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AI & Interoperable Simulation for Pandemics and Crisis Management

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Abstract
The adoption of Strategic Engineering as combined use of Artificial Intelligence, Simulation and Data Analytics to support decision making has a great potential in dealing with Pandemics due to their complexity and the impact of VUCA (Volatility, Uncertainty, Complexity & Ambiguity) on them. From this point of view using advanced paradigms such as MS2G and adopting interoperability standards is a major enabler to guarantee their effectiveness in dealing with these problems; this paper represents an introductory work on a joint research devoted to finalize experimentation and test to develop this new capability within Research Centers for supporting the Society during pandemics

Keywords: Education and Training; Modelling and Simulation; Pandemics, Strategic Engineering; MS2G

1. Introduction
Modeling and simulation is the most promising approach to be used in analysis of pandemics and biological threats due to the complexity and dimension of these phenomena affected by this type of crisis (Bossomaier et al., 2009). Indeed, simulation has a long history in studying the evolution of epidemics in natural cases (Avalle et al. 1995, 1996, 1999), biological warfare (Finke et al., 1999) and to address specific diseases such as AIDS (Kaplan, 1989), syphilis (Oxman et al., 1996), hepatitis C (Deuffic et al., 1999) and COVID-19 (Peng et al., 2020). During recent covid-19 crisis, we observed extensive use of statistical models to evaluate the evolution of epidemics, therefore it is evident that these elements are able to provide reliable a posteriori analysis, if data are valid, but result uncapable to predict the impact of our decisions a priori; this means that we can predict how crisis will evolve up to the moment there are not changes in current situation in terms of contagious logic, contamination policies, policy changes, population major reactions and/or radical mutations (Dieckmann et al., 2020). Therefore, this old approach is useful for high-level analysis on statistical data, when reliable and available, but do not support too much the crisis management respect actions and containment policies and procedures to be adopted. Vice versa, a simulation integrating models of epidemics, population and the different layers (e.g. health care, transportations, containment resources, economy) could predict risks

and opportunities as well as consequence of current decisions (Backfrieder et al., 2012; Bruzzone et al., 2017c). In this way it turns possible to evaluate most promising COA (Course of Actions) and to understand much better the context and it natural variance respect decisions.

2. Advanced Simulation Approaches & Uses

It is important to outline that, nowadays, there is a great potential in pandemics studies by using M&S (Modeling and Simulation). Therefore, it is crucial to combine it with AI (Artificial Intelligence) by moving forward from simplified Monte Carlo models to advanced simulation (Galvão et al., 2012). In this framework most promising approaches are especially that ones based on IA (Intelligent Agent) able to drive the simulator by reproducing the population dynamic behaviors and reaction to crisis, integrated with efficient stochastic discrete events engines within an interoperable frame (Allen et al., 2008; Mao & Bian 2011; Bruzzone et al., 2020a, 2020b). This late aspect is crucial for being ready to support federation of different models to extend the usability and to create a comprehensive synthetic environment to address the multiple layers impacted by pandemics (Massei et al., 2014).

In fact, the major advantage of the application of Modeling and Simulation respect traditional statistical models on evolution of epidemics is based on the ability not only to predict the natural evolution of the crisis and most probable outcomes of the current situation, but also to finalize complex "what if?" investigation about alternative COAs and to verify potential impact respect alternative decisions and containment policies versus different hypotheses on parameters not well known. By this approach it turn possible to conduct risks analysis and to investigate the range of possible consequences that are crucial during the management of an epidemic crisis.

3. An example of simple decision with big Impacts to be addressed by Simulation

For example, one of the open topics in managing the COVID-19 pandemic was the reopening of schools and its possible consequences (Melnick & Darling-Hammond, 2020); the distance learning was a fundamental capability therefore it could create a decline in education quality (Azevedo et al., 2020) and in future it could require to improve infrastructures and methods to mitigate this aspect. Therefore in addition to the school degenerated service, that should be analyzed in terms of trade-off respect the impact of epidemics, it should be also considered the crucial role of *babysitter services* provided, nowadays, by schools to families with both parents working away from grand parents as usually happen in industrialized society (Bayham and Fenichel, 2020). In these cases the school closure force parents to stay at home to watch the children with impacts on work and people consensus respect decision makers; the aspect of consensus for decision makers and reaction of population is crucial to understand the evident multiple failures in handling the covid-19 crisis in western countries and should be an important aspect to consider for the future. In particular, the short-term consensus represents a major disruptive factor affecting decision making in this context that could be improved by adopting models able to predict consequences of decisions and create awareness on the scenario risks (Bruzzone et al., 2017b). It should be outlined that a very powerful capability of modern simulation integrated in web service could be also its ability to support crowdsourcing that within this kind of crisis could enable access to huge capability provided by large communities experimenting virtually scenarios, plans and idea in creative and transdisciplinary ways; in this way the simulator could quickly assess the impacts of different ideas and proposals, validate them and create comparative ranks to support Institutions and Organizations with usable proposals checked by the models (Bruzzone, 2013). Therefore another major advantage of this use of Simulation is the possibility use it to share with people the impact of adopted policies and to create an awareness and understanding of the crisis that could lead to consensus based on medium-long term positive return of several decisions (Bruzzone, 2017a). This could extend the perception horizon of people by creating a simulation based view of the future and be very useful to break the death spiral created nowadays by short term views and simplistic surface views on socials (Bruzzone et al., 2014b). Obviously before to move in this direction it will be necessary to consider the risk to create panic and to develop a new mind set both in population and decision makers for adopting the basic concepts of Strategic Engineering (Bruzzone and Di Bella, 2018b), but it is evident that in future this evolution is one of major potential in creating a new virtuous circle for developing Society in positive way. The example of school reopening, that is just one over a million decisions impacting on the epidemics could likely lead to increase the close interpersonal contacts, and the risk to further spread the contagion, even considering that children and teenagers could not adopt adequate measures of social distancing due to many different reasons (Wenzel et al., 2001; Bayham et al.,2020; Stage et al., 2020). Despite all these considerations the use of IA driven simulation within an interoperable framework allows to evaluate the outcomes of the different decisions and to investigate the impact of different hypothesis on not precisely know parameters that influence the evolution of the the epidemic.

4. Modeling Epidemics & AI

Obviously, the simulation should include models of many factors to properly estimate the epidemic dynamics, such as the protection measures, people life cycles and even the social network and environmental conditions (Bruzzone et al., 2016; Chen & Carley, 2003).

It is evident that social and psychological aspects, for instance influencing the reaction of population and the impact of stress is an important element to be included in the simulation during situation similar to covid-19 that are widely distributed and require a relatively low containment respect much more lethal cases (Bossomaier et al., 2009; Di Bella, 2015). The human behavior models are fundamental element of this context and this raise up the importance to adopt an advanced integration of AI, IA and M&S over articulated data source.

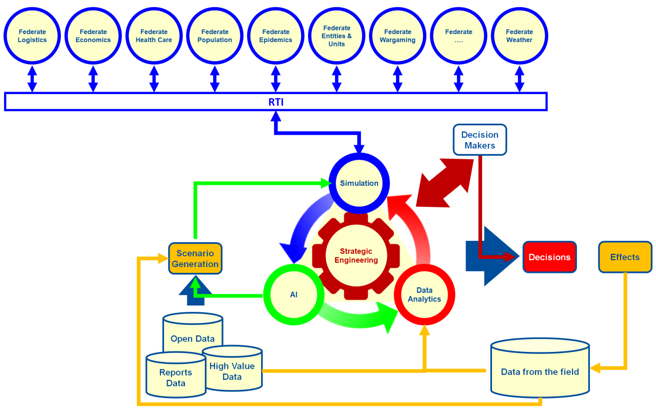

Figure 1. Overview of Strategic Engineering Applied to Pandemics.

Indeed, Strategic Engineering suggest that the closed loop proposed by the above figure could be implemented in order to guarantee the capability to address complex systems (Bruzzone, 2018a). In this case, a key point are the data and nowadays we have Big Data from multiple sources to model current epidemic situation and the even more critical status of the population and terrain in general sense. Open Data for instance have a great importance being able to represent up to date picture of the towns and terrain to be integrated with high value data source, therefore usually there are many errors, inconsistencies and these systems are missing major information, for instance about how to correlate people preferences and their census. The use of AI could allow to proceed in data fusion to reconstruct population and its status for our purpose and it crucial for being able to dynamically update the scenario based on existing situation and to dynamically retune the models based on field response to our decisions (Bruzzone et al., 2020b). In addition the use of Intelligent Agents (IA) reproducing humans and their individual and social reactions to the crisis as well as their regular behavior is fundamental to carry out pandemic simulation (Bruzzone et al., 2011).

While we are still dealing with Covid-19 pandemic effects, we must focus on acquiring as much knowledge as we can to anticipate and better face the next global crisis by simulation. So, it is evident the necessity to develop innovative solutions that could couple sophisticated new generation models with other simulation tools for supporting multiple uses: training, operational planning and operation support, while in future crowdsourcing and new radical integration in the planning procedures should be considered.

From this point of view it is crucial the element of interoperability considering that to maintain and introduce new aspects into the model it is very important to create composable frameworks; in addition the composability of the simulation in terms of a Federation among multiple models dealing with different aspects have another major advantage: it maximize usability and diffusion for a crisis so disruptive as covid-19 that could drastically benefit of Military Resources; within this framework in facts there are multiple Research Teams as well as Training Centers and Organizations/Services that already use extensively simulation for crisis management and disaster relief. So for them reusing their simulation frameworks speed up drastically their readiness to react and ability to provide service to other units and external entities during the crisis, but it requires to integrate within these system new capabilities provided by new epidemic models, population simulators and other elements that are crucial to face these problems.

In this sense the HLA (High Level Architecture) represent a major advantage, considering that represent the standard in use to allow different models to interoperate. Therefore, it is crucial to understand the importance of conceptual interoperability in addition to technological aspects, because the models to interoperate should be designed to hold this capability in terms of logic (e.g. possibility to influence internal parameters, sensitivity on other simulator changes, time management issues, etc.). In this case the authors are considering the possibility to federate wargaming solutions, devoted mostly to manage containment units and responder resources with population models and epidemic simulators. The wargaming and entity level simulators used by military users are not only good to address the management of traditional decontamination units and CBRN procedures, but also other resources such as logistics support, health care facilities, checks and controls, tracking support, etc. Indeed in current crisis the problem is not a high intensity biological hazard into a limited area and the containment of the epidemics, nor a biological warfare scenario, vice versa this crisis and potential future pandemics dela with a very diffused contamination within the Society and the capability to maintain operational the crucial element of civil life: work, major services and networks such as health care, logistics, power, water, gas, economy, education, etc.

It is fundamental to outline that the above mentioned models and simulators need data and the validity of their results relies on them; in the current crisis it has been evident that data are a mess in terms of validity, consistence and completeness. Obviously real data of an epidemic represent a National Security issue and it is evident that it could be not possible to have easy access, but despite this element, this crisis is affected heavily by VUCA (Volatility, Uncertainty, Complexity & Ambiguity) and often the impact of contingencies, the inefficiency of the collection systems, the different interests and the saturation of resources, created very misty conditions providing quite unreliable data (Johansen & Euchner, 2013; Bruzzone, 2018b, Roda et al., 2020).

In this sense a comprehensive interoperable simulation could be also the crucial tool to validate and estimate missing data and information, by reverse engineering being able to apprehend the significance of already available data so as to foresee risks and take decisions on them. Thus, decision makers must be thoroughly trained and skilled to cope with complex scenarios that may uncover unexpected consequences on and from people's behavior.

In facts, the current crisis is just an example, but this research aims to create solutions ready to face future problems and being used for next events. In general these new simulation capabilities, resulting by creating federation addressing the above mentioned aspect, could have a much large validity and be extended to critical situations that in defense are mostly referred as Chemical, Biological, Radiological and Nuclear (CBRN) crises where urgent and efficient responses are required to prevent major casualties and avoid threats (Stolar, 2012); in this context, obviously, the preparedness is hence the key to tackle incidents and avert the disaster (Mossel et al., 2015).

It should be outlined that training and education represent probably the first step forward in this direction and it is preparatory to support policies and procedure redesign and containment measure reengineering, so it turn crucial to be able to reproduce these complex scenario in a clear and understandable way, despite their complixity, so here it comes the M2SG (Modelling, Interoperable Simulation and Serious Games) paradigm (Bruzzone et al., 2014a) that support the creation of immersive, intuitive and interoperable simulators able to create scenario awareness and continuous check on plausibility and effective use of the models. Within this paradigm the use of serious games (Bijl et al., 2011) is integrated with interoperable simulation leveraging the benefits from both frameworks and it turns possible to integrate a immersive virtual experience with engagement and competitiveness among the students, trainees and users (Perrotta et al., 2013).

In this case the Simulation Team has developed different MS2G that address the problem and that are conceptually designed to be interoperable (Raybourn 2014; Bruzzone, 2018a), while some preliminary tests have been already conducted in the direction of this research since some years among the authors. In particular we can mention VESTIGE and to TOPRO based both on intelligent agents (Galvão et al., 2012; Bruzzone et al., 2020b) that simulate the behavior of people during pandemics by introducing unexpected events and challenges.

In particular VESTIGE (Virus Epidemics Simulation in Towns & Regions for Infection Governance during Emergencies) that addresses pandemics and it based on Strategic Engineering concept combining AI, Data Analytics and Simulation to support decision making in closed loop data arriving from the field (Bruzzone et al., 2020a). VESTIGE simulates the scenario evolution by adopting human behavior models over a virtual population recreated based on AI processing of open data. The system has been demonstrated in relevance to Smart Government and several applications, and extend previous researches on PONTUS & Decision Theatre devoted to support Operations and Strategic Planning as part of Smart City Project ((Bruzzone et al., 2018c). In facts, the conceptual models as well as the simulation experimentations over pandemics have been conducted by Simulation Team Scientists and Senior Partners of SIM4Future since over 10 years (Avalle et al., 1999; Bossomaier et al., 2009;Bruzzone et al.,2019).

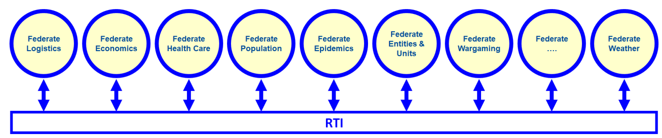

Figure 2. Overview of main scene.

Vice versa, TOPRO (Town Protection during pandemics and CBRN crisis) has been developed by SIM4Future and it is devoted to simulate operations related to a Town or Region protection during a CBRN crisis or a pandemics generating high risk of contamination. The Simulator reproduces People Behaviors, Units & Entities as well as the different activities devoted to containment and management of the crisis such as Check Point, Protection, Cordoning of Areas, Test Centers, Vaccination, etc. TOPRO reproduce different entities including law enforcements, military units, health care resources, sensor networks, social media info, etc. The solution support different modes including reproduction of a scenario within the virtual framework as well as interactive crisis management respect crucial activities such as identification of Critical Areas, containment procedures, tracking contaminated and suspect people, isolation of areas, protection of strategic assets. Indeed TOPRO could be used for Education and Training as well as to prepare Decision Makes, Authorities and Operational Planners to be ready to face pandemics and CBRN crises. Also TOPRO uses extensively the IA and allow to reproduce social and individual reaction of the population considering human behavior models and social networks. Both systems have been designed for being integrated within an HLA Federation and were used to carry out demonstration of these capabilities respect a

CBRN urban contamination created by hazardous material spill, a water contamination impacting a town due to a river flooding as well as a outbreak during a pandemics on a town over a border among different countries (Araz et al., 2012).

The general scheme to be adopted for the proposed federation is summarized by the previous figure and could be adapted to integrate the above mentioned epidemic models over different RTI looking for a flexible solution, considering that often it could result necessary to be compatible with the different constraints of specific federates usually limited in terms of time management and interoperability support.

The experimentation is currently planned for the next months based on the selection of one of the above mentioned simulators with wargaming solutions and other models in used by the authors in their centers.

5. Conclusions

The proposed research aims to maximize the capabilities of available simulators by creating join federations integrating them to support crisis management respect biological threats and epidemics. This is just a preliminary paper devoted to outline, criticalities, capabilities and potential offered by this approach as well as to pose the basis for future research and experimentation in this direction. The paper could be considered a pragmatical overview on how the concept of Strategic Engineering related to integration of AI and different Models could lead to create new capabilities in facing complex crises as well as to deal with complex Systems. As anticipated in the next months the authors will proceed in the set up of the experimentation framework and will conduct test to validate these concept on the field.

As main insights gained, we foresee the potential of this kind of tools both in education and research, in particular as a decision-support tool in different fields that range from pandemics to contamination issues. We are still on working on improving user interaction and game modes to be more precise and reflect reality with higher accuracy (Bruzzone et al. 2020a, 2020b).

References

Allen, L.J.S., Bolker, B.M., Lou, Y., Nevai, A.L., 2008. Asymptotic profiles of the steady states for an SIS epidemic reaction-diffusion model, in: Discrete and Continuous Dynamical Systems. pp. 1–20. https://doi.org/10.3934/dcds.2008.21.1

Araz, O.M., Jehn, M., Lant, T., Fowler, J.W., 2012. A new method of exercising pandemic preparedness through an interactive simulation and visualization. J. Med. Syst. 36, 1475–1483. https://doi.org/10.1007/s10916-010-9608-7

Avalle L, A.G. Bruzzone, F. Copello, A. Guerci, P.Bartoletti (1999) "Epidemic Diffusion Simulation Relative to Movements of a Population that Acts on the Territory: Bio-Dynamic Comments and Evaluations", Proceedings of WMC99, San Francisco, January

Avalle L., Bruzzone A.G., Copello F., Guerci A. (1996) "Determination and Quantification of Functional Parameters Relative to Contamination Vector Logic in an Epidemic Simulation", Proceedings of ESS'96, Genoa, October 24-26, Italy

Avalle L., Bruzzone A.G., Copello F., Guerci A. & A.Scavotti (1995) "Preliminary Analysis for the Creation of a Territorial Epidemic Simulation Model", Proc. of ESM95, Praha, June 5-7

Azevedo, J. P., Hasan, A., Goldemberg, D., Iqbal, S. A., & Geven, K. (2020). Simulating the potential impacts of covid-19 school closures on schooling and learning outcomes: A set of global estimates.

Bayham, J., & Fenichel, E. P. (2020). Impact of school closures for COVID-19 on the US health-care workforce and net mortality: a modelling study. The Lancet Public Health.

Bijl, J.L., Boer, C.A., 2011. Advanced 3D visualization for simulation using game technology, in: Proceedings - Winter Simulation Conference. Winter Simulation Conference, pp. 2810–2821. https://doi.org/10.1109/WSC.2011.6147985

Bossomaier, T., Bruzzone, A.G., Massei, M., Newth, D., Rosen, J., 2009. Pandemic dynamic objects & reactive agents, in: International Workshop on Modeling and Applied Simulation, MAS 2009, Held at the International Mediterranean and Latin American Modeling Multiconference, I3M 2009. pp. 115–122.

Backfrieder, W., Bruzzone, A., Longo, F., Novak, V., & Rosen, J. (2012) “The 1st International Workshop on Innovative Simulation for Health Care”, Vienna, Austria,

Bruzzone, A.G., Sinelshchikov, K., Massei, M., 2020a. Epidemic simulation based on intelligent agents. 9th Int. Work. Innov. Simul. Heal. Care, IWISH 2020 86–91. https://doi.org/10.46354/i3m.2020.iwish.015

Bruzzone, A.G., Sinelshchikov, K., Massei, M., Pedemonte, M., 2020b. Town protection simulation. 19th Int. Conf. Model. Appl. Simulation, MAS 2020 160–165. https://doi.org/10.46354/i3m.2020.mas.021

Bruzzone, A.G., Sinelshchikov, K. & Massei, M. (2019). Application of blockchain in interoperable simulation for strategic decision making. International Summer Computer Simulation Conference, Summersim, SCS, Berlin, Germany, July 22-24

Bruzzone, A.G., 2018a. MS2G as pillar for developing strategic engineering as a new discipline for complex problem solving, in: 30th European Modeling and Simulation Symposium, Keynote Paper at EMSS Budapest, . pp. 405–411.

Bruzzone, A. G., & Di Bella, P. (2018b). Tempus Fugit: Time as the Main Parameter for the Strategic Engineering of MOOTW. Proceedings of WAMS

Bruzzone, A.G., Sinelshchikov, K. & Di Matteo, R. (2018c). Population Behavior, Social Networks, Transportations, infrastructures & Urban Simulation for Decision Makers. 30th European Modeling and Simulation Symposium, EMSS, Held at the International Multidisciplinary Modeling and Simulation Multiconference, I3M

Bruzzone A.G., (2017a) "Smart Simulation: IA, Simulation and SG as enablers for Creating New Solutions in Engineering, Industry and Service of the Society", Keynote Speech at International Top-level Forum on Engineering Science & Technology Development Strategy- AI and Simulation, Hangzhou, China

Bruzzone A.G., Massei M., Longo F., Maglione G.L., Di Matteo R., Di Bella P., Milano V. (2017b) "Verification and Validation Applied To an Interoperable Simulation for Strategic Decision Making Involving Human Factors", Proc.of WAMS, Florence, September

Bruzzone, A.G., Agresta, M. & Sinelshchikov, K. (2017c). Simulation as decision support system for disaster prevention. In proceedings of SESDE 2017, Barcelona, September

Bruzzone, A. G., Massei, M., Longo, F., Cayirci, E., di Bella, P., Maglione, G. L., & Di Matteo, R. (2016). Simulation models for hybrid warfare and population simulation. In Proc. of NATO Symposium on Ready for the Predictable, Prepared for the Unexpected, M&S for Collective Defence in Hybrid Environments and Hybrid Conflicts, Bucharest, Romania, October (pp. 17-21).

Bruzzone A.G., Massei M., Agresta M., Poggi S., Camponeschi F. & M. (2014a) "Addressing Strategic Challenges on Mega Cities through MS2G", Proc. of MAS2014, Bordeaux, September

Bruzzone, A., Massei, M., Longo, F., Poggi, S., Agresta, M., Bartolucci, C., & Nicoletti, L. (2014b). Human Behavior Simulation for complex scenarios based on intelligent agents. In Proceedings of the 2014 Annual Simulation Symposium (pp. 1-10), April

Bruzzone A.G. (2013) "Intelligent Agent-based Simulation for supporting Operational Planning in Country Reconstruction", Int.Journal of Simulation & Process Modelling, 8(2-3), 145-159.

Bruzzone, A.G., Massei, M., Madeo, F., Tarone, F., Petuhova, J., 2011. Intelligent agents for pandemic modeling, in: Emerging M and S Applications in Industry and Academia Symposium 2011, EAIA 2011 - 2011 Spring Simulation Multiconference. pp. 23–30.

Chen, L., & Carley, K. (2003). The impact of network topology on the spread of anti-virus countermeasures. In Proceedings of NAACSOS Conference.

Chunara, R., Andrews, J. R., & Brownstein, J. S. (2012). Social and news media enable estimation of epidemiological patterns early in the 2010 Haitian cholera outbreak. The American journal of tropical medicine and hygiene, 86(1), 39-45.

De Rooij, D., Belfroid, E., Hadjichristodoulou, C., Mouchtouri, V.A., Raab, J., Timen, A., 2020. Educating, training, and exercising for infectious disease control with emphasis on cross-border settings: An integrative review. Global. Health 16. https://doi.org/10.1186/S12992-020-00604-0

Deuffic, S., Buffat, L., Poynard, T., & Valleron, A. J. (1999). Modeling the hepatitis C virus epidemic in France. Hepatology, 29(5), 1596-1601.

Di Bella P. (2015) "Present and Futures Scenarios and Challenges for M&S terms of Human Behaviour Modeling", Invited Speech at I3M2015, Bergeggi, Italy, September

Dieckmann, P., Torgeirsen, K., Qvindesland, S.A., Thomas, L., Bushell, V., Langli Ersdal, H., 2020. The use of simulation to prepare and improve responses to infectious disease outbreaks like COVID-19: practical tips and resources from Norway, Denmark, and the UK. Adv. Simul. 5. https://doi.org/10.1186/s41077-020-00121-5

Finke, E. J., Loscher, J., & Koch, H. (1999). Planning of medical support for a threatened or actual biological environment. Principles, policies and procedures. In NBC risks current capabilities and future perspectives for protection (pp. 69-93). Springer, Dordrecht.

Galvão, T.A.B., Neto, F.M.M., Bonates, M.F., Campos, M.T., 2012. A serious game for supporting training in risk management through project-based learning. Commun. Comput. Inf. Sci. 248 CCIS, 52–61. https://doi.org/10.1007/978-3-642-31800-9_6

Johansen, B., & Euchner, J. (2013). Navigating the VUCA world. Research-Technology Management, 56(1), 10-15.

Kaplan, E. H. (1989). What are the risks of risky sex? Modeling the AIDS epidemic. Operations Research, 37(2), 198-209.

Mao, L., Bian, L., 2011. Agent-based simulation for a dual-diffusion process of influenza and human preventive behavior. Int. J. Geogr. Inf. Sci. 25, 1371–1388. https://doi.org/10.1080/13658816.2011.556121

Massei M., Poggi, S., Agresta, M., & Ferrando, A. (2014) "Development Planning Based on Interoperable Agent Driven Simulation", Journal of Computational Science, 5(3), 395-407

Melnick, H., & Darling-Hammond, L. (2020). Reopening Schools in the Context of COVID-19: Health and Safety Guidelines from Other Countries. Policy Brief. Learning Policy Institute.

Mossel, A., Peer, A., Goellner, J., Kaufmann, H., 2015. Requirements Analysis on a Virtual Reality Training System for CBRN Crisis Preparedness, in: Proceedings of the 59th Annual Meeting of the International Society for the Systems Sciences (ISSS). pp. 1–20.

Oxman, G. L., Smolkowski, K., & Noell, J. (1996). Mathematical modeling of epidemic syphilis transmission, 23(1), 30-39.

Peng, L., Yang, W., Zhang, D., Zhuge, C., & Hong, L. (2020). Epidemic analysis of COVID-19 in China by dynamical modeling. arXiv preprint arXiv:2002.06563.

Perrotta, C., Featherstone, G., Aston, H., Houghton, E., 2013. Game-based learning: Latest evidence and future directions, NFER (National Foundation for Educational Research).

Raybourn, E.M., 2014. A new paradigm for serious games: Transmedia learning for more effective training and education. J. Comput. Sci. 5, 471–481. https://doi.org/10.1016/j.jocs.2013.08.005

Roda, W. C., Varughese, M. B., Han, D., & Li, M. Y. (2020). Why is it difficult to accurately predict the COVID-19 epidemic?. Infectious Disease Modelling.

Stage, H. B., Shingleton, J., Ghosh, S., Scarabel, F., Pellis, L., & Finnie, T. (2020). Shut and re-open: the role of schools in the spread of COVID-19 in Europe. arXiv preprint arXiv:2006.14158.

Stolar, A., 2012. Live CBRN agent training for responders as a key role in a safe crisis recovery, in: Barry, D.L., Coldewey, W.G., Reimer, D.W.G., Rudakov, D. V. (Eds.), NATO Science for Peace and Security Series - E: Human and Societal Dynamics. IOS Press, pp. 58–66. https://doi.org/10.3233/978-1-61499-039-0-58

Wentzel, K. R., & Battle, A. A. (2001). Social relationships and school adjustment. Adolescence and education: General issues in the education of adolescents, 1, 99-118.