calculation is based on. Options include the consideration of relationships from the currently selected time step only or the specification of a time range. The definition of the time range and the considered relationship types determine which nodes and relationships are included in the calculation. Finally, the user can select the normalization procedure for the calculation after which the calculation is performed and the results are displayed in the network. The workflows described above exemplify the user guidance and assistance when developing scenarios with the *ScenarioBuilder BOS* implemented in this work. The application was tested in various civil protection and disaster response exercises to evaluate the software and to assess the methodology of social network analysis in the field. The results of this evaluation are discussed in the next chapter.

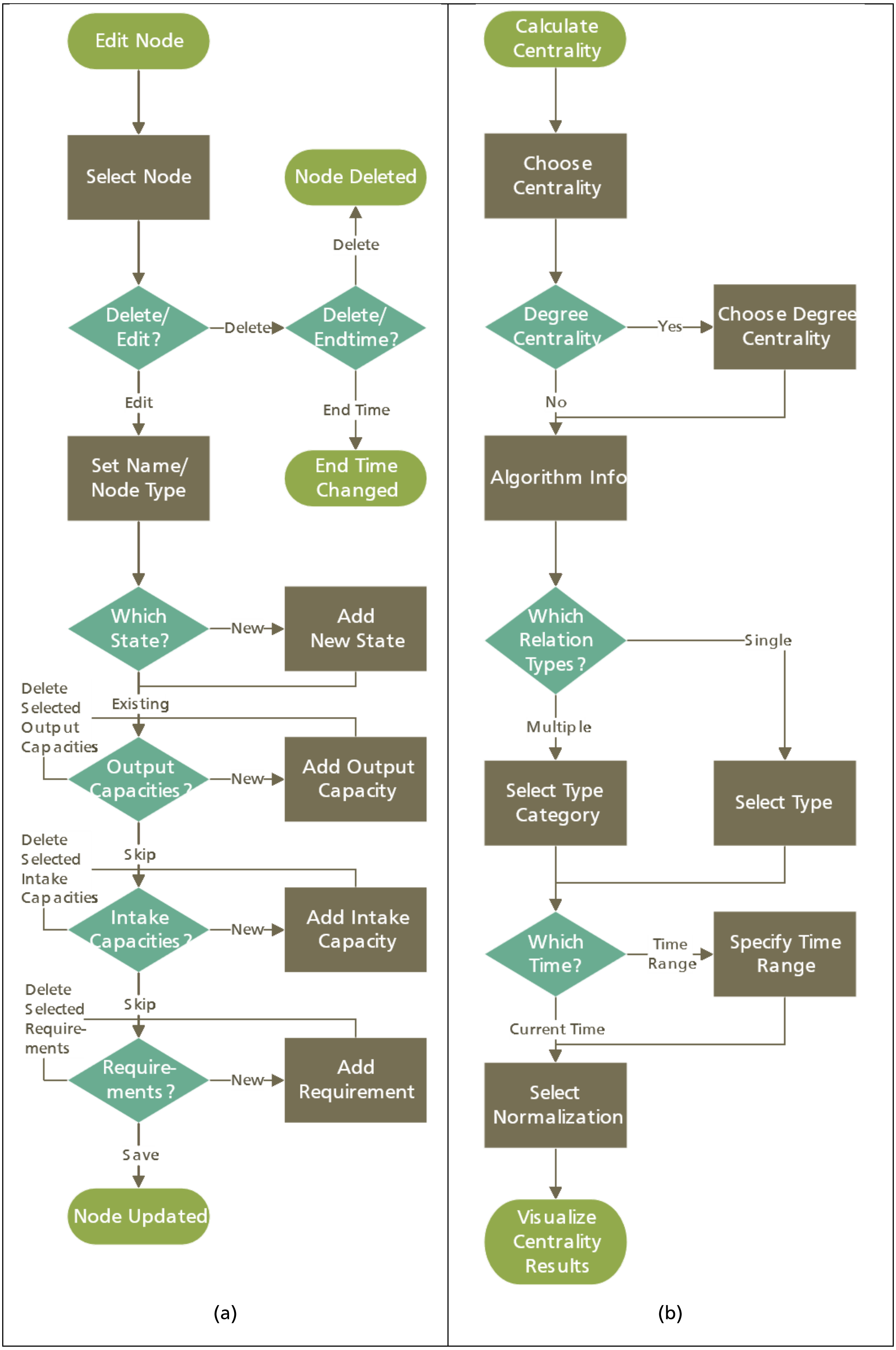


Figure 7.5: User interface workflows for (a) editing a node and (b) calculating centrality in the ScenarioBuilder BOS

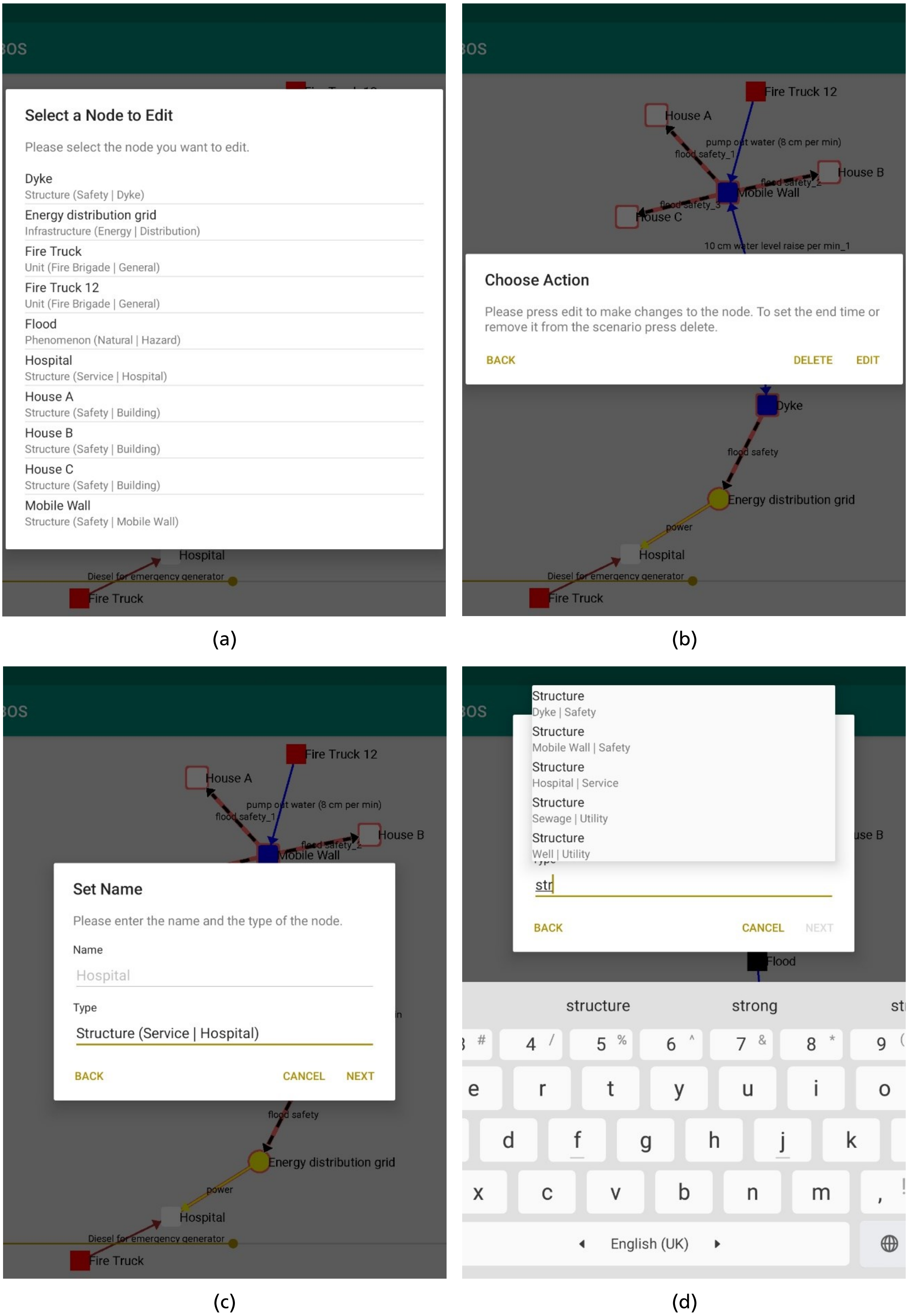


Figure 7.6: Dialog workflow for editing nodes step 1; (a) select node, (b) choose action, (c) review name and (d) select node type

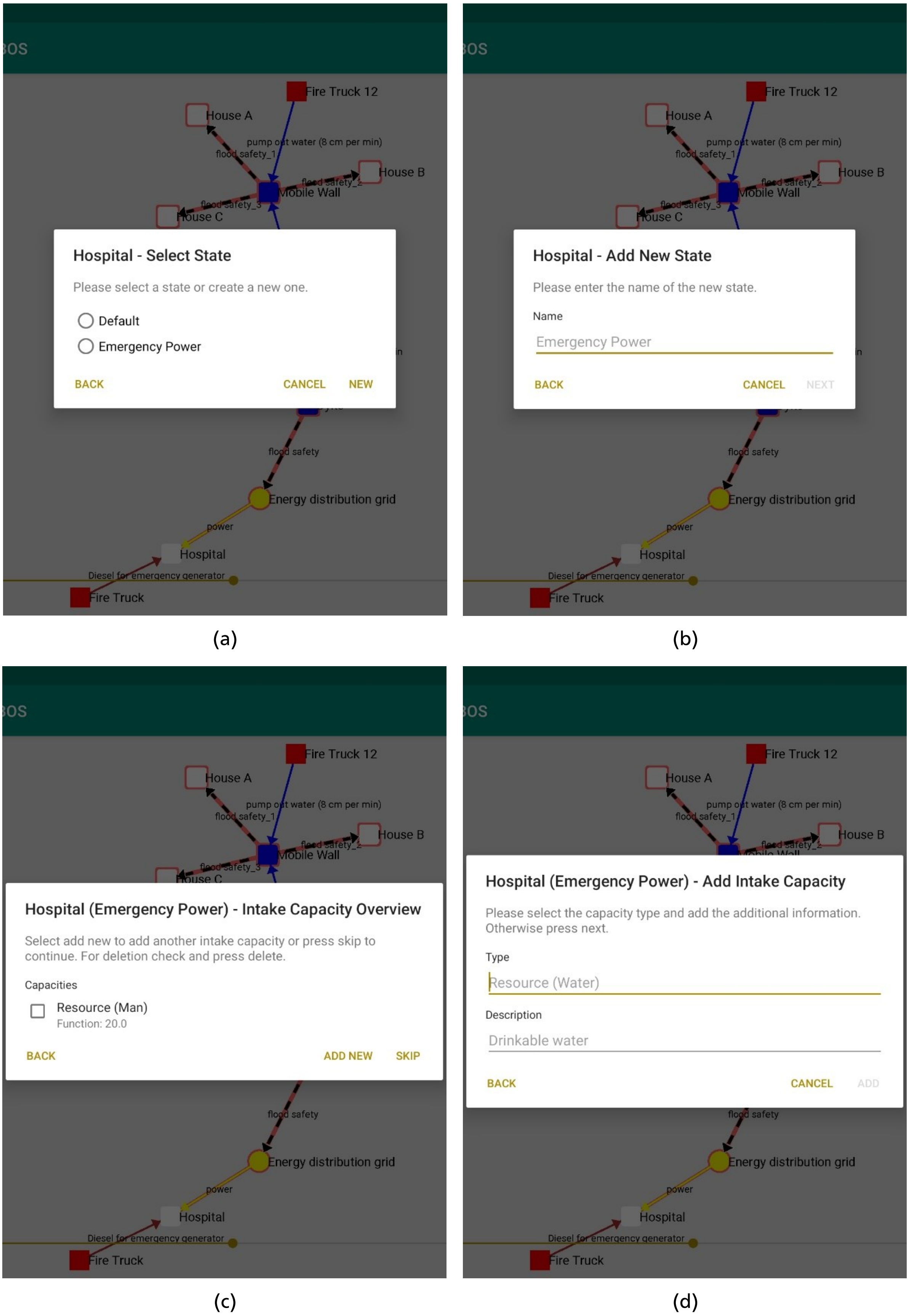


Figure 7.7: Dialog workflow for editing nodes step 2; (a) select an existing state, (b) add a new state, (c) review existing capacities and requirements and (d) add new capacities and requirements

8. Evaluation

In the last chapter the *ScenarioBulider BOS*, an Android-based demonstrator application to support the planning and evaluation phase of exercises in civil protection and disaster response, was presented and the user interface along with possible interactions was explained. The application was tested and evaluated in different use cases in the context of this work, which will be discussed further in this chapter. At first, an overview of the observed use cases is provided and then each case is illustrated and discussed individually. While the first use case represents a validation of the simulation functionalities of the application and offers a fictitious example for its use in exercise planning, the remaining three use cases are examples from real exercises of different organizations that are used to review the application in the context of exercise evaluation. In the last section of the chapter, the individual use cases and the corresponding feedback from practitioners are summarized and the added value of the application and social network analysis as a methodology for exercises in civil protection and disaster response is discussed.

8.1. Introduction into the Use Cases

The evaluation of *ScenarioBuilder BOS* is intended to validate the functionalities of the application on the one hand and to evaluate the practical use of the tool and the methodology for planning and evaluating civil protection and disaster response exercises on the other hand. In the following sections, four use cases are presented in which the *ScenarioBuilder BOS* was used either during the planning or alternatively as part of the evaluation of an exercise. In the first use case, called “Flooded City”, the application is used as a support tool for planning the exercise, especially for developing the scenario. While it was designed without the cooperation of practitioners, this fictitious scenario is mainly intended to validate the simulation functions of the application as well as describe a possible future use of the conceptualized software in scenario development.

The other three use cases serve to assess the supporting character of the *ScenarioBuilder BOS* in the evaluation of exercises. For this purpose, three disaster control exercises of different organizations were observed and evaluated using the application between 2018 and 2019. These include the “Winterübung TEL” exercise of the city of Darmstadt, the “Wesersturm” exercise of the district of Höxter and the “KatKom 2-2019” exercise of the state of Berlin. In all three cases, the exercises were observed without prior involvement in the planning process. Furthermore, in all observed exercises the objectives and the respective scenario were communicated before the start, but no introduction to the organizational structures and the specific tasks of the individual actors was given. During the exercises, the respective exercise leaders made no demands regarding observation.

The data collection for the following analysis for the “Wesersturm” exercise and the “KatKom 2-2019” exercise was based on a systematic observation of the communication relationships between the actors under consideration. For the “Winterübung TEL” exercise, the communication data from the *CENARIO® ilias*[3] staff software was used as data for the evaluation and supplemented by observations of actions and communications. The data of all exercises was entered into the *ScenarioBuilder BOS* and for each exercise both an exemplary evaluation was performed and an evaluation report was written. The evaluations using *ScenarioBuilder BOS* were carried out independently of the regular exercise evaluations of the respective organization and without the involvement of the exercise leaders or other participants. The evaluations specifically examined the communication structures of the observed areas and related them to the corresponding situations of the exercise. Furthermore, preliminary interpretation and explanation approaches for the given interrelationships were formulated in the evaluation reports. Each evaluation report was divided into the following sections:

- Contact information
- Background of the doctoral project and research questions
- Observation and evaluation methodology
- Descriptive evaluation
- Further analysis
- Remarks

The resulting reports were made available to the exercise leaders and discussed using telephone interviews and a feedback questionnaire.

8.2. Scenario Development for the "Flooded City" Exercise

The "Flooded City" exercise is a fictional exercise to validate the application's scenario simulation functionalities and to describe how these functionalities can be used to support scenario development. The underlying base scenario takes place in a medium-sized city with a river running through it. After continuous heavy rainfall, a flood event has occurred in the city area. Two areas of the city are particularly affected by the flood, a residential area and a mixed district of residential and commercial buildings. The latter's energy distribution grid, among other things, also supplies the local hospital. Between the river and the mixed area there is a dyke for permanent flood protection, but it is already close to its capacity limit. In the residential area, the authorities have installed mobile walls that are supposed to hold back the water for a period of time. The basic scenario is visualized with the *ScenarioBuilder BOS* as shown in Figure 8.1. A total of eight nodes with corresponding characteristics such as states as well as capacities and requirements are defined for the representation. In detail, the scenario consists of the following elements:

- The "Flood" node is a phenomenon from the group of natural hazards and defined with only one state. It has an output capacity of the resource water with a presumed unlimited quantity.

[3] https://www.cenario.de/produkte/krisenmanagement/cenario-ilias/

- The "Dyke" also only has one state and is a type of safety structure. It has the ability to provide flood protection, but can only hold off a water level of 300 cm before it breaks down.
- As a node, the "Mobile Wall" is almost identical to the "Dyke" in its properties, but its ability to hold off water is limited to a water height of 200 cm.
- The nodes "House A", "House B" and "House C" are all structures from the building category and each have a requirement for flood protection defined.
- The "Energy distribution grid", which also has only one state in the entire scenario, is an infrastructure type from the energy distribution category. If the node has sufficient flood protection, it can distribute the resource energy in unlimited quantities.
- The "Hospital" of the service structure type is the only node in the scenario that has two states. While it can supply 800 patients in the regular state with a given power supply of 100 kW/h, the number of people that can be supplied is reduced to 200 in the emergency power state. To be able to operate the generator for emergency power supply however, the node is dependent on a continuous supply of diesel.

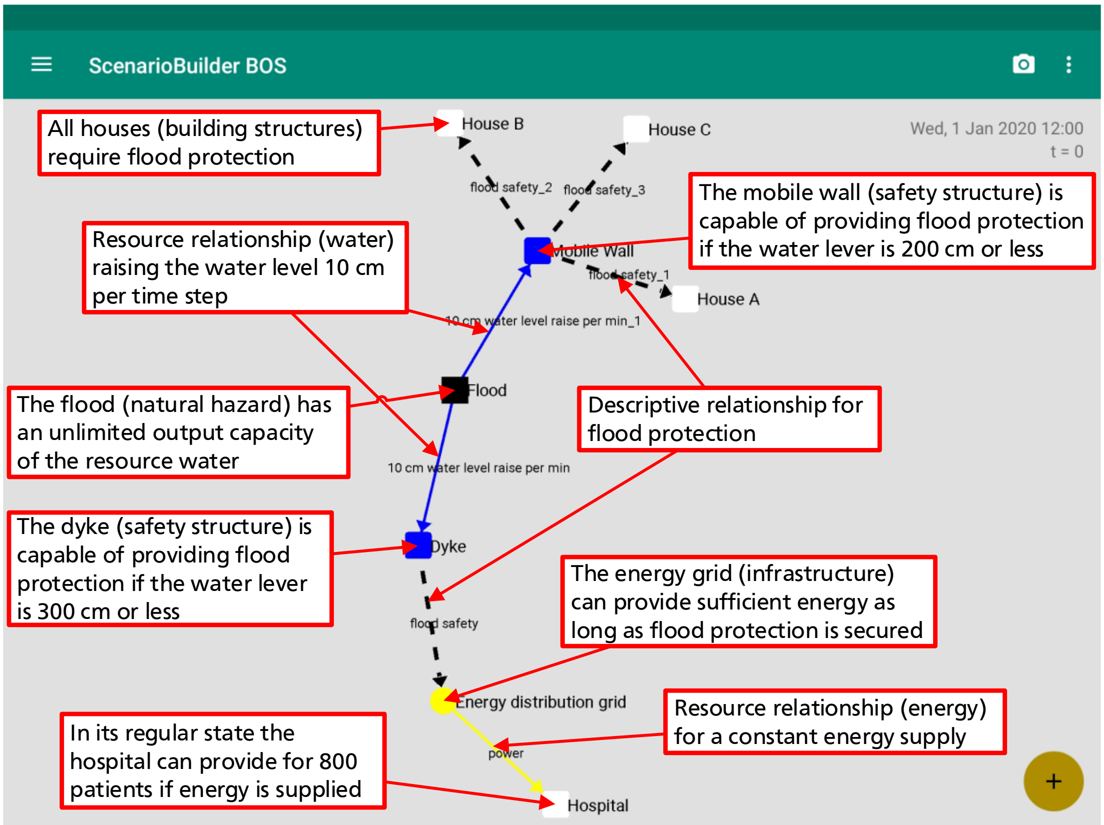


Figure 8.1: Base scenario for time step t=0 of the "Flooded City" exercise

As Figure 8.1 further shows some relationships are given in addition to the defined nodes to describe the initial situation of the scenario. For example, the "Flood" node provides a resource relationship to the nodes "Mobile Wall" and "Dyke", both of which have a capacity of 10 cm water height per time step. Thus, in both cases a linear function is present that describes how much water flows from the flood onto the two protective structures. Furthermore, a total of four flood protection relationships are defined, which act from the "Dyke" and the "Mobile Wall" on the surrounding nodes. These descriptive relationships are not defined by any functions and are active as long as the "Dyke" or the "Mobile Wall" can provide safety for the surrounding structures. Finally, the scenario defines a resource relationship to describe the constant energy supply from the "Energy distribution grid" to the "Hospital". Under the given circumstances, the simulation of the scenario shows that at time step $t = 21$ the capacity limit of the "Mobile Wall" is reached first and at the time step $t = 31$ the capacity limit of the "Dyke" is reached as well. As subsequently shown in Figure 8.2, starting at time step t=31 both nodes have failed, which has cascading effects on the surrounding nodes, since flood protection is no longer guaranteed.

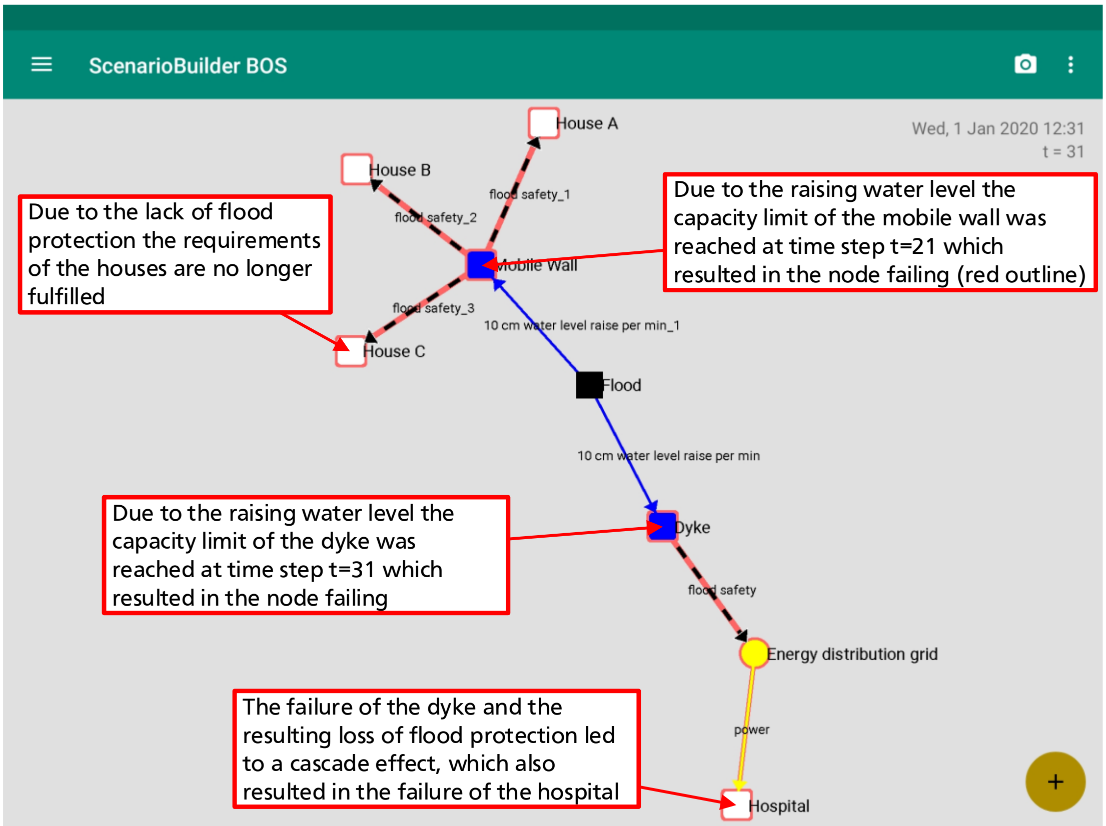


Figure 8.2: Base scenario of the "Flooded City" exercise at time step t=31 if no measures are taken

Once the basic scenario has been created and the critical points in time have been identified, *ScenarioBuilder BOS* can be used as a support tool to further develop the scenario or plan the injections. Since the simulation calculates the effects of each change to an element on the overall scenario, *ScenarioBuilder BOS* offers a way to guide the user through different options for measures and develop suitable combinations for the exercise objectives. For the "Flooded City" exercise, two main areas of deployment are defined as examples. Firstly, the use of pumps is intended to delay the overload of the mobile walls to at least one hour after the beginning of the flood in order to organize an evacuation of the residential area or to set up further protective measures (in the scenario a time step is equal to a minute in real time). On the other hand, an emergency power supply for the local hospital is to be ensured through the supply of diesel fuel. The measures can be implemented with the *ScenarioBuilder BOS* based on the units available in the organization. In the case at hand, a node "Fire Truck 12" is defined for time step $t = 10$, which has a water pump capacity of $-8\ cm$ per time step and is therefore able to pump out a quantity of water that leads to a reduction in water height of 8 cm per time step. In addition to the node, a corresponding relationship is defined between the "Fire Truck 12" and the "Mobile

Wall” with the same capacity. This measure delays the capacity limit of the “Mobile Wall” to the time step $t = 61$. In addition, from time step $t = 40$ onwards, the newly defined node “Fire Truck” and a corresponding relationship provide a diesel supply of the “Hospital” node. As a result, this node changes to the “Emergency Power” state and can now support a limited number of patients as described above. Figure 8.3 shows the scenario after the implementation of the measures in time step $t = 40$. Similar to these measures, the scenario can be further developed and simulated as necessary.

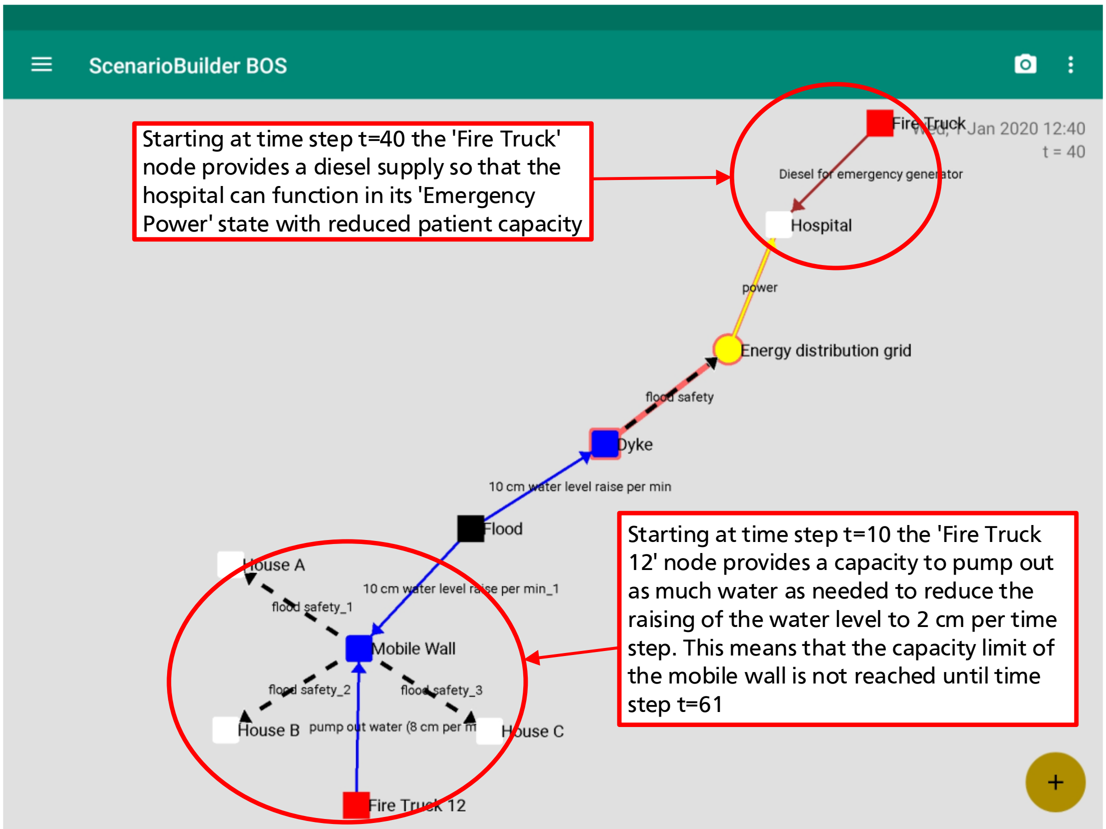


Figure 8.3: Example scenario development for the "Flooded City" exercise at time step t=40 after some measures have been applied

8.3. Evaluation of the “Winterübung TEL” Exercise

Scenario and Exercise Objectives

The “Winterübung TEL” exercise took place on February 18, 2018 in Darmstadt and was a joint disaster control exercise of the professional fire brigade, the voluntary fire brigades, the various rescue service providers, the Technical Relief Agency and the psychosocial emergency care. The exercise was based on the scenario of a severe thunderstorm that swept over the city of Darmstadt and caused major damage to various buildings. In addition, there were power and water supply failures in large parts of the city and people were injured (Wickel, 2018). In order to ensure a long-term supply of the emergency forces, a technical operations management (TEL) and various operational sections (EA) were set up on the site of the former Cambrai-Fritsch barracks and the units were to provide medical care, food, etc. for approximately 500 emergency forces (ibid.). The objectives of the exercise were to establish a command and control organization for commanding larger units as well as an autonomous supply center. In addition, the cooperation of the various civil protection and disaster response units was to be practiced and the functionality of the corresponding equipment tested. An impression of the exercise and the construction of an autonomous supply center for the disaster response teams is given in Figure 8.4.

Figure 8.4: Construction of the supply center for the disaster response teams during the "Winterübung TEL"

Observation and Evaluation Methodology

For the "Winterübung TEL" exercise, the messages transmitted by means of the *CENARIO® ilias* staff software were analyzed and mapped in the form of communication relationships between the individual actors in the exercise. A total of twelve actors were identified and subsequently represented as nodes in the *ScenarioBuilder BOS*. From the staff software, 513 communication relationships could be extracted between the defined actors, which were assigned to different relationship types. A distinction was made between (see Figure 8.5 and Figure 8.6):

- Requirements/requests (red dotted lines)
- Assignments/commands (blue dotted lines)
- Questions (orange dotted lines)
- General information exchange (black dotted lines)

The resulting scenario network described an interaction network of the teams communicating via *CENARIO® ilias* over the period of the exercise.

Since some of the individual actors were not actively involved in the exercise the whole time, events were defined in the application so that a distinction could be made in the evaluation between active and non-active actors. In the visualization using *ScenarioBuilder BOS*, each relationship shown corresponded to a message between a sender and a receiver. In several cases, the sender of a message in *CENARIO® ilias* did not specify a receiver, so that the staff software transmitted the message to all other actors. This behavior was transferred to the *ScenarioBuilder BOS* when the data was imported, so that multiple relationships were defined for a message to multiple recipients. Also, two relationships were used for assignments or commands that should be acknowledged by other teams. The actual command was defined as an assignment whereas the acknowledgement was defined as general information for the respective recipient. Interactions were always defined for the time in which they took place, so that the resulting scenario corresponded to a dynamic network.

Selected Evaluation Results

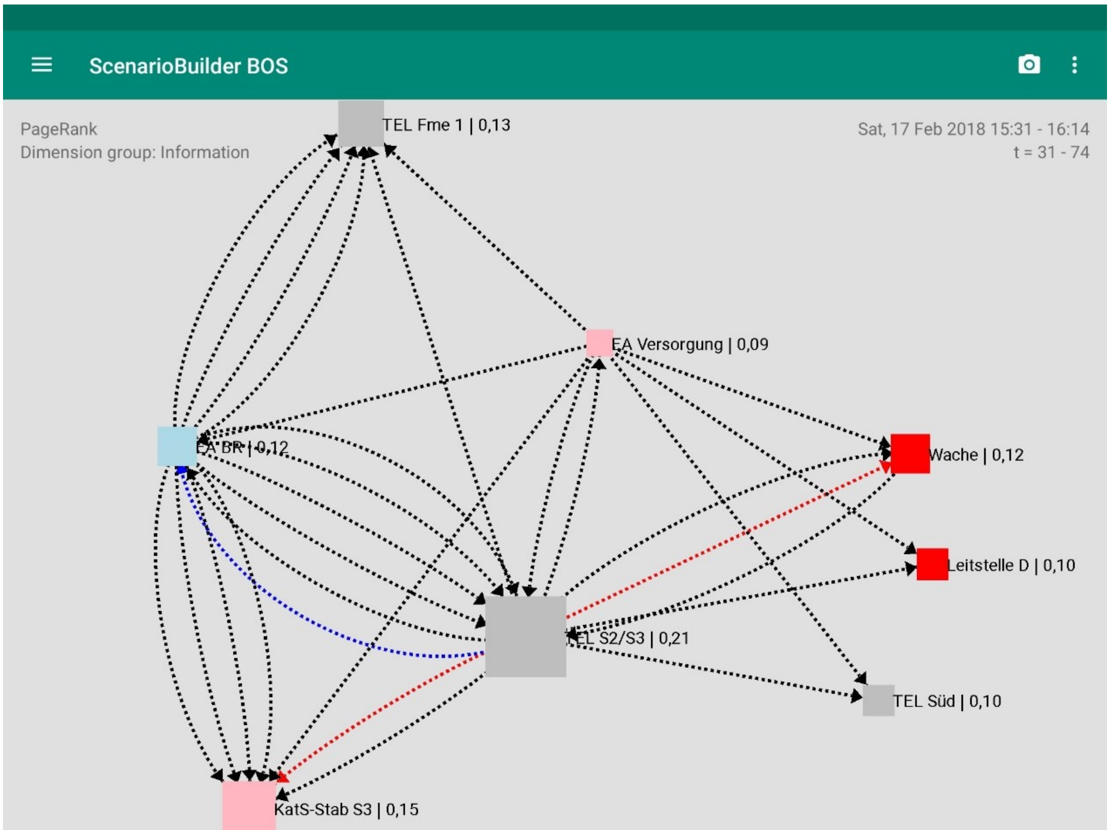
Figure 8.5 shows analysis examples of the resulting *ScenarioBuilder BOS* scenario for two situations from the exercise. The first situation (Figure 8.5 (a)) describes the communication processes during the settling phase of the "TEL Süd" immediately before the official start of the exercise (3:31 - 4:14 pm). Although the "TEL Süd" had already signaled its readiness, communication during this time mostly occurred via the "TEL S2/S3". Having a degree of 16 and a PageRank value of 0.21, the "TEL S2/S3" characterized itself as a central actor in the situation. Particularly noticeable for the considered time period was the high number of interactions of the "EA BR". A closer look at the interactions showed that the "EA BR" had communicated information about newly arrived units four times to the "TEL S2/S3", the "TEL Fme 1" and the "KatS-Stab S3" respectively. By solely using degree centrality, this way of communication led to a distortion of the center of the network towards the "EA BR", which may not have been justified in this situation and should be evaluated further. However, as Figure 8.5 (a) shows, the influence of the "EA BR" in relation to the overall network when considering the PageRank was rather small compared to the "TEL S2/S3". This could be explained by the fact that the majority of other actors rather sought communication with the "TEL S2/S3" during that time. In the later course of the exercise, the center of communications had clearly shifted to the "TEL Süd", as shown in Figure 8.5 (b), for example. The "TEL Süd" adopted a coordination and bridging position between the civil protection staff (here represented by the actor "KatS-Stab S3") and the operational sections, as provided for in the disaster management structure in Hessen (see Figure 2.1). Their central role can easily be recognized by the very high degree-value and the star structure of the network.

In addition to the descriptive analysis over the course of the exercise, the data could also be used for further investigations. For example, when looking at the communicated assignments and requirements over the entire period of the exercise as carried out in Figure 8.6, it was possible to examine whether the defined command structures were adhered to. With regard to the given exercise one requirement relationship of the "EA Hirten" was immediately apparent (see Figure 8.6 (b)), since it was directly addressed to the "KatS-Stab S3" without passing the "TEL Süd". A closer look showed that this requirement was simultaneously made to the "TEL Süd" as well and could therefore be neglected. Another striking result from the exercise was shown in the analysis of the general information (black dotted lines) over the time of the exercise. The analysis of the outdegree, i.e. the outgoing information, showed that the "EA Versorgung" distributed by far the most information into the network. This was due to the fact that often no receiver was defined and thus the information was transmitted to all actors. However, this form of communication carries the risk that individual, possibly relevant information could get lost in the mass of interactions and should be reflected for the individual case.

Practitioner Feedback

The feedback for the evaluation of the "Winterübung TEL" exercise and the *ScenarioBuilder BOS* as a tool for the evaluation of exercises in civil protection and disaster response was given by the exercise leader. For this purpose, a preliminary discussion was held on September 25, 2019, which was supplemented by a written feedback based on a questionnaire on November 14, 2019. It was stated that there was no previous knowledge in the field of social network analysis. The application was generally perceived as very useful and able to provide added value. According to the exercise leader, the graphical representation of the scenario could be quickly grasped by laypersons. However, a supporting text-based evaluation should be carried out in a in a language understandable to laymen and, if possible, without the use of technical terms from network analysis. It was communicated as particularly positive that the network representation of the communication relationships in the application enabled an evaluation of the chosen communication paths. In particular, it could be checked whether the participants adhered to the specifications of the so-called "Besondere Aufbau-Organisation (BAO)", a predefined structure (incl. communication structure) of the spatial configurations of units for better handling of complex emergency situations. Here, the importance of the representation of path dependencies was emphasized, since not only a complete communication to superordinate management levels but also to subordinate operational sections is necessary and the analysis of path dependencies could be used to evaluate this information flow.

The combination of relationship types and the analysis of different time periods was considered important, whereby the temporal view is particularly relevant for an understanding of the dynamics of the scenario. The interpretation approaches presented in the evaluation were also found to be helpful and could provide a good starting point for own further approaches. Especially the questions about the expected value of communication relationships and the reflection on the number of interactions and the selection of message recipients were perceived as important. According to the exercise leader, the methodology allows for a new type of evaluation and enables the observation of interactions that have not been considered before. Overall, the tool can contribute to an improvement in the evaluation of the exercise, as the evaluation becomes much more meaningful and an anonymous illustration is made possible. The high amount of work required to transfer the data into the application is seen as problematic. Furthermore, it would be desirable to include other communication channels such as telephone calls and radio messages in the evaluation. Possible enhancements were seen in particular in the possibility of graphical representation of not allowed interactions. Also, an even simpler usability and language would be desirable. Finally, it was communicated that an interesting question for future evaluations would be how many and which unnecessary interactions are caused by the imprecise wording of orders.



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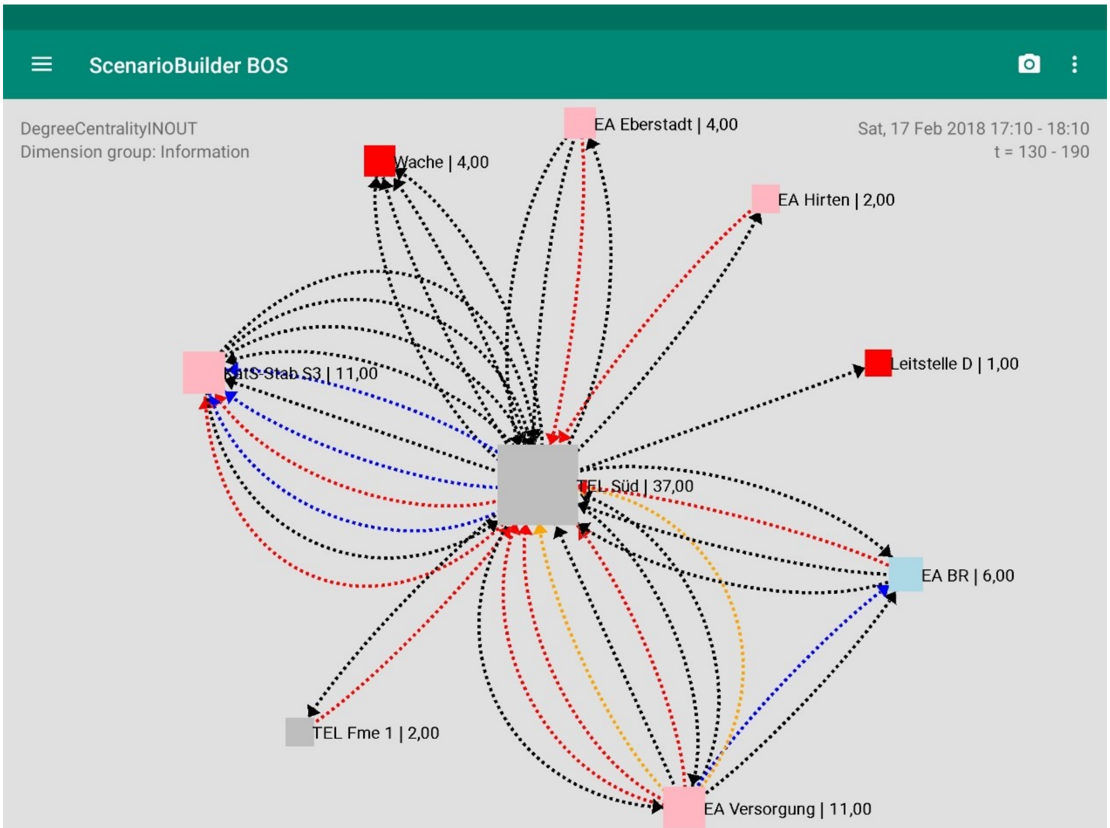
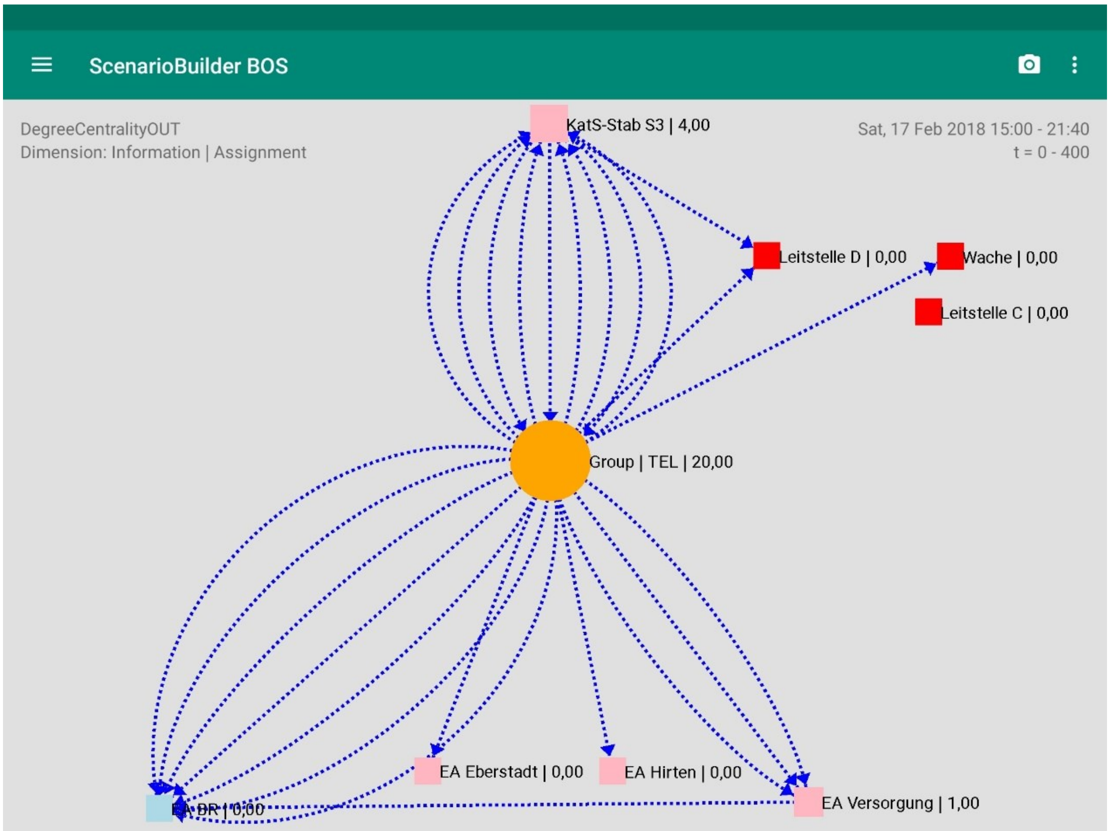


(b)

Figure 8.5: Examples of centrality analyses of the actors from the different organizations within the “Winterübung TEL” on the basis of all communication relations (general information – black, requirements – red, assignments – blue and questions – orange) using (a) PageRank and (b) degree centrality



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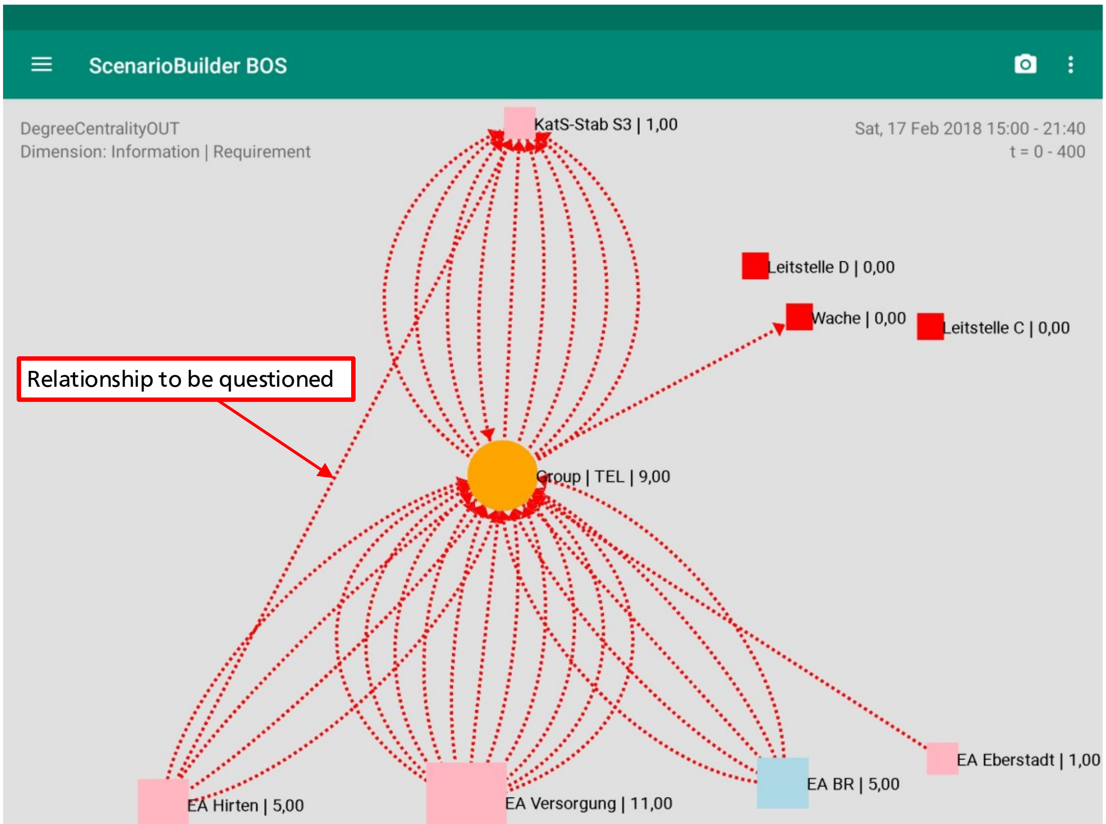


(b)

Figure 8.6: Degree centrality (number of direct interactions) analyses of all communicated (a) assignments (blue dotted lines) and (b) requirements (red dotted lines) over the course of the “Winterübung TEL” exercise

8.4. Evaluation of the "KatKom 2-2019" Exercise

Scenario and Exercise Objectives

The "KatKom 2-2019" exercise took place on June 12, 2019 at various locations in Berlin and Potsdam. The exercise was based on a fictitious accident scenario at the research reactor "BER II" with an immediate massive release of radioactive material. In the exercise, the processes and measures of the disaster control plan (SenInnDS, 2019) were practiced for the area surrounding the research reactor. Each of the organizations involved in the exercise defined its own exercise objectives. For the radiation monitoring center (Strahlenmessstelle) in Berlin, the focus was on the implementation of the processes and the associated tasks. These included alerting and contacting all relevant actors, forecasting and the generation of the situation picture, dosimetric monitoring for personal of the emergency services and preparation for own measurements.

Observation and Evaluation Methodology

For the evaluation of the "KatKom 2-2019", the communication relationships within the radiation monitoring center Berlin observed during the exercise were analyzed. However, since the teams of the radiation monitoring center are very spatially distributed and the observation of the interactions and relations of all actors by one person could not be guaranteed, it was decided to record only those of the staff management. The resulting scenario describes an ego network with all outgoing and incoming relationship interactions from the "Stabsleitung SMS". The communications were categorized according to different relationship types. In detail, a distinction was made between (see Figure 8.7):

- Requirements/requests (red dotted lines)
- Assignments/commands (blue dotted lines)
- Discussions (purple dotted lines)
- Questions (orange dotted lines)
- General information exchange (black dotted lines)
- Reports (green dotted lines)

In addition to the "Stabsleitung SMS", the actors recorded included the various teams of the radiation monitoring center as well as a number of external organizations with whom communication was carried out by telephone. Also, due to the spatial separation of some actors, the teams for the processing of the samples, the vehicles and measurement technology as well as for the output and evaluation of the dosimeters were combined in a node "Team Dosimeter/Messfahrzeug/UR". A total of 12 nodes and 108 relationships were recorded for the evaluation, excluding the interactions during the briefings. In addition to this data, general conspicuous features such as unrest in the staff or ambiguities were also noted.

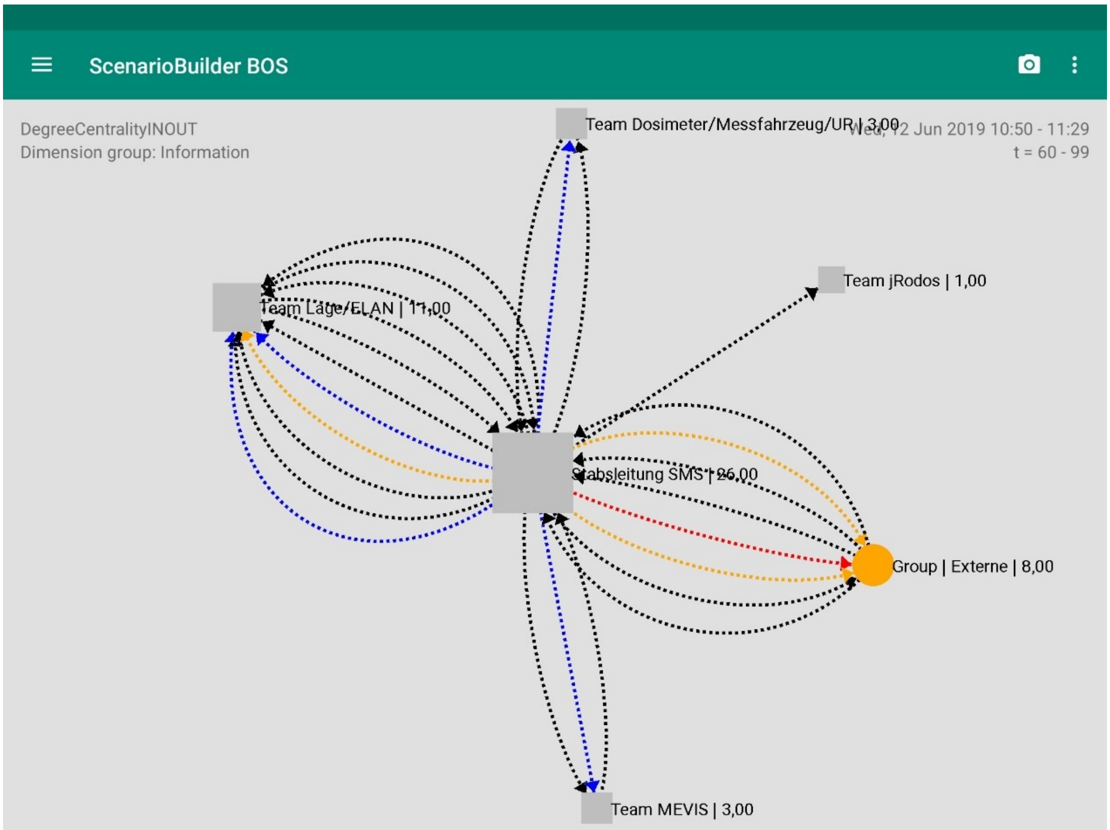
Selected Evaluation Results

Figure 8.7 shows an example of the ego network in two different phases of the exercise. Figure 8.7 (a) shows the situation shortly before the first briefing. Here, two events in particular had a strong impact on the interactions between the actors. On the one hand, a functional failure of the *ELAN* software led to several exchanges of information and the need for clarification on how to distribute corresponding information. In addition, there was a lot of exchange about various measurement results with both the internal teams and the various external organizations. On the other hand the second situation shown in Figure 8.7 (b) took place after the situation described above. During this period, the discussions on the release of radioactive material in particular, the determination of the soil concentration after the dispersion and the examination of the report of an external organization were formative events. In comparison with the illustration of the interactions from Figure 8.7 (a), the communications during this period were significantly different. While at the beginning of the exercise, in addition to the orders of the “Stabsleitung SMS” to the different teams, the communications mainly manifested themselves in the form of information relations, in the later course of the exercise the types of interactions were much more diverse. Both internal teams and external organizations made more requests to the “Stabsleitung SMS” and, due to an unclear expression of information in one relationship, more discussions were held. If one looks at the degree centrality over the course of the exercise it can be seen that the number of interactions with the individual teams remained relatively constant. Here it became apparent that the tasks of the various teams varied greatly in terms of the number of interactions required. While the teams represented by the “Team Dosimeter/Messfahrzeug/UR” node worked largely in an independent fashion and therefore only few interactions with the “Stabsleitung SMS” were necessary, teams that prepared the situation reports or performed various calculations on the situation were more dependent on information from other actors and thus interacted much more frequently with the “Stabsleitung SMS”.

In addition to the task-specific interaction patterns of the individual teams, the further differentiation of outgoing and incoming relationships allowed a more in-depth examination of the communication relationships between the “Stabsleitung SMS” and the other actors. As shown in Table 8.1, for example, the information exchange between the “Stabsleitung SMS” and the external organizations (represented by the node “Group|Externe”) originated from the external parties most of the times (14 out of 17 times) and thus the communication here rather served to acquire information from outside. A similar picture emerged for “Team MEVIS” (eigth out of 11 relations originated from “Team MEVIS”). Here, regularly updated calculation results were presented to the “Stabsleitung SMS” without the need for frequent information coming from the staff management.

Table 8.1: Degree centralities (number of direct interactions) of all actors of the “KatKom 2-2019” exercise on the basis of general information exchange over the period of the exercise

Node	Degree	Indegree	Outdegree
Group | Externe	17	4	13
Stabsleitung SMS	57	35	22
Team Lage/ELAN	18	10	8
Team jRodos	6	3	3
Team MEVIS	11	3	8
Team Dosimeter/Messfahrzeug/UR	5	2	3



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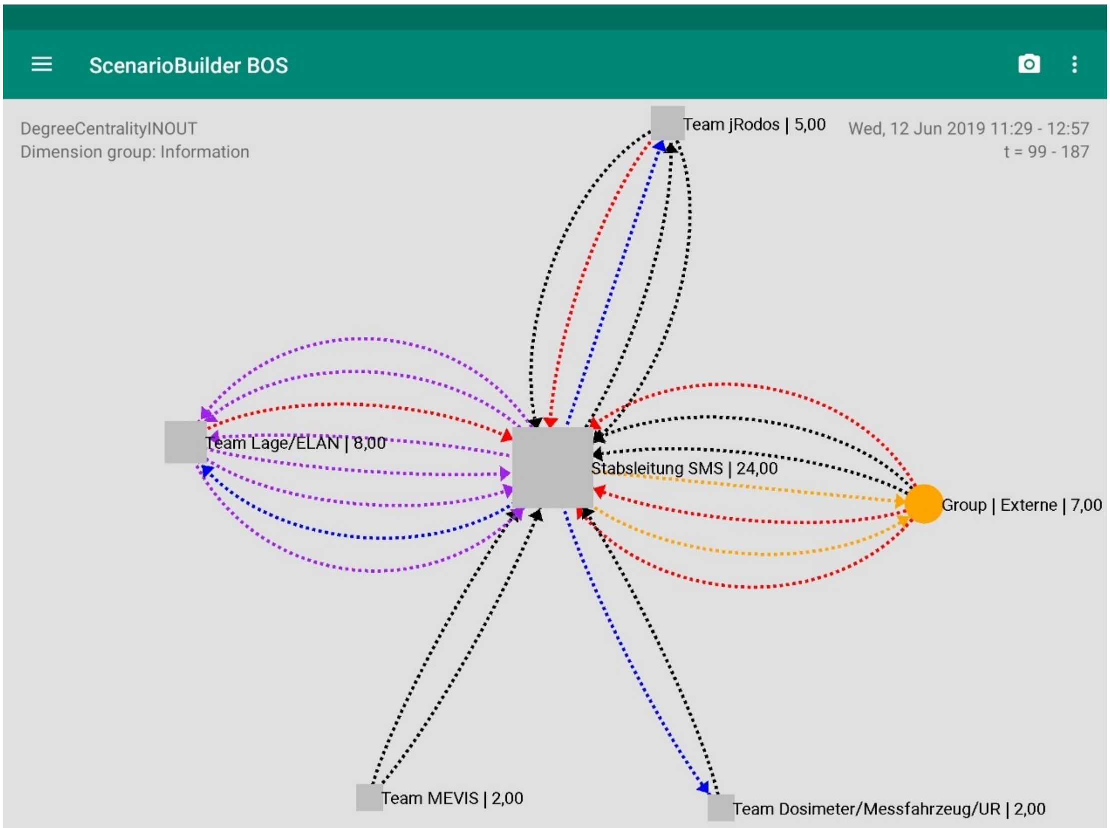


(b)

Figure 8.7: Examples of centrality analyses of the actors within the "KatKom 2-2019" exercise on the basis of all communication relations (general information – black, requirements – red, assignments – blue, discussions – purple and questions – orange) using degree centrality at different times of the scenario

Practitioner Feedback

For the “KatKom 2-2019” exercise, feedback on the evaluation and application was given by the team of the radiation monitoring center (Strahlenmessstelle) Berlin. This was done in two steps. First, the results of the evaluation report were discussed on the basis of a short written feedback and a subsequent telephone conversation on July 30, 2019. In addition, a written questionnaire-based feedback was given on September 24, 2019 both on the evaluation and on the *ScenarioBuilder BOS* as a tool. In the feedback it was stated that there was no previous knowledge of social network analysis. The presentation of the exercise analysis was reflected as understandable. However, some teams that were not on the same floor as the “Stabsleitung SMS” were not included in the analysis. As the procedures and communication channels of the radiation monitoring center are practiced regularly, the visualization via the *ScenarioBuilder BOS* tool did not provide any new insights. The combination and differentiation of the relationship types and the time-differentiated consideration of the exercise were classified as not absolutely necessary in regards to the radiation monitoring center. However, at the higher municipal level in disaster control exercises, this differentiation would be more useful. The interpretation approaches and recommendations given on the basis of the analysis were considered helpful and coincided with the results of other observers.

The added value of the application is mainly seen on two levels: On the one hand, in conjunction with a staff software used to make obstacles in information transfer and processing visible. On the other hand, for balancing the workload of individual staff members or communicators. However, the high effort required for data collection is seen as very critical or disproportionate. This became particularly clear during the “KatKom 2-2019” exercise, since the spatial separation of the individual teams meant that it was not possible to completely record the exercise situation in the radiation monitoring center with just one person, so that only an observation from the point of view of the “Stabsleitung SMS” was carried out. This inevitably led to less meaningful results. With regard to the further development of the application and its use in future exercises, special attention should be paid to the marking and tracking of individual information relationships (in the sense of visualizing path dependencies). Furthermore, especially in the context of the evaluation, the structural organization of the units to be considered should be entered in the tool before the exercise begins. Taking these aspects into account, the potential of the application as a contribution to an improved exercise evaluation is clearly recognizable. This is especially true if an automatic recording of interactions at different nodes would be possible in the future.

According to the team of the radiation monitoring center, *ScenarioBuilder BOS* could also be used in earlier phases of the exercise, especially during the exercise conduct. In this way, expected communication relationships could be entered into the application in advance and could then be used by the exercise supervisors for a check during the exercise. However, this would require an automated recording of the interactions, which should only take place with the agreement of the individual actors and should also be controlled by them.

In addition to the feedback from the radiation monitoring center, an overarching feedback on the application could also be provided by the company *ESN Sicherheit und Zertifizierung*, that was commissioned with the evaluation of the overall exercise. As before, this also consisted of a telephone call (October 22, 2019) and a written questionnaire-based feedback. Here, it was stated that previous knowledge in the field of social network analysis existed, but the methodology had not been used in the context of planning and evaluating exercises. It was further said that the representations of the *ScenarioBuilder BOS* for scenario analysis are understandable and that it is very useful to examine different relationship types and their combinations as well as to consider different time periods. An added value of the application was seen in two areas: On the one hand, the investigation of path dependencies offers the potential to analyze how a communication develops and what effects it has. On the other hand, the combination of the personal perception of the actors, the structure of the organizations and the consideration of the centrality of communication relationships could be used to draw conclusions for the analysis of the effectiveness of an organization. Thereby, the greatest challenge was considered in the collection of data, which is why functions for automatic collection should be a subject of discussion in the future.

8.5. Evaluation of the “Wesersturm” Exercise

Scenario and Exercise Objectives

The "Wesersturm" exercise took place on June 01, 2019 in Höxter and was a supra-regional disaster control exercise with about 700 emergency forces. The starting point was a storm that had moved across the district of Höxter the previous night and had led to a collapsed roof in a hazardous materials processing plant (Robrecht, 2019). It was assumed that hazardous material containers were damaged. In addition, there had been a collision due to the storm between two ships on the Weser river, one of which had chemicals on board and was moored in the port of Corvey. The second ship was drifted off the river. A number of people were injured. The storm also caused trees to fall and blocked roads, so that not all routes were passable by the emergency services (ibid.). Section command lines were set up in the affected towns of the district and the “Mobile Führungsunterstützung von Stäben (MoFüSt)” of the administrative district of Detmold was alerted and was to take over the leadership of the section city of Höxter in the morning. The MoFüSt is a mobile crisis management unit organized as a staff. The exercise was intended to practice the alerting processes and the reporting system as well as the different disaster management concepts of the state and the district of Höxter. In particular, it was about integrating the supra-regional forces into the local operational structure and practicing procedures and communication between the operational sections. The procedures were also rehearsed in the local hospital.

Observation and Evaluation Methodology

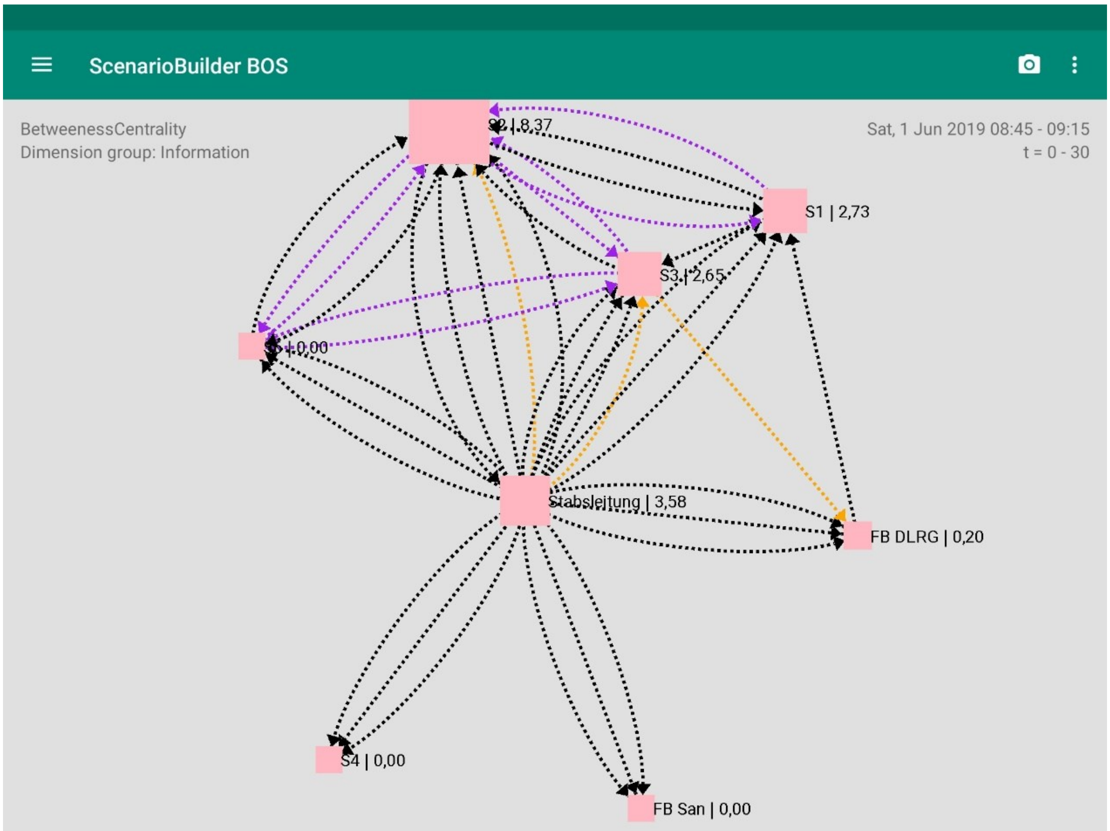
The data basis for the evaluation of the “Wesersturm” exercise was formed by the observed communication relationships between the individual actors of the MoFüSt. With the exception of the interactions during the situation meetings, the relationships were recorded over the course of the exercise and categorized in different relationship types. The information within the situation meeting was not recorded, as it followed a pre-defined pattern. This means that the information was passed on in sequence through each subject area and was always directed to all actors. In total, *ScenarioBuilder BOS* was used to define a communication network consisting of eight nodes and 245 relationships. As previously described, a distinction was made between the following types (see Figure 8.8 and Figure 8.9):

- Requirements/requests (red dotted lines)
- Assignments/commands (blue dotted lines)
- Discussions (purple dotted lines)
- Questions (orange dotted lines)
- General information exchange (black dotted lines)

For discussions, which are often characterized by several mutual exchanges of information, two connections were used, one incoming and one outgoing. In the course of the exercise, a person from the S1 team changed to the S3 team as a support and a resource relationship (black line) was added to represent this action. In addition to the systematic recording of the interactions, general conspicuous features such as unrest in the staff or ambiguities were recorded. As with the previously discussed examples, the “Wesersturm” exercise represented a dynamic network with interactions that varied over time.

Selected Evaluation Results

With the help of the *ScenarioBuilder BOS* the data of the exercise was analyzed and evaluated. Figure 8.8 shows two examples of the analysis of centrality at different times in the exercise. Figure 8.8 (a) illustrates the situation within the MoFüSt at the beginning of the exercise. At this time, impulses were given by the “Stabsleitung” (head of staff) through information about the exercise and two discussions took place. The centrality observations of the communication relations for this period focus in particular on two actors: the “Stabsleitung” and the “S2” (situation management). The “Stabsleitung” was involved in the most of the interactions during this period compared to all other actors (degree value of 24). For the interaction network, it had a special relevance since almost all interactions in which it was involved originated from it, resulting in a very large influence on the network. In this role, the “Stabsleitung” integrated in particular the “S4” (supply management) and the “FB San” (consultant), who were otherwise not involved in any further interactions. Interesting here was also the way in which information was conveyed: Often the communication took place via announcements to all actors and thus had a high degree of accessibility. At the same time the “S2” took on a special role as a ‘communication bridge’, as can be seen by the results of the betweenness centrality calculation (see Figure 8.8 (a)). This can be further explained by the fact that in this phase the staff concentrated on ‘getting out in front of the situation’ and the development of the situation map, which was one of the central tasks of the “S2”. Figure 8.8 (b) portrays the situation 90 minutes later. At this time, the increasingly central role of “S3” (deployment management) had become clearly visible, as its major task was to coordinate planned measures and communicate orders to the subordinate teams. With a degree of 27, the number of its interactions was clearly above the 1-sigma environment (18.36) that can be seen as an indicator of a central actor in the network (see section 6.3). Since the majority of the interactions emanated from the “S3”, it had a high influence on its environment at that time, which was supported by its high betweenness value, ensuring a continuous flow of information.



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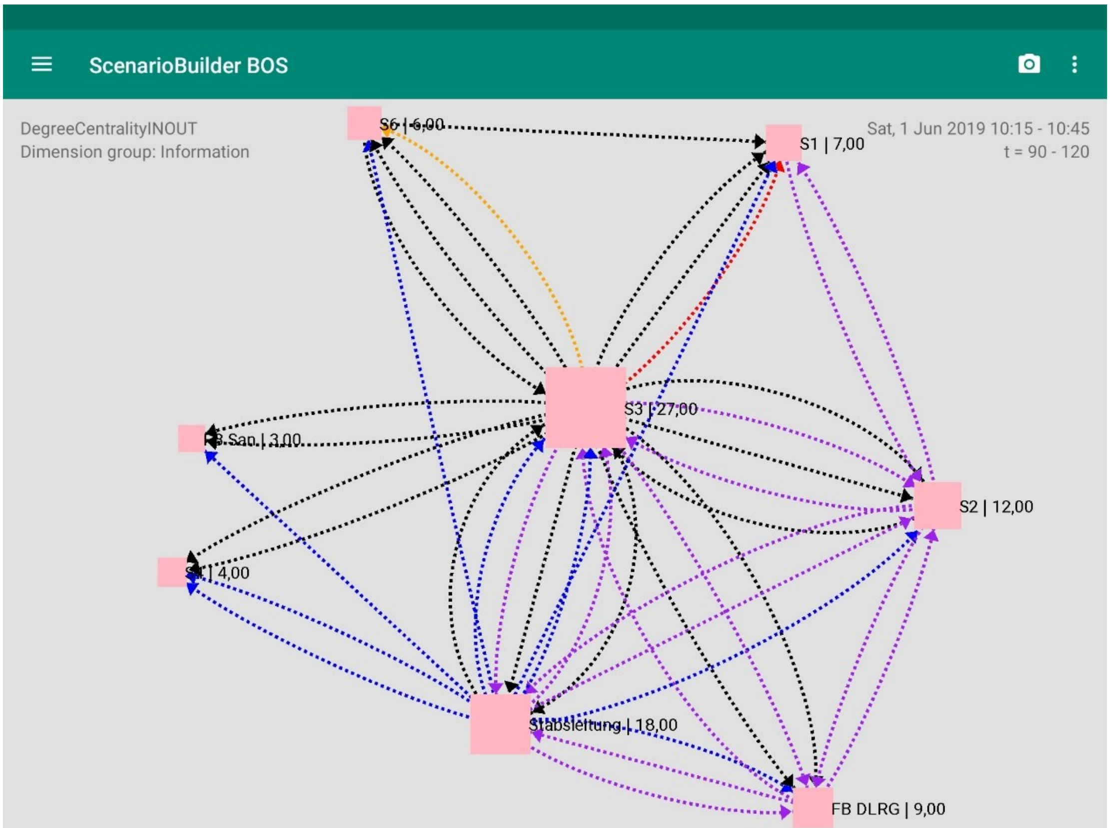


(b)

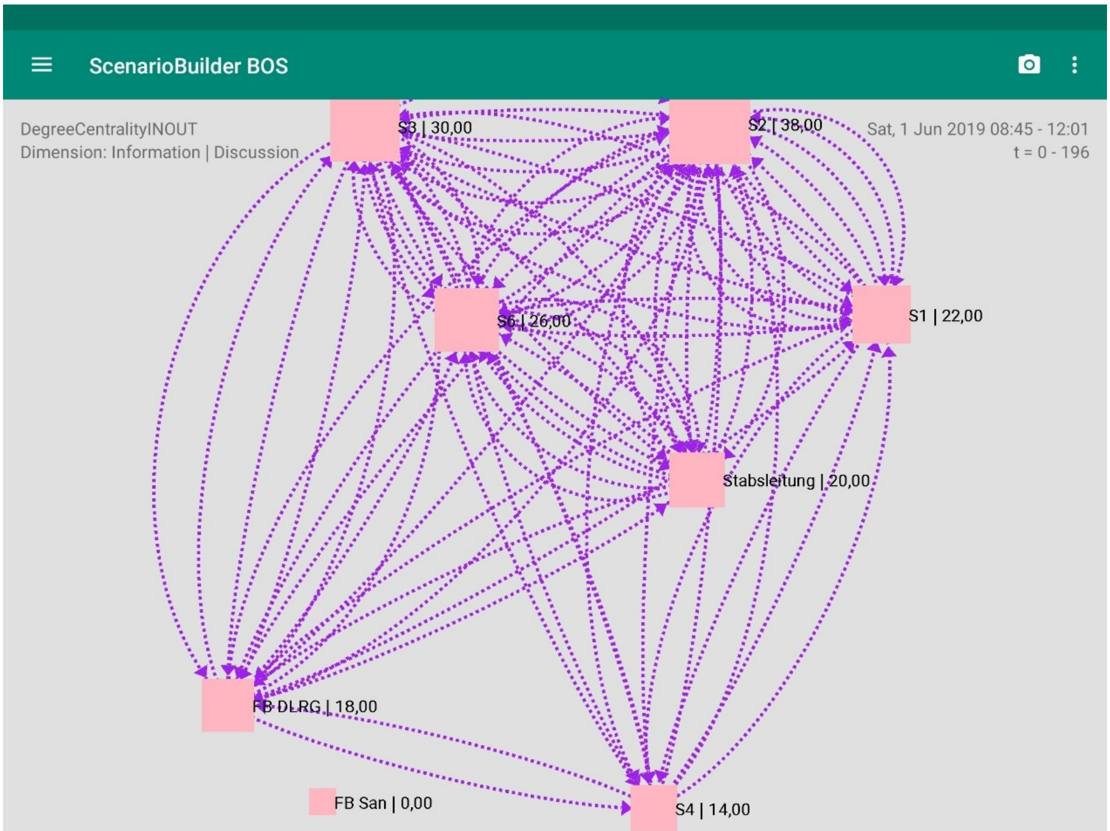
Figure 8.8: Examples of centrality analyses of the actors within the "Wesersturm" exercise on the basis of all communication relations (general information – black, requirements – red, assignments – blue, discussions – purple and questions – orange) using (a) betweenness and (b) degree centrality

Looking at the discussions and assignments communicated throughout the exercise as shown in Figure 8.9, it is noticeable that the "S2", "S3" and "S6" teams were the ones mainly involved in the upcoming discussions, but that the "S2" team discussed with most of the other actors. When considering assignments, the picture was very clear since all assignments were given by the "Stabsleitung". Another interesting aspect of the exercise is that of interaction density. It was at its highest when problems for the staff caused by uncertainties in one of the operational sections occurred. Towards the end, when the scenario changed into a static situation, the number of interactions among each other decreased significantly. Furthermore, the involvement of the consultants requested by the staff, especially for the "FB San", happened almost exclusively in the situation meetings. From the second half of the exercise onwards, the "FB DLRG" was much more involved in the planning of the measures.

Practitioner Feedback

The feedback for the "Wesersturm" exercise was given by the crisis management department of the Detmold district government which also supervised the MoFüSt during the exercise. As before, the feedback was given in an initial discussion on February 10, 2020 and a written questionnaire-based feedback on February 21, 2020. The practice partners stated that they had no previous knowledge in the field of social network analysis. The network-based presentation of the analysis results by the *ScenarioBuilder BOS* was seen as a new yet understandable form of presentation and was in line with the findings of the exercise. These could thus be confirmed with the application. A combination of different relationship types and the analysis of the scenario at different times was perceived as very useful, since an analysis in the given depth would otherwise not have been possible.

The practice partners assessed the added value of the tool for one-time exercises as rather low, since a high effort has to be made for the collection of the data if it is to be used for an error analysis. For regular exercises with the same personnel and different scenarios or the same scenario and different personnel, they considered the tool to be an important and valuable part of the evaluation. The practice partners saw the difficulties in using the tool and the methodology not only in the effort required to collect the data, but above all in the fact that the presentation of the communication relationships alone does not show whether they are goal-oriented or sufficient because there is no indication of the quality of the communication. Therefore, an analysis based solely on the existence of the relationships could lead to misinterpretations. Accordingly, they saw the user assistance in the evaluation of individual communication relationships as a relevant function for the future. In summary, they concluded that the tool can contribute to an improvement in the evaluation of exercises, depending on the preconditions. However, its use in planning is only relevant if the focus of the exercise lies on the analysis of the communication relationships.



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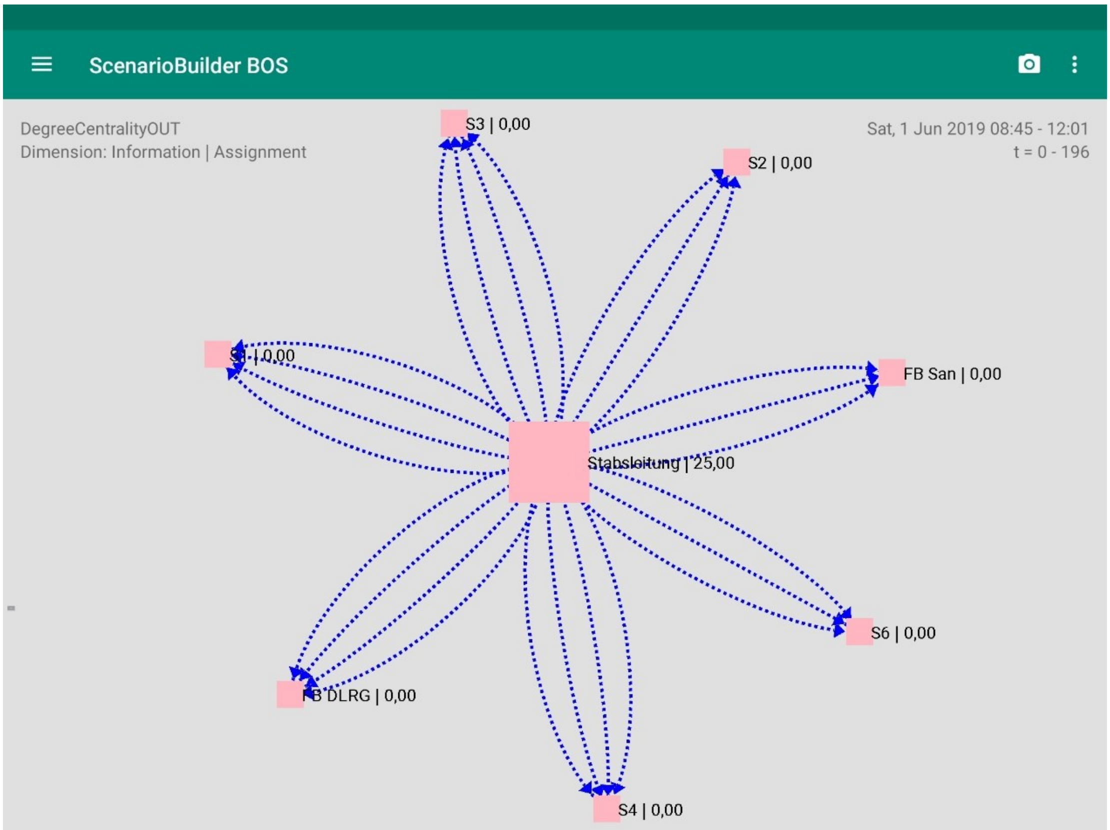

(b)

Figure 8.9: Degree centrality analysis of all discussions (purple dotted lines) (a) and communicated assignments (blue dotted lines) (b) over the course of the “Wesersturm” exercise

8.6. Discussion

Looking at the four use cases for the validation and evaluation of the *ScenarioBuilder BOS* in their entirety, conclusions can be drawn for the questions underlying the work on the usefulness of social network analysis methods in civil protection and disaster response exercises. Since in the course of the work an evaluation including the involvement of practitioners was only possible in the phase of evaluation of exercises, the conclusions primarily refer to this area. For the evaluation of the added value of the application within the planning of exercises only hypotheses can be formulated with the available results. The three real-world use cases considered, “Winterübung TEL”, “KatKom2-2019” and “Wesersturm” are very different in their characteristics. Although they all describe communication networks, they reflect three different levels of communication. Whereas in the “KatKom 2-2019” exercise the network is built up as an ego-network around a person and its interactions with other persons and teams, the “Wesersturm” exercise considers a cooperating group with staff structures and its internal communication processes. Finally, the “Winterübung TEL” exercise examines a superordinate level in which all actors of the exercise who have communicated with each other via the *CENARIO® ilias* staff software are considered. From an organizational perspective, the fire brigade is the focus of both the “Winterübung TEL” and the “Wesersturm” exercise, while the “KatKom 2-2019” exercise focused on a specialized authority, namely the radiation monitoring center. Last but not least, a systematic observation of the communications was used as the data basis for both the “Wesersturm” and the “KatKom 2-2019” exercises, while the “Winterübung TEL” scenario used data from the staff software. Despite their differences, the analysis in all exercises was carried out following the same systematic approach and the same functions of the *ScenarioBuilder BOS* were used. The analysis of the scenarios focused on the possibility to analyze different time horizons and different combinations of relationship types. In addition, various centrality measures were used to develop interpretation approaches that reflect relationship patterns differently.

The application was positively evaluated in all cases. The visualization of the communication structures was presented in a way that was understandable for the users and could confirm their own findings or even offer new insights into the different situations. The consideration of the exercise as a dynamic scenario with different communication relationships and the resulting varying interaction patterns was perceived as an enrichment and allowed for a more in-depth examination of arising problems. By analyzing the centralities of individual actors, interpretation approaches could be developed that in most cases provided added value for the evaluation. Although all practice partners stated that they see a great potential for the evaluation of future exercises in the application, distinctions can be found. For example, it was determined that the added value of the application is perceived as being significantly stronger when the patterns of interaction are more complex and not obvious at first glance. For example, the interaction patterns in an ego-network in which only the direct exchange between two actors is represented are easier to understand than when several actors are interlinked, as can be observed in staff structures or when the entire exercise communication is considered. This is all the more true when the given structures within an organization or authority are frequently practiced with the same persons as can be seen in the example of the radiation monitoring center. Nevertheless, an added value can be found in these as well as in the analysis and visualization of communication on the basis of networks. Thus, especially when examining the different types of communication and viewing them over different time horizons, it is possible to take an in-depth look at the workload of personnel and to make more far-reaching and thus more complex analyses. If the same scenario is practiced more often or if expectation values for communication structures in certain situations are defined beforehand in the planning phase, a more in-depth analysis can also be carried out to deal with any problems that arise, as the different networks can be compared and deviations identified.

An evaluation of communication interactions, as pursued by the *ScenarioBuilder BOS* using a network-theoretical approach, is largely unknown in the current practice of exercises in civil protection and disaster response, but offers very different possibilities for analysis. In addition to the evaluation of the workload of individual actors mentioned above, statements can also be made about chains of command and the structural set-up of the organizations observed. By analyzing different time periods and relationship types, exercises can be illustrated from a retrospective point of view and divided into individual situations, enabling the user to analyze the role of various actors. The concept of centrality is also very much in evidence here as it allows different perspectives on a situation. From the discussions and the written feedback regarding the application, it can be concluded that the added value of the application can be maximized if it is interactively included in the evaluation process. Although individual aspects can be captured in reports by means of illustrations and descriptions, this form of presentation has its limitations and the available functions of the application cannot be used to their full extent. In the feedback from the practice partners, for example, the demand for a possibility of linking different relationships was expressed several times in order to follow information as it spreads or to understand the effects of certain interactions. These investigation opportunities are made possible by functions such as path dependency or scenario replay, which further underlines the argument for using *ScenarioBuilder BOS* as a support for exercise evaluation.

The different use cases illustrate that different sources can be used as a data basis for the evaluation. In particular, data from systematic observations of formal and informal communications are of particular relevance. In addition, communication data from staff software, analogue communication via the message form as well as communication via radio, telephone or email are suitable. Moreover, it can be assumed that a combination of the different sources can lead to more precise statements of interaction patterns. This can be illustrated using the example of the “Wesersturm” exercise. Here, only the interactions of the actors in the staff were considered for the analysis. A potential addition would have been the incoming messages and reports from the operational forces that were received in the individual subject areas. With the help of the additional communication data, it would have been possible to link interactions between staff members with information and requests from incoming messages and to reflect how individual messages affect the work of the staff. The combination of different data sources also has the potential to add knowledge of the content of interactions to situations and allow a more accurate assessment of the benefits and necessity of individual interactions. Contrarily, a lack of such knowledge of the content of interactions is a problem that has been repeatedly expressed by practitioners and makes it difficult to analyze and evaluate individual interactions. Therefore, possibilities to bypass or mitigate this problem should be the subject of further discussion. Initial approaches besides the combination of several data sources mentioned above could be the definition of interaction patterns as an expected value for comparing theoretical and real communication. Additionally, it would be possible to conduct an initial analysis of the communications with *ScenarioBuilder BOS* already during the briefing with the participants in order to expand the scenario with their additional information.

The problem most critically reflected by practitioners when using the application and methodology of social network analysis in the evaluation of exercises is that of data collection. Data collection is especially a problem in the case of distributed actors, since the required number of observers is usually not available, as became apparent during the evaluation of the "KatKom 2-2019" exercise. This problem can be partly compensated by implementing interfaces for a data transfer from staff software to *ScenarioBuilder BOS*. For example, the staff software *CENARIO® ilias* used in the "Winterübung TEL" exercise offers an export function that exports relevant data in a CSV format, thus providing an easy way to automatically enter said data into the application. Similar possibilities are also conceivable for other data sources like digital radio through technologies such as speech-to-text or for computer vision, but further research is needed. Especially data acquisition through systematic observations is difficult to automate from today's point of view, which is why a trade-off between costs and benefits must always be made. In principle, communications of structures such as staffs appear to be observable even with few personnel, as for example the "Wesersturm" exercise has shown. At the same time, well-functioning communication is of great importance for these structures, which also often work with the same or at least similar personnel, so that a consideration of the existing communications appears to be a very meaningful and feasible task.

Summarizing the results of the three use cases for the evaluation, the use of *ScenarioBuilder BOS* shows a great added value for future exercises. Based on the concepts and methods of social network analysis, the application offers a new possibility for the evaluation of exercises in civil protection with a special focus on communication relationships that have hardly been considered so far. In order to use the application profitably, it is important to provide possibilities for automated data acquisition, for example from staff software. Furthermore, more advanced concepts should be developed on how nodes and relationships can be enriched by annotations in order to highlight errors or to add other information to the scenario and to support an interactive evaluation. In order to obtain a high statement quality, it is necessary to train observers and exercise instructors so that on the one hand the required data basis is available and on the other hand practitioners are enabled to develop their own analyses and interpretation approaches based on the network data and corresponding concepts such as centrality.

The use of *ScenarioBuilder BOS* also offers some potential for the planning phase of exercises, but this can only be formulated as hypotheses at this point. In principle, two cases appear to be sensible options for use: Analogous to the possible uses of the application in the evaluation, expectation values for communication patterns in certain situations can be created in the planning phase in order to use them to examine the workload of individual participants in advance from a planning perspective, for example. From the statements of the practitioners it can be concluded that this case is however only interesting for planning if an examination of the communication structures is defined as an exercise goal, since otherwise the comparatively small benefit would not warrant the additional effort and exercise planners will commonly rather rely on empirical values. The second case for which the use of the application in planning appears to be useful is the one described with the use case “Flooded City”. Trough simulations and calculating cascading effects, the *ScenarioBuilder BOS* can support exercise planners in foresighted thinking when developing scenarios as well as when defining the exercise boundaries. This case seems to make sense especially in the context of the increasing number of large-scale exercises, since scenarios for these exercises can reach a high complexity and quickly become difficult to understand.

9. Conclusion and Future Work

In the course of this dissertation, it was investigated to what extent software applications can be used to support exercises in civil protection and disaster response. This was done by considering the emergency sector as a critical infrastructure and with reference to the concepts of preparedness and prevention as well as criticality. An approach based on network theory was chosen and an attempt was made to model and examine scenario-based exercises in multilayer graph networks of different types of relationships. The work contributes to various areas of research on critical infrastructure and in particular to the role of exercises in civil protection and disaster response.

Starting from the definition of critical infrastructures, the thesis addresses the emergency sector and explains its dual role in the infrastructure system. As a critical socio-economic service infrastructure on the one hand and as the main actor for all measures to protect the population and other critical infrastructures on the other hand, the emergency sector has a central role to play. An important element of the sector's preparedness and prevention strategy is the exercise, especially that of civil protection and disaster response, which is characterized by inter-organizational cooperation, since it focuses on people as the sector's most important asset and enables them to act in crisis situations.

In order to gain an understanding of the structural characteristics of civil protection and the exercises that are so important for it, the first step in this work is to identify the responsibilities and differences at federal, state and municipal level. In a second step, the work then goes into detail about the exercises and elaborates the objectives and methods associated with them on the basis of a literature review and interviews with various actors in the field. It turns out that each exercise is very different and depends strongly on the needs of the respective organizations and authorities. In the further analysis of the exercise methodology and the current situation of the exercise in practice it becomes clear that especially the planning is very complex and that there is a need for supporting tools in the development of the scenarios, while a particular attention is drawn to the difficulty of thinking ahead during scenario development. Another need can be identified in the context of exercise evaluation: It is apparent that, despite the awareness regarding the importance of evaluations, hardly any systematic procedures are available, and that the evaluation as a whole is often not carried out with the necessary consistency. It is particularly striking that although the review of communication during the exercise is a central aspect of the evaluation, communication relationships have not yet been recorded and systematically analyzed.

By evaluating the relevant research literature from the fields of organizational research, emergency management as well as risk and criticality research, the potential of social network analysis for the aspects of planning and evaluation of exercises is identified and comprehensively worked out in the dissertation. Social network analysis enables an intuitive representation of the sometimes very complex relationship structures and is equipped with concepts and methods that offer possibilities for interpretation and a better understanding of the respective situation. In particular, the aspects of visualizing networks and their representation in the form of multilayer graph structures with different relationship types and temporalities are emphasized. It is also shown that the concept of centrality, which is applied in a variety of related works, can be evaluated as very useful for the application context. On the basis of the comparative work and the previous analysis of the exercise situation, three forms of networks are identified that are suitable for the exercise context. These include communication networks, dependency networks and scenario networks as a combination of the aforementioned. Based on the findings on the use of social network analysis in the planning and evaluation of exercises, the dissertation formulates requirements for a software application that refer to aspects of the literature as well as to contents and problems conveyed by practitioners of the emergency sector. In addition, different available software solutions are examined with regard to their possibilities in the exercise context. It is found that no currently available solution meets the requirements that arise for exercises in civil protection and disaster response.

In order to meet the specific requirements of a given exercise, a concept for a network-based support software is designed and implemented in a tablet-based demonstrator application called *ScenarioBuilder BOS*. With the help of this software the user is supported in modeling and developing exercise scenarios and in analyzing and evaluating them in various ways. The aim of the application is to enable the user to develop interpretation approaches and to question actions and relationship structures by presenting the scenario from different perspectives. In order to achieve this goal, the visualization of the dynamic scenario networks is the center of attention. Two superordinate use cases are considered in the application, namely scenario development and scenario analysis. For the scenario development the user has the possibility to define actors and relationships and to assign them to different types. Furthermore, time dependencies can be described so that each scenario is described as a dynamic multilayer network. Since the defined requirements have resulted in the need for possibilities to simulate scenarios, the application can also be used to describe and evaluate capacities and requirements of nodes. In addition to the simulation, a number of functions are available for the analysis of the developed scenarios. In particular, the possibility of visualizing different time horizons and relationship combinations should be mentioned. Furthermore, central actors in the network can be identified and recommendations for action can be derived on the basis of the concepts and procedures of centrality. By visualizing path dependencies, the application offers the possibility to observe the influence of individual relationships over time and to investigate effects on the network. The representation can be influenced by the user through various options, such as the choice of different layouts. Through the means of the demonstrative implementation of the concept in an Android-based tablet application, the software tool could be used directly for practical exercises. To further support the usage of the tool, the user interface is chosen in a way that allows easy data entry and editing.

In order to evaluate the application as well as the usefulness of social network analysis as a methodology to support the planning and evaluation of exercises, the dissertation describes four use cases, three of which are evaluations of real civil protection and disaster response exercises in different organizations and authorities. The fourth case describes the use of the application to develop the scenario for a fictitious exercise and serves to validate the simulation and other functions of *ScenarioBuilder BOS*. The evaluations show that the application and the associated methodology of social network analysis have great potential, especially for the evaluation of exercises. It enables a systematic recording and evaluation of especially communication relationships and can thus make a valuable contribution, for example, to assessing the workload of actors, analyzing compliance with command structures or explaining dynamics in teams. Furthermore, based on the discussions with practitioners, it can be assumed that the tool also offers added value in the planning of exercises, especially as a support in the calculation of cascading effects within scenario development. However, in order to achieve the formulated added value, solutions and process strategies for the identified problems, for example the high workload of data collection, have to be developed and further studies have to be carried out. Which possibilities would be conceivable for this and to what extent further functions of the application can be added is discussed in the following section.

Outlook and Further Research Questions

For the introduction of the *ScenarioBuilder BOS* in regular exercises additional work is necessary in the future. On the one hand, the application should be further developed technically on the basis of the problems identified during the evaluation, and on the other hand, it is important that subsequent evaluations are carried out in order to identify the potential in the planning phase more precisely and to train users in the use of the software. For this purpose, it is necessary to plan the use of the tool in the context of an exercise from the start and to communicate corresponding requirements regarding recording and evaluation to the observers and exercise controllers. When using the software in the context of an evaluation, the actors and the organizational structures should also be stored in the application in advance and it should be defined where observers are to be positioned and which relationships they are to record. In principle, the aim for the evaluation should be that it is carried out interactively, for example in the form of an evaluation workshop, so that a discussion about developed interpretation approaches can take place and the various participants can develop an understanding of their role in the overall context of the scenario network.

For the further use of the application, it is elementary to create possibilities of simplified and automated data acquisition, since the added value of the application might otherwise not be in proportion to the effort. Various options are available for this. For example, many staff software products have functions to export the data, which would provide a simple way to create interfaces or import data. With regard to the simplification of scenario development, interfaces to personnel and material databases would also be useful, from which, in particular, derivations for capacities and requirements can be drawn. Under strict adherence to data protection and with the consent of the respective personnel, it would theoretically be possible to achieve automated recording of interactions via telephone and radio or those that arise in direct exchange, using technologies such as speech-to-text or similar. However, since there are many different problems that can arise when using such an approach, like the recognition of relevant information for the application or the removal of radio noise, it should first be examined whether the benefits generated by this method justify more in-depth research on the subject or whether a discussion in the course of an evaluation workshop would be more productive.

A further possibility to extend the application is especially given by additional functionalities for annotation and the enrichment of scenarios in the context of evaluation. This could be used to mark incorrect interactions and provide support for the evaluation. An implementation of further methods from graph theory is also conceivable. Here, procedures for the comparison of two graph networks are particularly suitable in order to be able to compare the effects of different situations on the relationship structures in a scenario, for example. Another example are cluster detection methods that can be used if several teams are represented in a scenario and the interactions between the teams are to be examined more closely. Since a report must be written at the end of each exercise, including the results of the evaluation, further functionalities to support documentation in general and the writing of reports in particular are also useful possible enhancements of the application. With regard to the visualization of the scenario networks, it can be stated that so far the visualization is exclusively based on a representation in two-dimensional graphs. Especially for very complex scenarios, other forms of representation such as three-dimensional graphs or the use of virtual reality for representation are also conceivable.

In the long term and with an established data basis, further developments are possible in addition to the functions mentioned above and those resulting from the user feedback. For example, it could be considered how machine learning might be used to automatically detect problematic situations in a scenario on the basis of the given relationship structures or to offer recommendations for avoiding them. In this context, the use of the application can provide added value both in scenario planning and evaluation, since expected values for relationship structures could first be defined in planning and then be compared with the actually given structures in the course of the evaluation. This would give rise to further interesting research questions, for example, as to which deviations from the expected value can be tolerated without restrictions or whether conclusions can be drawn from the exercise regarding the effectiveness of the organization.

Taking into account the possibilities for extending the *ScenarioBuilder BOS* as presented in this section, this dissertation has shown how exercises in civil protection and disaster response can benefit from the use of software and methods of social network analysis. It should be noted, however, that no software can replace the learning effect that the practical exercise enables. As such, the concept presented here is only one of the ways in which exercises that are of great importance for the preparedness and prevention of the emergency sector can continue to function effectively as an element in the security apparatus. Or to put it in the words of the philosopher Will Durant from his work “The Story of Philosophy” (1961):

“Excellence is an art won by training and habituation: We do not act rightly because we have virtue or excellence, but we rather have those because we have acted rightly; [...] we are what we repeatedly do. Excellence, then, is not an act but a habit.”

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List of Figures

Table Directory