Agent-based modelling to identify possible measures in case of Critical Infrastructure disruption

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ABSTRACT

Understanding critical infrastructures and in particular protecting them in case of natural or man-made threats or disasters is the objective of our research. As use case, the security of the power supply in the year 2030 for the city of Karlsruhe was selected. This scenario contains interdependencies between the electrical power grid and IT components as well as critical infrastructures such as water supply and health care. To simulate the critical infrastructure, their dependencies and potential measures to mitigate effects, agent based simulation models have been developed and applied. The ultimate objective of the research activity is to develop a holistic analysis framework to quantify and evaluate requirements and design decisions of the many players in such complex infrastructures.

Keywords

Critical Infrastructure protection, agent based model, countermeasures

INTRODUCTION

In 2012, the German Helmholtz research organization initiated a research line on security. Three large Helmholtz Centers, the German Aeronautics and Space Research Centre (DLR), the Research Center Jülich (FZJ) and the Karlsruhe Institute of Technology (KIT), formed a consortium, combining their vast knowledge in cyber security, sensors and platforms, emergency management and security of critical infrastructures in one project. The central activity so far focuses on critical infrastructures (CI) and critical infrastructure protection (CIP). In particular, the project aims at establishing a platform to advise CI owners, operators, local emergency management organizations and research related to CIP. To demonstrate the research approaches, a common scenario was defined that focuses on a terrorist attack on the ICT components of a future power grid in 2030, investigating the consequences and possible measures to mitigate or prevent a longer lasting power blackout.

This paper focuses on data collection of single CI components and of potential countermeasures or pre-emptive measures. In addition we discuss the methodology to be applied in the use case. It is organized as follows. First the methodological approaches applied will be presented, followed by a used case and the data collection. At the end, preliminary results of the use case will be discussed and first conclusions as well as future research activities highlighted.

METHODOLOGICAL APPROACHES

CIs in modern societies are highly interconnected and dependencies exist at various levels (e.g. Rinaldi, Peerenboom and Kelly, 2001). To describe these complex interdependencies, different simulation approaches exist. Ouyang provided a comprehensive review of different simulation approaches including agent-based modeling (ABM), system dynamics, hybrid system modeling, input–output model, hierarchical holographic modeling, the critical path method, high level architecture, and petri nets (Ouyang, 2014). He provided information about application studies as well as weaknesses and strengths of each of the various approaches. He concluded that depending on the purpose different approaches might be preferable. However, in particular for the more comprehensive approaches such as ABM and hybrid modelling, the need of data is high but the availability of data might be low. In (Yusta, Correa and Lacal-Arantegui, 2011), a similar comparison was performed focusing on energy security relating to critical infrastructure protection. Among the simulation techniques used. ABM is one which is applied in many simulation frameworks. He concluded that to understand the dynamic behavior of the infrastructure systems, simulation techniques such as system dynamics, Monte Carlo simulation or ABM are suitable.

ABM allows to introduce distributed problem solving and considers trade-offs between the interests of all parties involved (e.g. Shoham and Leyton-Brown, 2009). All parties of interest, e.g. various critical infrastructures, population, crisis management organizations, resources can be represented by one or more individual agents. Any agent interacts with others and the relevant environment. This interaction is based on a set of rules, which represent the interaction in reality. The agents consider also prior experiences in their decision (Tesfatsion and Judd, 2006). In this way, CI components are represented by individual agents which can interact with each other and also negotiate about resources needed.

There exist several simulation frameworks that can be used to set up agent based simulations. In this project the REPAST platform is used as it is open source, has a strong user community and can be easily combined with GIS systems and other external tools (Collier, Howe and North, 2003).

As a starting point agents are defined for the health care system (e.g. hospitals, elderly care and pharmacies) and water supply. In a second step, households, emergency management organizations with their crisis teams and first responders will be also set up. Key parameters representing a CI are the resources needed for operation as this defines to some extent the dependencies and the self-help capabilities of each individual CI realization.

USE CASE

The selected scenario is a projection of an energy grid into 2030. It is assumed that renewables and de-centralized production is much more prominent than today. Assuming smart grid capabilities and enhanced stability management, information and communication technologies (ICT) become extremely important. Assuming that ICT is not managed by only one actor in the energy grid of 2030, cyber threats are a potential cause for grid instability and power blackouts (e.g. Wang and Lu, 2013). In the use case, all three areas, CI, power grid and ICT, will be considered (Fig. 1). As initial event, a cyber-attack at the ICT structure, operating the smart grid is envisaged. Studies will be carried out to investigate the stability of the energy supply under different conditions, the consequences to the CI and which measures are applicable to reduce the threat or remediate the consequences. To do so, coupled simulation models of the three layers are under development. For the CI part, the ABM approach has been selected. For the other parts, our project partners use their own approaches.

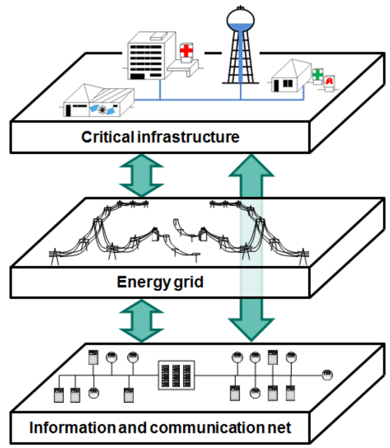

Figure 1. Three layer scenario of the power grid in 2013

DATA COLLECTION

Critical Infrastructures

The city of Karlsruhe, located directly at the Rhine River, is a town of about 300000 inhabitants and located in Baden-Württemberg, Germany, close to the borders with Rhineland-Palatinate, and France. It covers an area of 17 346 hectare, of which 40 % is urban area, 26 % is forest, and 21 % is agricultural land.

Based on literature and Internet search, we identified 138 relevant facilities in the water supply and health care sectors.

The water supply of Karlsruhe is mainly organized by Stadtwerke Karlsruhe. The four small towns Hohenwettersbach, Grünwettersbach, Palmbach, and Stupferich are supplied by another provider and not part of our simulation set-up for the city of Karlsruhe. According to the "Studien des Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag" study (Petermann, Bradke, Lüllmann, Poetzsch and Riehm, 2011) waterworks and high level tanks are main elements of water supply. Although one great waterworks is located in the urban area of Rheinstetten, we take this into account as it produces more than 35 % of drinking water of Karlsruhe. Important information collected comprised among others number of extraction wells, max. pumping per day (m³), drinking water abstraction (m³), number of emergency power generators and their performance. The latter one was only available for one facility. Number and capacities of high-level tanks were also collected.

In addition to the hospitals such as Städtisches Klinikum, inclusive psychiatry sites, the St. Vincentius-Kliniken, two dialysis practices and some special clinics complete the list of the health care systems. The category special clinics comprise an ophthalmic clinic, dental clinic, and a cardiology clinic. Selection criteria are that the clinic has patient beds, execute operative interventions, and medicate medically necessary interventions. Though, cosmetic clinics are not considered. Information collected includes the number of intensive care beds, inpatients per year, ambulant patients per year, operating theatres and staff members. In addition power and water consumption was collected or estimated.

There are three categories of care facilities, care facilities without assisted living, care facilities which provide additional assisted living, and care facilities with only assisted living. The difference of the last category to assisted living at home by family members is only the concentration in a building. However, to include such a group of people into the model is a big challenge. Hence we limited ourselves to the first two categories, which contain still 43 facilities. Also facilities which take care of elderly people and/or handicapped persons but have no own accommodation capacities are ignored.

In the field of pharmacies no limitations relating to the element choice were considered. All pharmacies in the urban area of Karlsruhe, 80 in number, are relevant for the model. Most important for the simulation are the number of people which live in the sphere of influence of a pharmacy.

Countermeasure or pre-emptive measures

Besides the data collection, possible pre-emptive or management measures are of high importance. For example care facilities are equipped with food stocks for only one or two days while others have a food stock for more than five days. Some care facilities have an emergency supply, and hence go on a voluntary basis far beyond the standards set by law, whereas others do not (see (Hemmert-Seegers, Solarek and Kleber, 2014)). By contrast hospitals and water suppliers are legally obliged to have installed an emergency supply. Therefore, water supply and health care can perpetuate operation for at least one to two days according to (Heinrich, Kemmler, Rits, Schlesinger and Weinmann, 2009).

Measures of civil protection authorities and water supply operators are similar. However, one fundamental difference relates to the activation of emergency wells and the use of mobile water purification plants. We have compiled the following list of measures, which are all relevant for our simulation.

1 Use of emergency generators
2 Use of mobile water purification plants
3 Activation of emergency wells
4 Use resources and logistics of providers which are not affected
5 Directive: Limitation of water consumption
6 Grid-bound drinking water supply: Lower line pressure

7	Grid-bound drinking water supply: Reduction of quality
8	Drinking water from adjacent water suppliers by constructing a pipeline
9	Drinking water from adjacent water suppliers by use of tie lines
10	Use of tank vehicles
11	Use of mobile water tanks
12	Supply with packaged water: bottles, canister, pouch, etc.

Table 1: Measures of water supply

In the area of health care there are few intersections of measures between the civil protection authority and single facilities. Table 2 contains all sensible and feasible measures identified by the civil protection authority. Beside the use of emergency generators and providing and stockpiling of drugs, only the last point evacuation belongs to the common domain. Evacuation forms a special case, since they are carried out typically in mutual cooperation. The measures of hospitals and care facilities differ little from each other. In many cases consumption is reduced, for example by conserving water or rationing of food. In addition, single sectors are kept alive for example by longer working hours or alternative food preparation. One measure which is only applicable to hospitals is for example an early discharge of patients.

1	Composition of emergency reception centres in schools, sport halls, etc.
2	Installation of emergency reception centres like camps
3	Request mobile army surgical hospital (for example from DRK)
4	Commitment of persons (doctors, etc.)
5	Providing and stockpiling of drugs
6	Use of emergency generators
7	Allocation of additional waste container
8	Evacuation

Table 2: Measures of health care (civil protection authority)

FIRST RESULTS

To estimate the resilience in case of a longer lasting power blackout, the emergency power supply capacity is important. For hospitals this is typically 24 hours in Germany. This duration may differ for other CIs. To allow the agents negotiating about the energy needed, a cost function (costs incurred due to power interruption) has been defined. The cost value depends on parameters that are not known with complete certainly. These parameters need to be estimated and the range of possible values must be determined. For this purpose different approaches are required such as the analysis of historical power blackouts. The cost function comprises all relevant attributes such as the energy consumption, importance for the society and for other CIs, vulanarability and others. This allows negotiating how to distribute remaining resources among all parties involved, including the city households. Example calculations are shown in Figure 2. There, color codes indicate whether a region of the city is affected from the power blackout and if this is a partial (light) or complete blackout (dark). Dark and light dots indicate the situation of the CI. Following the exhaustion of self-help capabilities, the CI changes their status into dark, being no longer able to perform their obligations.

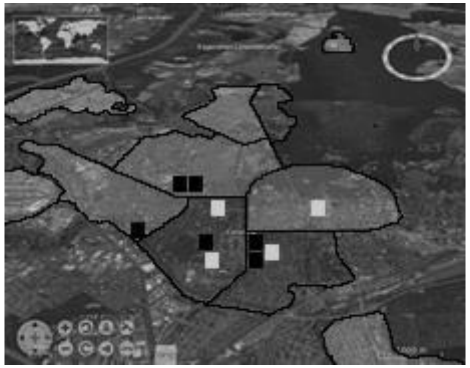

Figure 2. Aerial representation of the affected area (light, partial blackout and dark, total blackout); dots represent the status of a particular CI

For the health care, the city hospital is most important. This importance is reflected in the cost function used by the agents to negotiate with the power grid owners to obtain electricity – if available. A second information from the time dependent simulations is the information flow. All agents do not only approach each other, the power grid owner but also the emergency management organizations. For different scenarios, one can generate a pattern that can be used for preparedness and planning at which time and for which CI support is necessary. Again, here agents will be developed that simulate the distribution of limited resources.

CONCLUSION AND FUTURE WORK

Data collection is one of the most crucial steps in setting up an ABM simulation. Therefore, it is important to collect as much data as possible, and to close gaps with sensible assumptions verified by experts. So far the agents interaction with the environment and among each other is rule based. In a further development step, we intend to enhance their capabilities using multi criteria approaches, for further details see (Lin, Brauner, Münzberg, Meng and Moehrle, 2013). This enhancement would allow the use of further attributes and to set priorities with changing preferences, in particular from the decision making side of the emergency management teams. Once completed, to generate time dependent feedback loops, we intend to couple the ABM part in an improved manner with the power grid and ICT simulations, and thus investigate various attack scenarios and derive sensible countermeasures for them.

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