Indicators to compare simulated crisis management strategies

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ABSTRACT: Modelling and simulation help comparing complex and interrelated decision options in disaster risk and crisis management. To support the user in his specific decision situations, detailed simulation results need to be aggregated and communicated by indicators that characterize situation- and process-related aspects of alternative scenarios. The FP7-funded project CRISMA implements a modelling and simulation framework for stakeholder and crisis specific applications, which is demonstrated in pilot studies on coastal submersion, earthquake, extreme cold weather, chemical spill and large traffic accidents. This paper describes an approach to quickly understand and compare alternative simulation runs (which represent scenarios) with support of indicators that are calculated based on reference and model data in the simulation system.

Keywords: Indicator, Simulation, Crisis Management, Scenario, Decision Support

1. INTRODUCTION AND MOTIVATION

The impacts of natural and technological hazards are increasing, and their effects on health and wellbeing are amplified by population growth and economic activities. Moreover, media raise awareness about disasters, sometimes in biased manner, which altogether puts additional pressure on crisis management and requires retraceable justification of decisions during crisis response and for investments during the preparation phase.

Planning and training during the phase of emergency preparedness can be made more efficient by the use of modelling and simulation tools. Simulation of crisis evolvement and corresponding response activities can be helpful to estimate, for example, the impact variation of an earthquake or a large accident. Running the same simulation but using different parameters (e.g. input data or decisions) will give insight into the consequences of a decision. By defining clear reference scenarios, a comparison with alternative scenarios is possible. Such a comparison can be visualised by maps or tables, if appropriate with such results also illustrating evolvement over time.

Simulation in general is the imitation of the operation of a real-world process or system over time, specifically referring to potential future states (Aubrecht et al. 2008). The act of simulating something first requires that a model needs to be developed. This model represents the key characteristics or behaviours or functions of the selected physical or social system. The model represents the system itself, whereas the simulation represents the operation of the system over time. Key issues in simulation include acquisition of valid source information about the relevant selection of key characteristics and behaviours, the use of simplifying approximations and assumptions within the simulation, and fidelity and validity of the simulation outcomes (Banks 2001, Sokolowski 2009).

A high quality simulation requires the appropriate level of abstraction, reliable models and good data quality, which may imply many and complex data for input, calculations and output. These need to be transferred to aggregated values for the user of a simulation and for the decision makers. For this purpose, indicators are relevant that highlight important aspects of complex datasets and allow high-level comparison of alternative scenarios. It needs to be mentioned that in crisis management absolute ranges of "good values" for indicators cannot be given, since that would normally be "zero cost" and "zero affected persons". Everything else is mainly political decisions about less disliked options, which is the case in particular in situations with limited resources to address the problems faced. However, for a given reference scenario, ranking criteria can be provided for a specific decision context, but the need commonly remains to consider several indicators in the context of one decision.

To address these challenges, within the CRISMA[1] project a collaborative, modular and open planning and decision support system is developed, which offers to public authorities, civil security forces and economic actors the technical capabilities for modelling and simulating realistic crisis scenarios and analysing their possible consequences (Sautter et. al. 2012, Dihé et al. 2013). CRISMA tests its approach using reference scenarios that deal with electrical shortage during winter storms, coastal submergence and evacuation, earthquakes including forest fires, and response to chemical accidents and mass casualty traffic accidents.

Indicators in the CISMA crisis management simulation application will enable decision makers in crisis management to (1) asses the consequences of incidents and crisis scenarios, (2) compare possible impacts resulting from alternative actions, (3) support strategic decisions on capabilities and related investments, (4) optimise the deployment of resources dedicated to crisis response in-line with the evolvement of a crisis, and (5) improve action plans for preparedness and response phases. In this paper we present the types of indicators developed in CRISMA, and illustrate their usage in one sample application.

2. INDICATOR TYPES AND THEIR USAGE IN SIMULATION

In disaster risk management, indicators are a means of encapsulating a complex reality in a single measurable construct that offers a systematic approach to discuss and quantitatively evaluate different root causes of risk (Aubrecht and Özceylan 2013). Indicators provide quantitative information having a special significance regarding objectives and their performance: "*You should use an indicator to measure what needs to be reduced or heightened, or generally improved or changed*" (Krems 2012). In this sense, indicators replace intuitive opinions with verifiable data, and for this purpose indicators can be absolute values or ratios. They produce a basis for comparison of scenarios with others (benchmarking), over time, as well as with target values (criteria).

Four different types of indicators have been elaborated on for CRISMA that are considered relevant for decision support related to simulated crisis scenarios. Based on user requirements, a generic approach for each of these types has been described, which then was exemplified for the above-listed reference scenarios. The indicator types can be summarised as follows:

1. Situation indicators are related to hazard, vulnerability and impact, e.g. magnitude of a hazard, severity of an impact, regional vulnerability. Situational indicators describe a status of the world, thereby covering e.g. meteorological parameters, or demographical, structural and network characteristics. High-level indicators that have been identified for a crisis area include "intensity of hazard", "number and features of elements at risk", and "damage per element type". The damage indicators can be used, among others, for decisions about resource allocation and evacuation during a crisis situation, or for mitigation options and resource investments in preparation. At a national level and in the context of electricity blackout, a sample situational indicator could be "the number of households without telecommunication for more than two hours per district".

2. Capacity and resource planning indicators address real world objects and personnel deployed in the scope of crisis management activities. They are grouped e.g. according to patient situation (numbers and status), resource situation (vehicle, equipment, responder), time until arrival of resources, and treatment performance of resources. Attention of this kind of indicators is put on the simulated response phase of crisis management that also influences decisions about investments for better preparedness. While, in the context of forest fires, fire brigade resources are identified as the key indicators, for evacuation indicators may look mainly at event-time-specific population distribution patterns, and during an accident scenario a differentiated focus may be put on ambulance indicators. Such an example is elaborated in chapter 3 of this paper.

3. Economic impact indicators (Perrels 2014) help to judge (1) expected economic impacts of hazards and (2) economic implications of the state of preparedness and resilience of an area. They are often valid for several hazards and serve both strategic and operational level crisis management decision making. The strategic-level indicators are useful for long term planning purposes (investments in capacity; new or changed policy incentives) to check preparedness or for learning and review. Relevant strategic indicators for CRISMA are a macro-economic impact multiplier (related to the original damage), fiscal gap indicator, and insurance coverage (per household/company and damage compensation). Operational-level indicators are precursors of economic damage model results; they facilitate early stage decision making in an unfolding crisis (or in training), e.g. related to built-up area, human losses or power outage.

4. Key performance indicators (KPI) can be used to evaluate the efficiency of the crisis management. The choice of the KPI is highly context-specific, but all KPIs share the following common characteristics: (1) KPIs measure either the absolute result or the efficiency of the crisis management or mitigation activities. (2) They are valid in the scope of the whole scenario – either cumulative or pertinent to the final world state at the end of the crisis. (3) They really matter to the stakeholders, i.e. a certain KPI is only relevant for some specific decisions by some specific stakeholders. KPIs in the CRISMA reference scenarios are either given for an entire study area or an extract, examples include "hours needed for evacuation", "number of depleted resources", or "duration of road interruptions".

The implementation of the indicator concept within the CRISMA architecture framework relies mainly on two components. First, there is an Indicator Building Block, which is informed about new World States (the data at a given time in a scenario) and then

[1] CRISMA: Modelling crisis management for improved action and preparedness - Integration Project, www.crismaproject.eu
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calculates the respective indicators. Second, there is an Indicators and Statistics View that visualises the specific indicator output as part of the CRISMA user interface, which is realised as a Web Mashup Platform called WireCloud.

3. APPLICATION OF INDICATORS IN A SIMULATION EXAMPLE

Indicators are intended to be formed and used differently in the various CRISMA applications, which address dedicated decision situations for specific reference scenarios. Here we illustrate the case of training exercise support for emergency response by ambulances. The reference scenario assumes a bus transporting 45 passengers, which collides with another vehicle in the German countryside. Many people are injured, some seriously. An emergency call is received by the operations center and emergency units are sent out to the scene. Even such a limited number of affected persons (compared to earthquake and flood impact scenarios) is already a major challenge given the number of first responders, hospital beds and ambulance vehicles immediately available in rural areas.

The operational response for a mass casualty incident is characterized by the treatment and transportation of patients. This procedure is constrained by available and usable emergency service resources (Hellmich 2010). First responders and other emergency personnel react according to standard procedures oriented towards 5-50 injured people in an accident (Weidringer 2009). Reaction means getting an overview of the situation, giving first aid, transporting injured people away from the scene to a safe area. A chief emergency physician (CEP) guides the designated medical incident commander and the emergency medical services. The CEP forms his operational picture of the situation and decides whether to request additional rescue personnel and technical support or not. Further he coordinates the planning of primary medical care, in particular by triaging patients and assigning treatment priorities (Sautter et.al. 2014).

The decisions relevant during this kind of crisis response are: where to position a patient treatment area, whether further resources are requested, when patients should be transported, to which hospital, and by which vehicle. All those decisions are based on predefined guidelines and, of course, experience of the person in charge. A relevant indicator that describes the situation refers to the number of patients, while indicators associated with resources include the number of first responders and vehicles.

To be able to evaluate and consequently improve crisis management within such a setting, two key performance indicators (KPIs) are identified: (1) time until *seriously injured* (red triaged) patients are put on the way to the hospital, and (2) ratio of medical responders per patient at the incident scene. This is an important but limited view focusing exclusively on the perspective of a chief emergency physician, since it only addresses the activities on the scene, but not the whole patient treatment period including transportation, treatment in hospital and recovery. It is obvious that optimising crisis management to only these selected KPIs could potentially mislead decisions in the long run, e.g. from the viewpoint of a hospital manager or the traffic police.

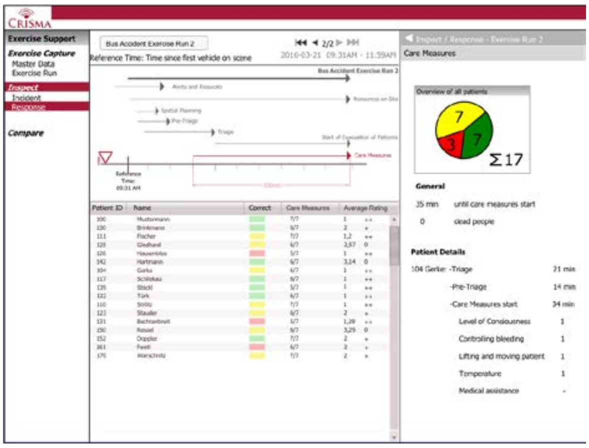

Fig. 1: Indicators and related details in a scenario

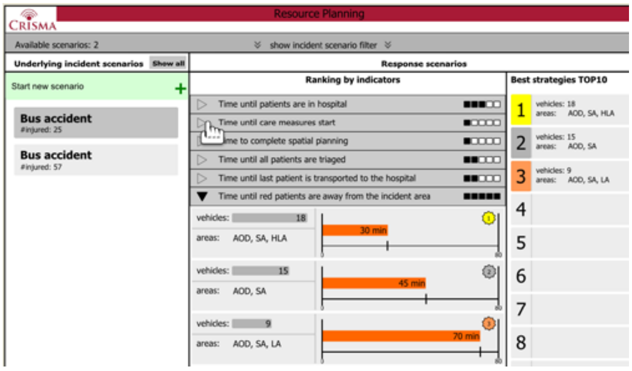

Fig. 2: KPIs to compare alternative response scenarios

The CRISMA simulation application for "resource planning" allows the configuration of a given reference scenario including the above-outlined "bus accident", featuring variables such as time and date of incident, location, number and injury status of patients (red, yellow, green), number and type of first responders, and available vehicles. An agent-based simulation platform represents the behaviour and decisions of these patients, first responders and ambulances (Meriste, 2005). Further scenario modification options are to consider scenario-specific health or injury patterns for the patients, or to make assumptions about skill level and recreation demands of first responders, or to define the transport capacity and fuelling needs of vehicles.

The model assumes that a vehicle is equipped with medical personnel as well as medical devices. As soon as the vehicle arrives at the scene the patients get treated according to their injuries, which takes a predefined time. Once emergency treatment is completed, the patient is transported to a nearby hospital. The simulation runs as long as patients or vehicles are on the scene. At the end the simulation delivers the indicators and KPIs mentioned above. Figure 1 illustrates a given scenario and shows the injury status of the 17 affected persons as one indicator, and also provides detailed information on each "patient-agent". Figure 2 compares alternative strategies with 25 injured persons, here with respect to the KPI of "time to have red patients away from the scene", and also suggests best strategies considering several weighted KPIs.

4. ADDED VALUE FOR THE POST 2015 FRAMEWORK FOR DISASTER RISK REDUCTION

The CRISMA simulation framework provides a tool set that supports a rigid and consistent management of disaster risk reduction. National authorities are able to provide assistance to local authorities by offering relevant reference scenarios. The indicators highlighted in this paper allow a harmonised approach to describe a given situation, the available resources, the expected economic impact and the KPIs of major concern. Thus, CRISMA supports the implementation of a strong institutional basis for awareness in crisis management.

The developed indicators support the identification, assessment and monitoring of disaster risks within and between regions. While CRISMA does not improve sensor based early warning of actual hazards, it enables to check the quantity and quality of resources available to answer assumed crisis scenarios. Thereby, it can be considered to support early warning of resource shortage. At the same time, the systematic and regular conduction of crisis management simulations and their indicator based evaluation helps to build a culture of safety and resilience at all levels. The results enable the decision makers to establish awareness programs, improve pre-event planning, communicate results and challenges to the public and provide transparency for investment priorities. This could be a first step to reduce the underlying risk factors, either by improving infrastructures, appropriate resources, or improving societal resilience.

5. CONCLUSION

In the CRISMA system the modelled and simulated crisis management scenarios will create large amounts of data. Indicators provide a condensed view that enables decision makers to more quickly understand a given situation as well as differences between alternative scenarios. During the definition of indicators, we faced the challenge that available research studies and applied methodologies for several questions and crisis phenomena are very complex and multidisciplinary. As such, the common understanding of available and applicable indicators in the scope and for the benefit of the CRISMA modelling and simulation approach has been considered a major achievement.

This paper introduced a way to improve crisis management strategies by using indicators in crisis management simulations. The approach was illustrated in the context of a mass casualty incident. It supports the Hyogo priorities, especially it allows national authorities to institutionalise the support of local decision-makers. Furthermore, it suggests ways forward especially towards systematic resource availability checks. Currently these indicators are tested in CRISMA pilot studies with many crisis managers in the context of applications that address specific decision situations related to various reference scenarios.

6. REFERENCES

Aubrecht, C. and Özceylan, D. (2013), "Identification of heat risk patterns in the U.S. National Capital Region by integrating heat stress and related vulnerability", in *Environment International*, p. 65-77.

Aubrecht, C., Köstl M. and Steinnocher K. (2008), "Visualization of Simulated Future Scenarios in Urban and Suburban Environments", Car, Griesebner, Strobl (Eds.), in *Geospatial Crossroads @ GI_Forum '08. Proceedings of the Second Geoinformatics Forum Salzburg*, Heidelberg, Germany: Herbert Wichmann, p. 31-41.

Banks, J., Carson J., Nelson B. and Nicol D. (2001), *Discrete-Event System Simulation* Prentice Hall, Upper Saddle River.

Dihé, P., Denzer R., Polese M., Heikkilä A.M., Havlik D., Sautter J., Hell T., Schlobinski S., Zuccaro G. and Engelbach W., (2013), "An architecture for integrated crisis management simulation", in *Proceedings of the 20th International Congress on Modelling and Simulation*, Adelaide.

Hellmich, C. (2010), *Quality management and certification in rescue*, Springer Verlag, Berlin.

Krems, B. (2012), "Kennzahl(en), Kennzahlenwert, Indikator", http://www.olev.de/k/kennz.htm.

Meriste, M., Helekivi, J., Kelder, T., Marandi, A., Mõtus, L. and Preden, J. (2005), "Location Awareness of Information Agents", Eder J. et al. (Ed.), in *Advances in Databases and Information Systems*, Lecture Notes in Computer Science, Springer Berlin Heidelberg, p. 199-208. Perrels, A., Nurmi V., Erlich, M., Cabal, A.(2014), "Natural Hazard Insurance Coverage and National Debt to Hazard Cost Ratios for Monitoring Hazard Resilience", in IDRC International Disaster and Risk Conference, Davos.Sautter, J., Engelbach, W. and Frings, S. (2012), "User-Centered Elaboration of an Integrated Crisis Management Modelling and Simulation Solution", in *7th Security Research Conference, Future Security 2012*, Proceedings, Communications in Computer and Information Science, Bonn, Vol. 318, p. 513-516.

Sautter, J., Hofer, J., Wirth, S., Engelbach, W., Max, M., Tenso, T. and Bracker, H. (2014), "Local-specific resource planning for mass casualty incidents", in *Proceedings of ISCRAM 2014 (11th International Conference on Information Systems for Crisis Response and Management)*, Penn State University.

Sokolowski, J.A. and Banks, C.M. (2009), *Principles of Modeling and Simulation*, Wiley, Hoboken.

Weidringer, J.W. et al (2009), Massenanfall von Verletzten und Erkrankten, in Bundesamt für Bevölkerungsschutz und Katastrophenhilfe (Ed.), *Gefahren und Warnung, „Schriften der Schutzkommission"*, Vol. 1, Bonn, p. 9-25.