# Online Appendix:

**Table A: ODD+D protocol for Multi-Agent-Based Stochastic Dynamical Model to Measure Community Resilience**

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|  | |  | | Guiding questions | | | Jaber Valinejad, Lamine Mili, Natalie van der Wal (2020) | | | | |
| 1. Overview | | I.i Purpose | | | I.i.a What is the purpose of the study? | | | To understand How critical infrastructures and social characteristics influence community resilience and How to measure community resilience. | |
| I.i.b For whom is the model designed? | | | For scientists, particularly those interested in community resilience, decision makers, power system planners, emergency services planners, social scientists, computer scientists, Industrial engineers, Web scientists | |
| I.ii Entities, state variables and scales | | | I.ii.a What kinds of entities are in the model? | | | * Two types of human agents - individuals as consumers and individuals as a prosumer who own distributed energy resources * Collectives (groups of agents) * The power systems, as a physical entity * The emergency services a physical entity * The mass media platform as cyber entity | |
| I.ii.b By what attributes (i.e. state variables and parameters) are these entities characterised? | | | Individuals as consumers: emotion, risk perception, information-seeking behaviour, experience, flexibility, learning, cooperation, personal characteristic, physical health, severity of the injury  Individuals as prosumers: distributed energy resources capacity, emotion, risk perception, information-seeking behaviour, experience, flexibility, learning, cooperation, personal characteristic, physical health, severity of the injury  Collectives: compassionate empathy, information-seeking behavior contagion, flexibility mirroring, experience diffusion, social mental well-being, social physical well-being, social well-being,  The power systems: expectations of power availability  The emergency services: expectations of emergency services availability  The Mass media platforms: Related news and information, positive news and information | |
| I.ii.c What are the exogenous factors / drivers of the model? | | | * A disaster induced by natural, human, or economic stressors. * Natural and sudden disasters (tsunami and explosions), Gradually events like hurricane and social crisis. * Natural disasters including droughts, earthquakes, extreme temperatures, floods, landslides, mass movements, storms, volcanoes, wildfires * Terrorist attacks | |
| I.ii.d If applicable, how is space included in the model? | | | Implicitly through the location of each community which determines their access to power systems and emergency services resources as well the geographical specifications to disaters | |
| I.ii.e What are the temporal and spatial resolutions and extents of the model? | | | Prediction are started at the beginning of a disasters.  Please see case study 1 (COMMUNITY OF NINE AGENTS FACING A HURRICANE )and 2 (SOCIETY OF SIX SEPARATE COMMUNITIES). | |
| I.iii Process overview and scheduling | | | I.iii.a What entity does what, and in what order? | | | Whether a human-made or natural disaster happens. It affects the availability of electricity depending on the type of event.  During the disaster, the level of fear of the people increases, and the physical health of them may be threatened according to the type of event. In this situation, the emergency services start to help the people in the community under the event. The availability of emergency services depends on different parameters, such as the geographical place of the community. When a disaster happens, various news is propagated through mass media platforms. An increase in the level of fear and uncertainty of consumers and prosumers is associated with an increase in the level of risk perception. As a result, to reduce their fear, they seek information regarding the disaster, hope to receive help from emergency services and other people. The people cooperate with each other to overcome the situation based on their experience and the level of flexibility. Prosumers can help consumers by sharing the electricity generated by distributed energy resources where the electricity from the utility is disconnected. | |
| 1. Design Concepts | | II.i Theoretical and Empirical Background | | | II.i.a Which general concepts, theories or hypotheses are underlying the model’s design at the system level or at the level(s) of the submodel(s) (apart from the decision model)? What is the link to complexity and the purpose of the model? | | | Fredrickson theory, Barsade theory, bottom-up approach. Absorption model, amplification model | |
| II.i.b On what assumptions is/are the agents’ decision model(s) based? | | | broaden-and-build theory, Damasio’s Somatic Marker Hypothesis. Once the level of fear is above a certain minimum fear threshold, it influences the level of risk perception, physical health, and cooperation. | |
| II.i.c Why is /are certain decision model(s) chosen? | | | * The negative emotion restricts individuals thoughts and actions while positive emotion broadens the set of thoughts and actions of people. On the other hand, joy prompts a feeling to play, contributing to physical, socio-emotional, and intellectual resources (skills) so that they lead to brain development. * In this model, all mantel and physical characteristics are assumed to be Gaussian random variables, as most psychological variables are approximately normally distributed. Similarly, the level of inter and intra-community behaviour diffusion are assumed to be Gaussian variables. Given the mean and the standard deviation of each of these random | |
| II.i.d If the model / submodel (e.g. the decision model) is based on empirical data, where do the data come from? | | | This model use the normal distribution for generation various parameters, states, strength contagion , and population | |
| II.i.e At which level of aggregation were the data available? | | | Household , individual level, group level, community | |
| II.ii Individual Decision Making | | | II.ii.a What are the subjects and objects of the decision-making? On which level of aggregation is decision-making modelled? Are multiple levels of decision making included? | | | Subjects: Prosumers, consumers, community, power utility, emergency services  Objects: an increase in the level of cooperation, empathy, the level of sharing electricity, the availabilty of emergency services in deprived area, and enhancing community resilince  Multiple levels of decion-making: individual levels, power system , and emergency services | |
| II.ii.b What is the basic rationality behind agent decision-making in the model? Do agents pursue an explicit objective or have other success criteria? | | | Agents pursue the objective of increasing the level of mental and physical well-being. | |
| II.ii.c How do agents make their decisions? | | | Based on the type of event, experience, the availability of electricity, emergency service and capacity of distributed energy resources | |
| II.ii.d Do the agents adapt their behaviour to changing endogenous and exogenous state variables? And if yes, how? | | | Yes, we consider the feature of the flexibility of agents so that the more flexible people can adapt themselves to the event better than the people with a low level of flexibility.  The level of flexibility influences the level of cooperation, fear, risk perception of agents. | |
| II.ii.e Do social norms or cultural values play a role in the decision-making process? | | | Yes | |
| II.ii.f Do spatial aspects play a role in the decision process? | | | Yes | |
| II.ii.g Do temporal aspects play a role in the decision process? | | | Yes | |
|  | |  | | | II.ii.h To which extent and how is uncertainty included in the agents’ decision rules? | | | The level of fear, risk perception, cooperation, flexibility, personal characteristic, experience and learning, information-seeking behaviour, contagion strength of communities follow normal distribution. | |
| II.iii Learning | | | II.iii.a Is individual learning included in the decision process? How do individuals change their decision rules over time as consequence of their experience? | | | Yes. We model the feature of experience and learning. By seeking information through mass media platforms and commutating with the people in their network, one can increase the level of experience and learn how to overcome the situation and increase the level of mental and physical well-Bing. | |
| II.iii.b Is collective learning implemented in the model? | | | Yes. According to information diffusion among the agents, the people at the macro level can learn. In our model, not only learning happens on an individual level, but also it occurs on a collective level when agents are able to exchange information. | |
| II.iv Individual Sensing | | | II.iv.a What endogenous and exogenous state variables are individuals assumed to sense and consider in their decisions? Is the sensing process erroneous? | | | Individuals sense the availability of electricity, emergency services, and news from mass media, and social trends. The sensing process is stochastic and together with uncertainty and is errorless. | |
| II.iv.b What state variables of which other individuals can an individual perceive? Is the sensing process erroneous? | | | Emotion contagion, information-seeking behaviour mirroring, flexibility contagion, and experience diffusion. The sensing process is stochastic and together with uncertainty and is errorless. | |
| II.iv.c What is the spatial scale of sensing? | | | At Global level, the spatial scale can be a group of people, county, city, states/province, and country. At local level, the spatial scale is consumers and prosumers. | |
| II.iv.d Are the mechanisms by which agents obtain information modelled explicitly, or are individuals simply assumed to know these variables? | | | The calculation of emotion, risk perception, information-seeking behavior, experience, flexibility, learning, cooperation, availability of electricity, and physical health is modeled explicitly. All other variables, i.e., type of disaster, the severity of the injury, personal characteristic, compassionate empathy, information-seeking behavior contagion, the capacity of distributed energy resources, flexibility mirroring, experience diffusion, related news and information, positive news, emergency services availability, availability of electricity supplied by the utility are known by the agents. | |
| II.iv.e Are the costs for cognition and the costs for gathering information explicitly included in the model? | | | No. | |
| II.v Individual Prediction | | | II.v.a Which data do the agents use to predict future conditions? | | | Data on past emotion, risk perception, information-seeking behavior, experience, flexibility, learning, cooperation, availability of electricity, and physical health  In addition, the other variables, i.e., type of disaster, the severity of the injury, personal characteristic, compassionate empathy, information-seeking behavior contagion, the capacity of distributed energy resources, flexibility mirroring, experience diffusion, related news and information, positive news, emergency services availability, availability of electricity supplied by the utility are known by the agents are necessary to measure the states at the same time. | |
| II.v.b What internal models are agents assumed to use to estimate future conditions or consequences of their decisions? | | | Each agent is characterized by a set of features, i.e., emotion, risk perception, information-seeking behavior, experience, flexibility, learning, cooperation, electricity, and physical health, and personal characteristic. Agents’ predictions are based on the past situations of the various states and are errorless. | |
| II.v.c Might agents be erroneous in the prediction process, and how is it implemented? | | |  | |
| II.vi Interaction | | | II.vi.a Are interactions among agents and entities assumed as direct or indirect? | | | The interactions and entities among agents are direct through emotion contagion, information-seeking behavior mirroring, flexibility contagion, experience diffusion, and sharing the electricity, availability of electricity, and emergency services. | |
| II.vi.b On what do the interactions depend? | | | Intellect, openness, channel strength, extraversion, emotion expression, the susceptibility of an agent, spatial  distance, access to a resource | |
| II.vi.c If the interactions involve communication, how are such communications represented? | | | Yes, the agents communicate with each other through  emotion contagion, information-seeking behavior mirroring, flexibility contagion, experience diffusion. | |
| II.vi.d If a coordination network exists, how does it affect the agent behaviour? Is the structure of the network imposed or emergent? | | | The decentralized or group-based coordination  structure of the agents exists. | |
| II.vii Collectives | | | II.vii.a Do the individuals form or belong to aggregations that affect and are affected by the individuals? Are these aggregations imposed by the modeller or do they emerge during the simulation? | | | Yes, Social groups, human networks, powers systems, emergency services. | |
| II.vii.b How are collectives represented? | | | We model the collective behavior using a bottom-up approach so that the individual behavior influences the collective behavior and vice versa. | |
| II.viii Heteroge­neity | | | II.viii.a Are the agents heterogeneous? If yes, which state variables and/or processes differ between the agents? | | | No. | |
| II.viii.b Are the agents heterogeneous in their decision-making? If yes, which decision models or decision objects differ between the agents? | | | The agents are not heterogeneous in their decision-making. | |
| II.ix Stochasticity | | | II.ix.a What processes (including initialisation) are modelled by assuming they are random or partly random? | | | Emotion, risk perception, information-seeking behaviour, experience, flexibility, learning, cooperation, personal characteristic, physical health, compassionate empathy, information-seeking behaviour contagion, flexibility mirroring, experience diffusion, | |
| II.x Observation | | | II.x.a What data are collected from the ABM for testing, understanding and analysing it, and how and when are they collected? | | | N/A | |
| II.x.b What key results, outputs or characteristics of the model are emerging from the individuals? (Emergence) | | | When flexibility is high, individuals experience a lower level of panic. Furthermore, the perceived risk of agents is lowered because of the high level of flexibility and low level of fear. As a result, information-seeking behavior which is very much linked with risk perception is diminished. In general, the positive features of individuals may rectify their behavioral drawbacks. In addition,  experience has a negative impact upon the level of fear, information-seeking behavior, and risk perception of agents. It positively influences flexibility if agents are optimistic. When agents do not have previous experience, they seek new information during a perilous situation. Therefore, their experience is increased. There is stable feedback between experience and risk perception in the cognitive process.  Plus, when people have a high level of cooperation, they share their electricity sooner than when they have a low level of cooperation. As a consequence, they have a higher level of physical health. Furthermore, due to the high level of cooperation and physical health, people experience a lower level of panic. | |
| 1. Details | | III.i Implementa­tion Details | | | III.i.a. How has the model been implemented? | | | Matlab | |
| III.i.b Is the model accessible, and if so where? | | |  | |
| III.ii Initialisation | | | III.ii.a What is the initial state of the model world, i.e. at time t=0 of a simulation run? | | | Please see case study 1 (COMMUNITY OF NINE AGENTS FACING A HURRICANE )and 2 (SOCIETY OF SIX SEPARATE COMMUNITIES). The all characteristic follow normal distribution. | |
| III.ii.b Is the initialisation always the same, or is it allowed to vary among simulations? | | |  | |
| III.ii.c Are the initial values chosen arbitrarily or based on data? | | |  | |
| III.iii Input Data | | | III.iii.a Does the model use input from external sources such as data files or other models to represent processes that change over time? | | | Disaster, | |
| III.iv Submodels | | | III.iv.a What, in detail, are the submodels that represent the processes listed in ‘Process overview and scheduling’? | | | Please see the section III: MODELING THE SOCIAL WELL-BEING OF A  COMMUNITY DURING A DISASTER. | |
| III.iv.b What are the model parameters, their dimensions and reference values? | | | Please see NOMENCLATURE and the section III. | |
| III.iv.c How were the submodels designed or chosen, and how were they parameterised and then tested? | | | We have followed the generative social science approach, where the concepts and the relations between concepts are modelled from the bottom up. From the scientific evidence in the literature, the basic patterns that are expected from the literature are verified. Then through agent interactions we study the emergent effects – that cannot be predicted from individual agent rules – to gain more understanding of the workings of community resilience and to possibly derive new hypotheses to be tested in the real world. We also have neuroscientific foundation, for example, emotion based on somatic marking. Plus, we have adaptively. For example, emotional model change within agent, information seeking behavior that adapts. Beside, we did sensitivity analysis and soft validation. | |

**References:**

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[2] Grimm, Volker, Uta Berger, Finn Bastiansen, Sigrunn Eliassen, Vincent Ginot, Jarl Giske, John Goss-Custard et al. "A standard protocol for describing individual-based and agent-based

models." *Ecological modelling* 198, no. 1-2 (2006): 115-126.

[3] Grimm, Volker, Uta Berger, Donald L. DeAngelis, J. Gary Polhill, Jarl Giske, and Steven F. Railsback. "The ODD protocol: a review and first update." *Ecological modelling* 221, no. 23 (2010): 2760-2768.