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INTERACTIVE VIRTUAL WORLD MODELS FOR CRISIS PREPAREDNESS – BETTER THAN THE REAL THING?

D. Havlik[1], W. Engelbach[2], M. Erlich[3] and M. Meriste[4]

[1] *Researcher, AIT Austrian Institute of Technology GmbH. Vienna, Austria*
Email: denis.havlik@ait.ac.at, denis@havlik.org
[2] *Leader Competence Team Informationsmanagement, Fraunhofer IAO, Stuttgart, Germany*
Email: wolf.engelbach@iao.fraunhofer.de
[2] *Project Director, Artelia Eau & Environment, Grenoble, France*
Email: marc.erlich@arteliagroup.com
[2] *Senior Researcher, Tallinn University of Technology, Tallinn, Estonia*
Email: merik.meriste@ttu.ee

ABSTRACT :
Success of crisis management largely depends on: (1) inherent resilience of the society; (2) preparedness level of the first responders; and (3) right "gut feeling" of crisis managers. "Learning by doing" to improve resilience and planning is difficult to do, especially for low-probability/high-impact events and for multi-hazards with cascading effects. Due to rarity of such events, many crisis managers, regional planers and other stakeholders have no first-hand experience in handling them. The best available alternative is learning by doing in a simulated crisis situation or during an exercise.
The EU FP7 project CRISMA (www.crismaproject.eu) – "Modelling crisis management for improved action and preparedness" has developed a methodology and software framework for simulation-based decision support systems. CRISMA targeted use cases in the preparatory phase of crisis management: short and long-term planning, desktop training and assessment in field trainings. Application prototypes cover different risk (floods, snowstorms, earthquakes, forest fires, accidental pollutions, mass accidents) and illustrate how the CRISMA framework can be used in a relatively simple but integrated manner to develop fully fledged decision support applications [Dihé et al., 2013]. This paper illustrates how each of these cases has been realized, explains how this work can be used to advance different aspects of crisis management preparedness and discusses if and why learning in virtual worlds can be more effective than from real world events.

KEYWORDS:
crisis management, decision support, resource planning, resource management, multi criterion ranking, interactive virtual world model

1. INTRODUCTION

Crisis situations are a fact of life, but many of catastrophes can be avoided or at least mitigated through improved preparedness. Resilience can be influenced at various levels [Walters, 2013], including e.g.: (1) exposure of the property and population; (2) resilience of the infrastructure; (3) availability of crisis management resources; (4) quality of the crisis management plans; and (5) experience of the crisis managers and first responders.

In theory, reaching a high level of resilience and preparedness for re-occurring crisis situations is easy. In reality, we often fail to learn from past events, e.g. because experimenting with alternative solutions is too costly in terms of real or perceived consequences [Donahue & Tuohy, 2006]. Preparing for low-frequency/high impact events is even more difficult because the population is less aware of the danger, political and economic decision makers are less willing to finance measures and the first responders less well prepared to react.

CRISMA primarily addressed following event types: coastal floods, winter storms with blackouts, accidents with mass-casualty-incidents, chemical spills, and earthquakes with cascading effects such as forest fires [Garcia-Aristizabal et al., 2015]. The choice is based on two criteria: (1) these events are "rare" (at least) for local responders and exceed their "daily business" activities by far; and (2) stakeholders involved in the project agreed that preparedness and resilience for these crisis types needs to be improved. This opinion is validated in a new survey on disaster preparedness [SA & Syed, 2015].

2. DECISION SUPPORT IN CRISMA

Decision makers in crisis management face many possible futures and interdependent consequences of alternative options. During a crisis, they have to quickly understand the situation and prioritise tasks at hand, taking into account the, often conflicting, business targets, reference values and priorities of the involved stakeholders. Especially for large crisis events, the available information is often incomplete, and the available time (for decision making) and resources (for resolving the issues) are insufficient. Decision making in such situations is often a combination of standard procedures and "gut feeling" [Rosqvist, Meriste, & Havlik, 2015]. CRISMA Decision support paradigm aims at improving both these aspects.

A generalized workflow of a CRISMA application is depicted in the Figure 1: The applications allow the decision maker to visualise the state of the world during the evolution of a crisis and help to compare such a state with possible alternative states that may be the result of certain decisions and emerging events. The selection of alternatives to be simulated and the selection of criteria and ranking criteria that are used for world state comparison are normative decisions. Depending on the concrete application, these decisions can either be taken in the setup phase or within the interactive decision-simulation-assessment loop[1]. CRISMA applications do not impose decisions, but allow comparing effects of various decisions (e.g. alternative investments or tactical measures) [Taveter et al., 2014].

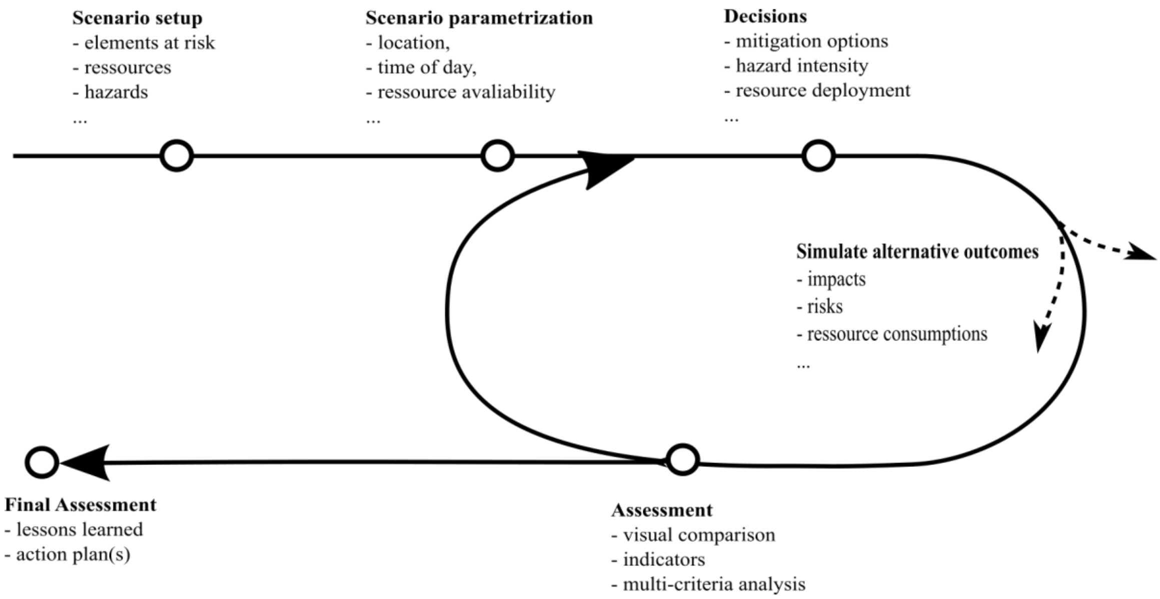

Figure 1: Generalised workflow of a CRISMA application

In order to simplify application development and data analysis, CRISMA applications always produce a series of snapshots of the simulated world [Dihé et al., 2013]. Such snapshot is called "world state", and it contains all information that is needed to analyse the situation or re-start the simulation from a particular point. A change from one world state to another is called world state transition (Figure 2). The world state transition maintains the structure of the world state and does neither change the dimension of the simulated world nor the type of elements that constitute the world state.

[1] Criteria and ranking can also be changed in the "final assessment" step.

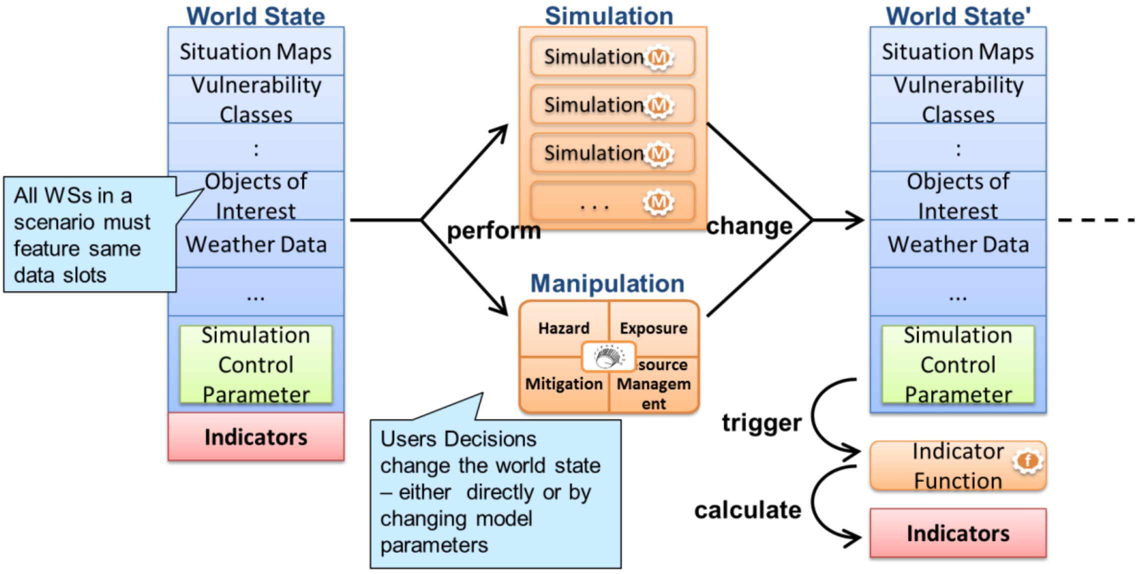

Figure 2: World-states and World transitions (from Dihé et al, 2014)

The creation of a new world state triggers the production of values of the corresponding indicators (aggregated data). Indicators serve as common denominator between world states and for a crisis management simulation analysis (e.g. economic impact analysis) [Engelbach et al., 2014]. Analysis of often complex simulation results can be further simplified by so-called criteria. Criteria are defined by mapping the indicators into 0-100% level of satisfaction. Unlike indicators, criteria can be easily visualized as a set of red / yellow / green color-coded gauges or semaphores representing e.g. level of satisfaction with cost of operation or human losses. They can also be further combined in a multi-criteria ranking function to assess the overall level of satisfaction with the given solution. A summary of the CRISMA decision-support concepts is shown in Figure 3. From left to right, the amount of information is reduced from “complete world data” to a single number.

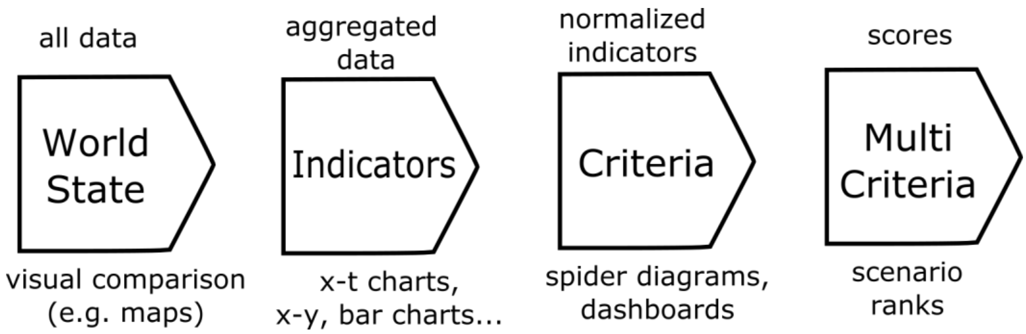

Figure 3: CRISMA Decision Support Concepts Summary

CRISMA decision support methodology and software emphasise on the fact that criteria and ranking functions represent opinions and not facts. They are highly situation dependent and different stakeholders are likely to disagree on definitions and relative importance of different criteria. Users are therefore encouraged to define several sets of criteria and ranking functions and compare the outcomes.

3) APPLICATION EXAMPLES

The main decisions in crisis management that CRISMA intends to support are related to infrastructure (long-term) planning, tactical alternatives and resource management. Infrastructure planning is always a long-term activity, whereas tactical alternatives and resources management can be simulated both within actual crisis or exercise situations and in the context of the long-term planning. Examples for the latter are decisions

about investments in additional crisis management resources, or risk assessments.
In order to test the re-usability of the CRISMA methodology and software, all CRISMA applications were developed as generic reference applications first and then configured and if needed extended (e.g. by interfacing the CRISMA software with existing systems) for use at a particular pilot location [Dihé et al., 2013; Havlik et al., 2015]. This adaptation is performed at three levels:

- Setup of a new CRISMA application by a **CRISMA developer**. This step may, for instance involve extending simulation models or adapting the user interfaces.
- Configuration of a new simulation case by a **CRISMA setup expert**. This may involve defining new types of local resources (e.g. faster ambulances, helicopters, etc.)
- Parameterisation of a new simulation run by a **CRISMA end-user or steward**. Such parameters may e.g. change the population exposure or amplitude of the event.

The relation between six CRISMA reference applications and five simulation cases that were realized in the project is illustrated in Table 1. Each of them focuses on a specific hazard, with different time and space scale to relate with, involving end users with different organisational backgrounds, emergency management responsibilities, and tasks with respect to the timeline of the evolution of the crisis.

Table 1: CRISMA reference applications and realized simulation cases

Reference application	**Scenario type**	**Specific simulation case**	**Country**
Nordic Winter Storm	Resource planning	Electricity outage in the far north of Finland.	Finland
Coastal Submersion	Regional planning	**Coastal submersion defence** for Charente Maritime region	France
Accidental Pollution	Desktop training	**Accidental spillage** from a container at large city port	Israel
Earthquake and Forest Fire	Regional planning	Earthquake and forest fire application	Italy + Portugal
Resource Planning	Resource planning	**Mass casualty incident**	Germany
Resource Management Training	Training assessment and model validation		

These applications can be roughly grouped in two categories: the French and Italian applications target long-term planning, whereas the Finnish, German and the Israeli applications target short-term resource management planning and training. This paper concentrates on French, German and Israeli applications that cover all aspects of the "virtualized learning by doing" loop:

- “Coastal submersion defence” (France) application simulates the effects of a coastal flooding and allows users to experiment with long-term measures for mitigating such effects. It is an example of regional long-term planning CRISMA application.
- “Accidental spillage” (Israel) application simulates the effects of resource management decisions on outcome of a crisis as an interactive desktop training.
- “Mass casualty incident” (Germany) application covers two aspects of the loop. First, how to improve the resource management plans. Second, how real world information (in this case from field training) can be captured and used both to assess the exercise and to validate and improve the simulation models.

3.1 Regional planning

Two of the CRISMA pilot applications target long-term planning. The Italian application simulates a re-occurring earthquake with secondary forest fires, whereas the French application supports the decision makers in identifying the impact and cost of coastal submersions and other flash floods (Figure 4). In both cases, the goal of the application is to simulate the long-term effects of the investments in resources, organisation and infrastructure on the outcome of the crisis.

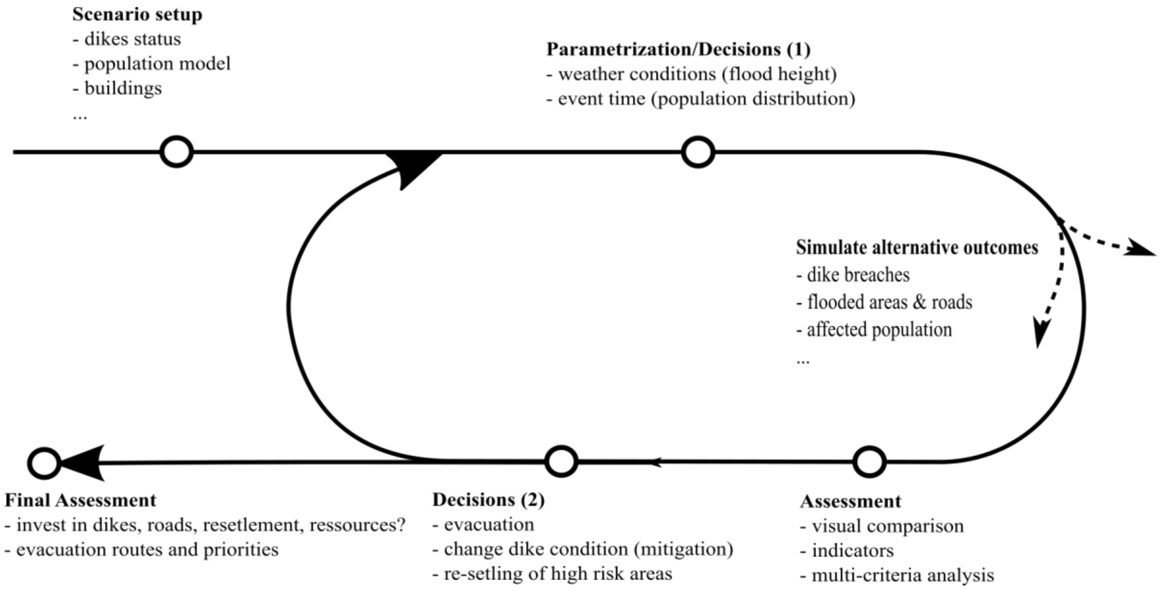

Figure 4: Coastal submersion scenario workflow

Coastal submersions are of rising concern in coastal regions, as storm surges with strong winds are becoming more likely due to climate change. Coastal submersions cover large areas, where buildings, dikes and other infrastructures are at risk to be severely flooded and damaged and citizens to be lost or badly injured. Stakeholders need means to:

- Assess multiple flooding scenarios by simulation of costal submersion events and evacuation behaviours.
- Assess the vulnerability of dikes and buildings for identifying endangered regions.
- Assess the impact of different mitigation options, like the modification of dikes' resilience, eventually reducing the impact of a possible flooding scenario.

The main goal of the French CRISMA pilot application is to enable local authorities to compare prices and effects of various long-term investments on a local scale and thus to find the most suitable solution for a specific region. For example, the user may decide to work with a limited budget in mind and compare effects of investing different portion of the budget in population re-settlement, improving dikes or improving the capacity of first responders. Alternatively, the user could decide to explore the "return of investment" at different investment levels and then argue with the authorities that a certain level of investment in infrastructure or resources is necessary to keep material losses manageable and to assure the safety of the population. In the later context, it is essential to also perform simulations with realistic population distributions. This is why the French and the Italian applications both feature a dynamic population model [Aubrecht, Steinnocher, & Huber, 2014].

3.2 Resource management planning

The German and Finnish CRISMA applications focus on resource planning. Creating resource deployment plans for MCIs is challenging for local first responder organizations because: (1) this type of accidents demand efficient deployment of a large amount of resources from different organizations in a very short time; and (2) the relation between deployed resources and the operation success is not easily deductible [Sautter, J. et al., 2014]. In the case of the German application, the underlying issue is a mass casualty incident (MCI) – an emergency situation with a large number of injured or affected persons that cannot be managed with regular emergency medical services (DIN13050 2009).

In this application, the users can test the effectiveness of different resource management tactics for a specific type of mass casualty incident at a specific location. Tactic is configurable by the user in three steps: (1) set tactical areas (treatment, staging, loading and advanced medical post) on the map; (2) decide which resources to ask for and when; and (3) decide on maximal resource allocation for each of the tasks as well as on the relative priorities of the tasks. The simplest possible resource allocation tactic is illustrated in Figure 5. In this example, no treatment area has been defined. As a result, the number of options is low and the relative priority of activities is practically "set in stone". The only "free" parameter is de-facto the number and types of vehicles assigned to each of the tasks2. LF, RTW, KTW, NEF, MTW and KOM in Figure 5 represent standardized resource types used by the German Red Cross. The application is aware of their capabilities as well as of the standard tactics for their use. For example, the rapid response vehicle (NEF) is the only vehicle with an emergency physician on board and therefore the only resource type that can be assigned to triage.

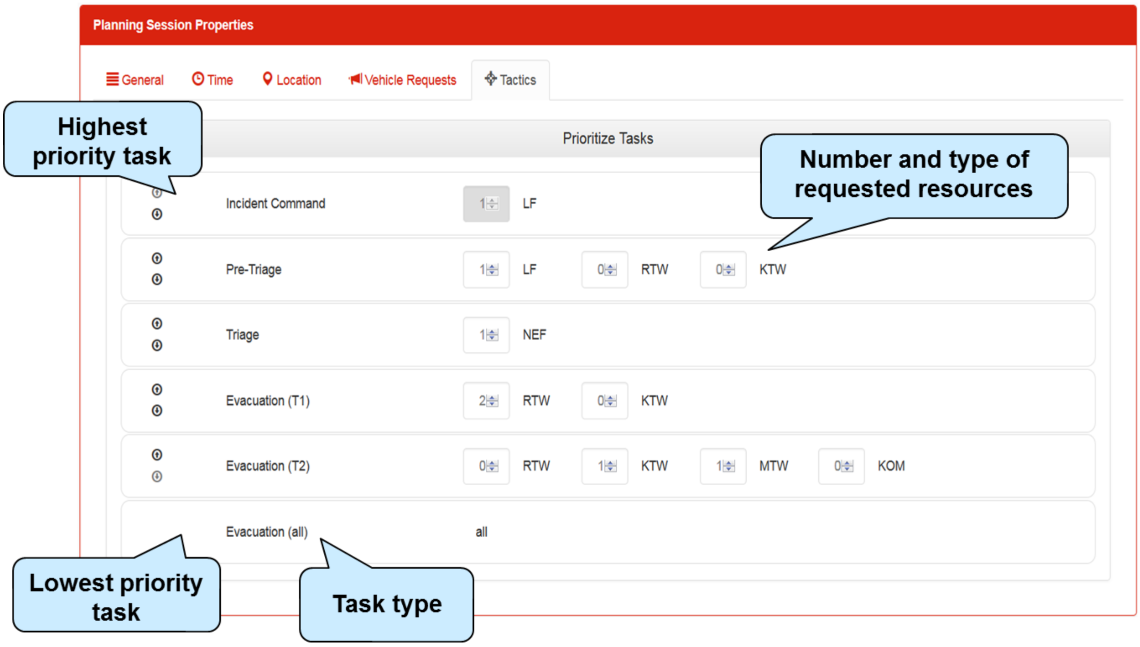

Figure 5: CRISMA resource planning application – task prioritization.

In more complex cases, the user has to prioritize much higher number of activities. The number of available resources is often lower than the number of resources that should be assigned to each of the tasks, especially at the start of the action. As in the real life, some of the activities will only be performed once the higher-priority activities have been finalized.

3.3 Desktop resource management training

In Israeli CRISMA application, the users are confronted with a serious game in which they give explicit orders to simulated resources and the application executes the orders and calculates the new world states [Havlik et al., 2015]. The application can be used in two ways: as a standalone serious game or as a background application only used by the trainer in a table-top-exercise.
In the first case, the trainees can immediately see the effects of their decisions and test alternative decisions by moving back-and-forth on the simulation timeline. In the second case, the trainee is only presented with a portion of information corresponding to the information available in a real world emergency by the trainer and forced to issue commands orally. The first usage pattern is better suited for self-study, whereas the latter is closer to decision making in real world emergencies and better suited for knowledge assessment. Main training

[2] The only task that might be given higher priority in this setup is the T2 ("yellow" patients) evacuation. This would be highly unusual but *might* make sense in a situation where a number of victims is very high and the nearest hospital so far away that "red" patients cannot be saved at all and yellow patients might perish.

user interface of this application is illustrated in Figure 6.

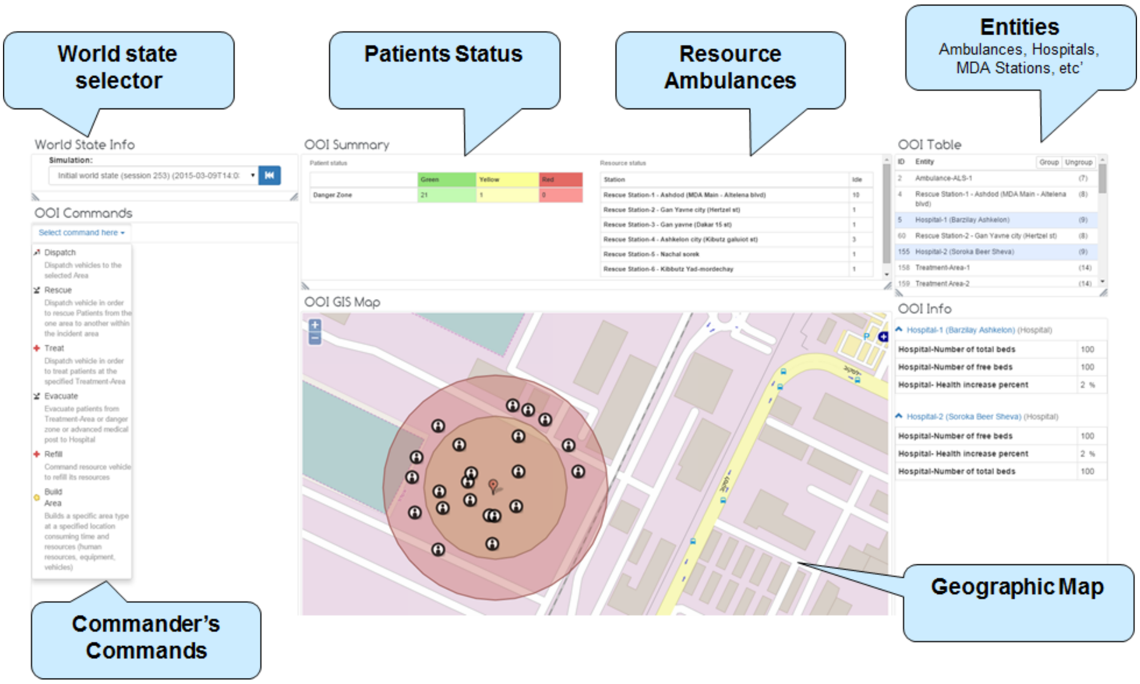

Figure 6: main user interface of the desktop resource training application.

3.4 Event assessment and model calibration

The CRISMA "exercise support" application simplifies the task of assessing the results of a field exercise. It allows gathering of real times that have been needed for various first-responders activities by a specific emergency response unit in field exercise trainings. The application provides templates for all patients with their postulated status (red/yellow/green and injury type), placeholders for data on timings and results of various activities as well as the separate input methods for capturing of the resource arrivals and departures and capturing of the site-related information. Part of the "capture" view of this application is shown in Figure 7.

Figure 7: Exercise support application – patients' information (fragment)

In CRISMA, the exercise support application was used to capture key performance indicators related to times needed for various activities, such as the “triage duration per patient” (Figure 8).

Figure 8: Time-related indicators in resource planning and exercise assessment applications

The information captured during the exercise can be used to improve exercise debriefing and field training assessments. More importantly, the field training situation can be made sufficiently similar to the one in the simulation model used in other CRISMA applications to support validation and calibration of the simulation models used in these applications.

4) DISCUSSION

The CRISMA applications allow playing with varying assumptions in the preparedness phase of crisis management. Users can learn from own “mistakes” in a simulated reality where experimenting and making mistakes is encouraged rather than sanctioned. This type of learning is inherently well suited for the crisis management since the underlying problems are very complex and the available time is often too short to fully analyze the situation.

Our application tests have indeed shown that the users will often compare more alternatives when using a CRISMA application than would be possible in real exercises or in the classical studies. Simulations can thus improve the capability to understand the potential impact of various short and long term measures (infrastructure investments, land use planning, resource management etc.) on crisis development and outcomes. However, it is important to keep in mind that the simulated world is always just a simplified model of the reality. For example, in the German application the patient models have been simplified by assuming that the health status declines linearly and that appropriate care measures can slow down or even reverse the decline. This is an appropriate reduction of complexity for training of control center staff, but may not be detailed enough for on-site response training simulations. Defining the appropriate level of abstraction for a simulation model and understanding the inherent limitations of the model when interpreting the results is extremely important and the “right” choice depends on the intended usage context. Accurate estimates of the underlying data (e.g. population at risk or building condition) and reliable natural hazard modelling are often more important for the use of simulation-based systems in planning applications than a number of available options. Opposite is true for the training applications where a possibility to issue different commands and observe their qualitative effects is often more important than accuracy of the models.

Moreover, the reduction of the problem complexity from “real world” over “world model”, “indicators”, “criteria” to “multi-criteria ranking” is both necessary and dangerous. In this process, the usability of the information for decision making rises but so does a possibility for misinterpreting the results. In the worst case scenario, the users belief in accuracy of the application predictions and appropriateness of the indicators and criteria could lead to overestimating of the own competences and negatively affect the usability of the preparedness plans or a performance of the trainees in the real crisis.

As a part of the analysis, decision makers therefore have to consider the limitations of the models with respect to the scale in time and space, the details of the models and the quality of data. Thus, the usage of CRISMA applications assumes mental interaction of the decision maker, and many conceptual considerations therefore affect the mind-set and usage context, not only the internal logic of the CRISMA applications. In our experience, the interaction in front of a simulation application is often at least as relevant as the simulations done by the computer system. In particular, defining the criteria and multi-criteria ranking functions and using these to assess and rank possible solutions can, and in our opinion should, be done iteratively by a group of stakeholders with different interests: Stakeholders explicitly express own preferences through definition of the criteria, ranking functions calculate and compare various options, and then the stakeholders can discuss the possibilities for reaching a compromise solutions in a systematic manner.

5) CONCLUSIONS

Virtual world applications that encourage testing and comparing of alternative scenarios and decisions are well suited for decision support in preparedness phase of the crisis management, but must be used with care. Although a simulated world may feel realistic, the underlying models inevitably reproduce only a small part of the worlds’ complexity and may indeed produce wrong results if misused [Coden et al, 2012]. The same is true for the use of indicators, criteria and multi-criteria functions for analysis and assessment of the virtual world states [Erlich *et al*, 2015]. This reduction of problem complexity is both necessary and dangerous. In the worst case, this reduction of complexity can lead to, allegedly scientifically founded, misunderstanding of the problem at hand.

Unfortunately, learning from past crisis events is difficult – even for re-occurring crisis events [Donahue & Tuohy, 2006]. In spite of the limitations mentioned above, we can therefore often learn more about the effects of various events and decisions on the crisis development and outcomes by experimenting on the virtual world models than in any other way. In this sense the interactive virtual world models for crisis preparedness may indeed be better than the real thing.

At a technology level, the consequent use of world states, indicators, criteria and multi-criteria ranking in all CRISMA applications has allowed to simplify application design and fostered the development of reusable software components. For example: (1) the analysis functionality is completely decoupled from the simulation and therefore reusable in all CRISMA applications; and (2) the patients and resources in Israeli and German pilots are simulated by same agent model(s) – in spite of the very different use cases.

The “less is more” visualization approach of CRISMA that is illustrated on figures 5-8 is in sharp contrast to the overall trend towards 3D immersive reality and realistic real-time serious games that utilize rich multimedia technologies for pre-specified CM tasks [Ahmad et al., 2012], [MacKinnon & Bacon , 2012], [Coden et al., 2012]. In our opinion, the problems addressed by CRISMA are (too) complex already and *should* be presented to users in simplified form. In addition, simplified presentation is a good way to remind users of the limited accuracy of the underlying virtual world models. This should be seen as a best practice for development of preparedness applications that address tactical and strategic levels of decision making.

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