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Models & Solutions for Strategic Decision Makers during CBRN Crises in Industrial & Urban Environments

Agostino G. Bruzzone[1,2,*], Marina Massei[1,2], Andrea Reverberi[2,3], Antonio Giovannetti[1], Alberto De Paoli[2], Massimo Pedemonte[2], Riccardo Rovelli[4]

[1]STRATEGOS Genoa University, via Opera Pia 15, Genoa, 16145, Italy
[2]Simulation Team, via Cadorna 2, Savona, 17100, Italy
[3]DCCI, Genoa University, via Dodecaneso 31, Genova, 16145, Italy
[4]ST Engineering Antycip SAS, via L. V. dell'Orto, 17, Saronno, 21047, Italy

[*]Corresponding author. Email address:agostino.bruzzone@simulationteam.com

Abstract

This paper proposes an architecture to deal Strategic Decision Making within Urban Area and Industrial Plants due to Risks related to TIC/TIM (Toxic Industrial Chemical, Toxic Industrial Material) that nowadays represent a major issues in our Society due to their diffusion and potential impact. The problem is addressed by comprehensive models in order to provide an effective support to high level Decision Makers thanks to the use of the innovative architecture proposed, based on Strategic Engineering approach. A case study and related Models and AI Solutions are presented to validate the proposed concepts in a specific case study. It is proposed an innovative architecture where the use of IA (Intelligent Agents) and M&S (Modeling and Simulation) are combined to process Big Data arriving from sensor networks and digital systems and to support decision by evaluating alternative COAs (Courses of Actions) were population, countermeasures as well as potential antagonists are simulated by IA together with physical models of critical phenomena (e.g. hazardous material spills, explosions, contamination, fires).

Keywords: Strategic Engineering, Simulation, AI, Modeling and Simulation, Safety & Security, CBRNe, TIM/TIC

1. Introduction

The diffusion of hazards and components in our Towns and Industries as well as their characteristics are generating big risks related to both accidents and man-made disasters. Obviously the current energy crisis and international geopolitical tension is leading towards further risks in handling to Toxic Industrial Chemical (TIC) as well as Toxic Industrial Materials (TIM). The presence of these combinations of dangerous materials and facilities provides challenges and facilitates threats in our towns nowadays; so it is evident the necessity to provide support for High Level Decision Making able to include interactions over multiple layers (e.g. transportations, communications, socials, cyberspace) that affect the impacts as well as the capabilities of entities devoted to react to crisis.

These scenario in the context of Homeland Security are often defined Chemical, Biological, Radiological, Nuclear, and high yield Explosives (CBRNe), therefore nowadays these terms are often used also in relation to Fire Fighting and Police Activities to face these kinds of crisis in Urban Areas as well as in Industries (e.g. Seveso Establishments, Storage of Hazardous Materials , etc.).

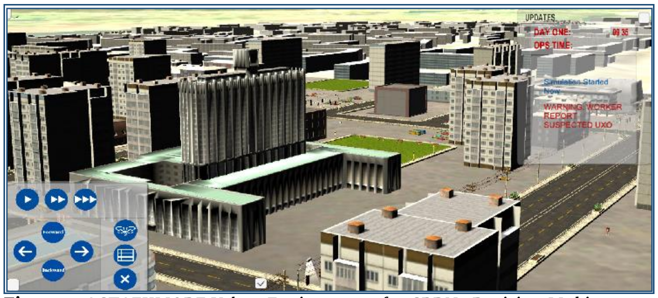

Figure 1, *ACTAEXMORE Urban Environment for CBRNe Decision Making*

There are very specific technical regulation for these cases as well as procedures and the squads leaders of the operational teams are often well trained to face these challenges, therefore the problem is still very challenging because these crises affect usually affect a wide area, largely overpassing the limits of specific hazardous facilities and affecting the whole territory.

This aspect introduce the necessity to coordinate many people and many authorities in a decision process that is usually pretty time sensitive and that often strongly impact on Population, Political Consensus, Area Economics and Legal Liabilities; all these aspect create a complex framework that slow down and create impasses, blocking de facto the capability to react to a real crisis despite technical resources; due to these elements it is strongly required to develop support for the Strategic Decision Making, not only to provide alternative, but to achieve a reliable soldi trustiness with High Level Decision Makers within a network of Institutions and Authorities.

This paper proposes a solution based on the innovative discipline named Strategic Engineering, that by combining Modeling, Simulation, Data Analytics and Artificial Intelligence could solve this shortfall and provide an effective support to Decision Makes as well as to develop new capabilities, mind sets and culture on serious critical CBRNe Scenarios related to Industrial Installation and Town Environments.

2. State of the art

The analysis on CBRNe is on going since very long times, therefore recent crises and diffusion of IED (Improvised Explosive Devices) further increased the studies (Powers, 2001; Ivanova & Sandler, 2006; Wilson, 2007; Coleman et al., 2019). Modeling and Simulation have been used in this framework in order to analyze scenarios not only at physical level, but even operational and also the authors have developed several researches in this sector (Bruzzone et al, 2015; Johnson & Ali, 2015; Ruiz et al., 2016, Longo et al. 2019). In similar way, Artificial Intelligence (AI) and Intelligent Agents (IA) have been used for CBRNe Scenarios (Bruzzone & Massei, 2017a; Wilner & Babb, 2021; Regal et al., 2022); while advances in sensor networks and JISR address these topics along last years (Winkler et al., 2012; Antoni et al., 2021). The new discipline, title Strategic Engineering, emerged few years ago had often addressed Security and Safety issues in similar contents and provide a very interesting support for this kind of problems (Bruzzone et al., 2017b); in this case the use combined of AI, Modeling and Simulation as well as Data Analytics is used in closed loop with real data from the field to support decision making.

3. Approach

We propose the creation of a Decision Support System (DSS) based on Strategic Engineering that integrates eXtended Reality (XR), Modeling & Simulation (M&S) and Artificial Intelligence (AI). The idea is to creates a new type of immersive virtual environment: a Virtual World (VW) that should be immediately usable, intuitive and non-invasive, intended for Decision Makers both at a Strategic and Tactical Operational Level (see figure 1).

Models related to CBRNe/TIM/ICT and other critical aspects and elements of the scenario could be integrated based on interoperability and combining them a dynamic updating system feed by Intelligence, Sensor Networks and other Data. These models should cover the urban context, the population, socials, cyberspace, EW (Electronic Warfare), STRATCOM/Communications.

In this sense the Simulation Models should cover also the various Actors present in the Scenario, the different available assets, JISR (Joint Intelligence Surveillance & Reconnaissance) Systems, as well as the boundary conditions (e.g. weather conditions) to represent, explain and simulate the crisis. Therefore the simulation to be adopted in this case, requires not only to address the crisis physical effects (e.g. cloud dispersion, contamination physical evolution, domino effect in case of explosions, etc), but also the impact of containment actions as well as potential activities of antagonists; over all, it is crucial to reproduce population behavior and reaction to the crisis so this kind of simulation relies strongly on the use of Intelligent Agents (IA) as that one developed by Simulation Team for similar scenarios as in PONTUS (Bruzzone et al., 2020). The size of the problem is huge, but the Authors and Simulation Team has many models that are available to be expanded and adapted for these purpose (e.g. projects such as IDRASS, JESSI, T-Rex, Coyote, ALACRES2, etc.), so currently this research is strongly relying on these cases (Bruzzone et al., 2017a); this is the base to develop a new research defined ACTAEXMORE (Advanced CBRNe, TIM/TIC Analysis by EXtended Reality, M&S & Intelligent Review) to be conducted quickly and in effective way to support decision making in this area. Indeed, the ultimate goal of this research is the creation of this innovative VW based on XR, M&S, AI and aforementioned Models, including Hardware/Software infrastructure. VW requirements include the need to be easy/fast to deploy thanks to a new compact mobile frame (e.g. SPIDER or Powerwall), and to provide an intuitive shared/interactive space for multiple decision makers, also usable by individuals (e.g. Smartphone) for basic vision/synthesis functions/review.

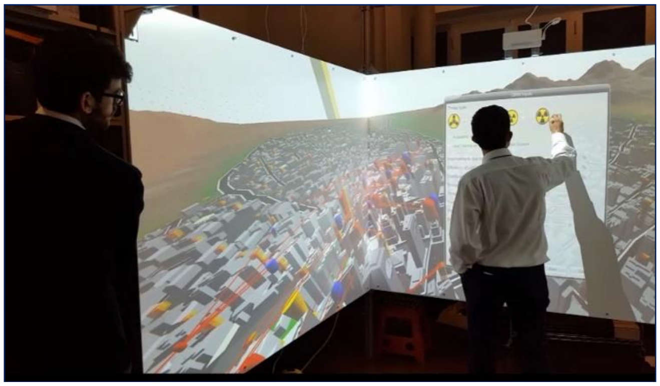

Figure 2, *SPIDER Immersive environment in IED*

This innovative VW will operate as a high-mobility "control room" with real-time updates with a simple secure connection, but also operational on the consolidated/hypothesized stand-alone mode. These aspects are fundamental to guarantee to be useful also in case connections go down or are compromised.

The authors aim to create an environment that thanks to the digitization of all available information, the Command group could be able to immediately understand the state of the crisis, assess the direct and indirect impacts, implement control over the current/updated situation, conduct simulations and analysis on alternative COAs: this corresponds to adopt Strategic Engineering approach for supporting CBRNe crisis prevention, mitigation and management.

Interoperability could be crucial to enable the possibility to integrate Data and Actions from heterogeneous networks into the VW, while the use of XR solutions, including interactive simulation and 3D vision in real time, enable to evaluate the impacts of different choices on the field, correcting estimates and hypothesis based on crisis evolution.

The Virtual World should guarantee the possibility to represent the current situation and let the simulation to evolve from it, including the actions and reactions of the various subjects, the reliability and availability of the resources. In this way it turns possible to provide information on risks and to make decisions by evaluating each COA or by defining new plans.

4. Engagement, Education and Training

The crucial aim of this research is to engage the Decision Makers; from this point of view, it is evident that they are usually expected to be very busy with few time and that often they don't have the technical background related to CBRNe, nor the impacts of these crises, even because there events are usually rare. At that decision level is not so crucial to know details of technical operations that will be fixed by their staff, but it is critical to understand the implications of the Scenario: so this is the aim of this Research that deals with engaging and immersing intuitively the High Level Decision Makers in the crisis providing clear connections and representations of the different COA. Obviously, the proposed Solution results very useful also for the Education & Training of both decision makers and their staff in virtual exercises and thus the authors are planning to develop a demonstration and validation of the project with experts.

From this point of view it very crucial to adopt intuitive and immersive solutions of XR to be used and properly tailored in this purpose; indeed the authors had experience in this field as proposed in figure 2: in this case the Simulation Team Spider is used on a public domain demonstration of models created for Defence Against Terrorism and developed jointly in cooperation between Simulation Team, Genoa University & Nato (Bruzzone et al., 2015).

5. Reverse Risk Analysis based on Strategic Engineering

In the proposed model one of the services provided is related to apply Reverse Risk Analysis by using the Simulator updated with available data in order to identify the impact of potential threats as well as the most dangerous areas.

The simulation is carried out by applying a mapping over the terrain and time to identify evaluating the target functions such as: contamination level, density of injured people, casualties, etc.

In the following is proposed the function to calculate the maximum exposition:

$$CLmax(x_0,y_0,z_0,t_0) = \frac{Max\left(\sum_{i=1}^{n}\int_{-\frac{1}{2}\Delta h}^{-\frac{1}{2}\Delta h}\int_0^{2\pi}\int_0^{\rho max}\int_{t_0-\frac{1}{2}\Delta t}^{t_0+\frac{1}{2}\Delta t} SC_i(P(x_0,y_0,z_0)+V(\rho\cos(\vartheta),\rho\sin(\vartheta),0),t)dt\, d\rho\, d\vartheta dh\right)}{\pi\ \Delta t\cdot\Delta h\cdot\rho_{ma}{}^2} \quad (1)$$

$$CLmax(x_0,y_0,z_0,t_0) = \frac{Max\left(\sum_{i=1}^{n}\int_{-\frac{1}{2}\Delta h}^{-\frac{1}{2}\Delta h}\int_0^{2\pi}\int_0^{\rho max}\int_{t_0-\frac{1}{2}\Delta t}^{t_0+\frac{1}{2}\Delta t} SC_i(P(x_0,y_0,z_0)+V(\rho\cos(\vartheta),\rho\sin(\vartheta),0),t)dt\, d\rho\, d\vartheta dh\right)}{\pi\ \Delta t\cdot\Delta h\cdot\rho_{ma}{}^2} \quad (2)$$

x_0, y_0, z_0 Point to be evaluated

t time to be evaluated

n number of crises, threats & their combinations

SC_i Simulated Contamination for i-th threat

Max Function determining the maximum

CL_{max} Max Contamination at a specific point and time

Δt delta time to evaluate

Δh Vertical Range to be evaluated

ρ_{max} maximum range around critical point

PA_i Probability of the i-th threat

RCL_{max} Max Risk of Contamination at a specific point and time

It is evident that there are ways to estimate the impact on the different target functions including maximum, average values, weighted combinations.

In addition to the possibility to identify the most dangerous places and moments, it is possible to use the simulation combined with the AI to identify the most promising threat locations over space and time, by testing for each threat the maximum impact over each point respect its Degrees of Freedom (DoF).

For instance, if we identify in a scenario as threats a TIC, some deposits of TIM, a IED (Improvised Explosive Device) and a sniper, it is possible to realize the need to adopt the proposed approach based on following description of problem complexity even in case simulation integrated with intelligent agents is available and able to simulate all the different parties, actions and reactions to crisis evolution:

Definition of the Degrees of Freedom of each Threat

For instance, the TIC will be a Chemical Facility located in the surroundings of the Town where we consider as DoF the kind of hazardous material to be released and the related quantity spilled out; vice versa for the TIM it could be possible to consider the impact of malicious or accidental events mixing materials and generating toxic/explosive consequences within the town, so the DoF is the location, the kind of event and its magnitude. The IED could have as DoF a set of alternative targets and the magnitude, while the sniper could have a variable location on the map/buildings. In the proposed example, considering to investigate a town within a square of 10km by 10km with 10 meter resolution, the experimental plan results as proposed in following table.

Table I: Threats and their DoF

Threat	*DoF*	*Description*	*Combinations*
TIC	2	4 kinds of components and 2 quantity levels (small and large)	$4 \cdot 2$
TIM	2	6 deposits and 3 magnitudes (small, medium, large)	$6 \cdot 3$
IED	3	Position (x,y) and 2 quantities (small, large)	$1e6 \cdot 2$
Sniper	1	Position (x,y) with location identified within the building on the site	1e6

AI to Simulate the Critical Combinations

The runs could be independent for the events or even combining multiple threats in different ways, therefore it is evident that in this case the experimentation workload turn to be exponential even in independent case; for instance in our case the basic runs to be conducted is:

$8 \cdot 18 \cdot 2 \cdot 1e12 = 2.88e14$ test per time resolution

So even with a fast time simulation, reproducing the crisis in just 1 second and using a cloud with 10’000 processors, around 910 years are required. In case, it is interesting to investigate a simulation test for each hour, over 24, considering all days equivalent within the week it corresponds to multiply by 24, while if we consider that it makes sense to consider differently working days, Friday, Saturday and Sunday (e.g. Religious and Sport Events) it could necessary to multiply by 96.

By the way, in case it results useful to consider multiple combinations (e.g. 2 snipers an 3 IED), the workload turns even worst, therefore it is well know that by Murphy’s Law and in case of man made accidents the threat combinations could be quite possible.

So, it is evident that is necessary to develop a testing campaign based on a special Design of Experiments (DOE) able to restrict the cases to be investigated based on the most critical ones; this is possible getting inspiration from human approach that is used to do it defining priorities: for instance, to identify were to deploy snipers, probably an area without paying target (e.g. in the middle of nowhere) could be excluded. This approach is done in our solution by Optimizing Algorithms able to consider the ranges of each Threat and the potential paying targets locations in order to identify best combinations for investigating mobile threats that generate very large number of tests based on their mobile position. In addition the combinations among the different factors is evaluated just in case of overlapping areas of influences on the scenario based on logical and procedural interference; that means that shooting in North of a Town influence a sniper in the South because it could act as a diversion, but probably it is not crucial the fact we analyze 10’000 combinations of different positions 10 meter from each other in North attack. In this case it could be possible to restrict the experimental workload to much more small numbers able to be investigated in few days, that for planning it could be useful. Therefore it is still evident that the exponential combinations of the tests to be done requires big computational power and cannot adopt a brute force for investigating the face

Summarizing Results and Identifying Criticalities

Once completed the experimental analysis, it turns necessary to assess the threats and related risks over the different areas and to identify most dangerous and probable sources of problems as well as symptoms. Even in this case the Data Farming conducted combined with Big Data from the field generate together a very challenging database to be processed in order to create an intelligent map of the problem. Strategic Engineering developing a learning approach to extract from identification and location of criticalities it result fundamental to create an useful solution for decisions makers.

Based on the considerations, it is evident the necessity to create Solutions that could be intuitive and immersive to introduce the High Level Decision Makers in this framework as well as to support operational people to address complex cases.

6. Conclusions

This paper introduces an innovative approach to deal with Decision Making on CBRNe scenarios at urban level at different levels by using Strategic Engineering approach. The Initiative is currently motivated by a joint cooperation on a research Project, but also due to the very high impact these kinds of Scenarios represent along our Cities.

Currently the authors are developing the Virtual World as framework where to conduct the experimentation and test algorithms and AI solutions, having a common framework for Virtual Experimentation, therefore in the next year more details about the scenarios to be investigated will be available through interaction with Decision Makers.

It could be very interesting even to further develop the Man Machine Interface able to make intuitive for Decision Makers to be engaged and immersed intuitively in these scenarios and current developments are addressing these issues.

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