A Multi-Agent System for Studying Cross-Border Disaster Resilience

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ABSTRACT

Resilience to disasters depends on measures taken before, during and after the occurrence of adverse events. These measures require interactions between people belonging to different organizations (public, private, non-profit) and citizens in normal and stressful situations. The efficiency of resilience measures results from the collective interaction of individuals, groups of individuals, and organizations, as well as the situational characteristics of the decision environment. The aim of the French-German research project INCA is to develop a decision support framework for improving cross-border area resilience to disasters. This project comprises the design and the implementation of a multi-agent system with the objective to study the behavioral and organizational implications of cross-border cooperation for crisis management and disaster resilience. The analyzed measures focus on citizens who require medical support and the integration of volunteers into the crisis management procedure. This paper outlines the potentials of the multi-agent system and provides first implementation insights.

Keywords

Multi-agent system, disaster resilience, coordination procedures, cross-border cooperation, volunteer management

INTRODUCTION

In spite of the trend towards urbanization, there is an increasing susceptibility of cities to crisis events due to their dependency on critical infrastructures as well as an increased exposure to natural disasters. However, crisis events such as epidemics or local natural disasters do not stop at national, geographic, political or cultural borders. It is therefore extremely important to develop cross-border concepts for resilience and crisis management. Since March 2017, a consortium of French and German researchers is focusing on the issue of cross-border resilience in the context of the research project INCA. The objective of the INCA-project is to develop a decision-support framework for improving cross-border risk and crisis management operations for the context of a long-lasting power blackout. A special focus of the research agenda is on the issue of cross-border cooperation facing the challenges of intercultural communication and inter-organizational coordination. The improved crisis management procedures should comprise the integration of volunteer helpers on both sides of the border to achieve a better and faster treatment of medical dependent people ("disaster victims"). Considering the individual and collective behavior of involved actors on an individual, organizational and country level constitutes an intricate challenge. From an analytical point of view, this task is accomplished by a multi-agent system, which makes it possible to depict, simulate and analyze the collective interaction of various actors in dynamic crisis. Multi-agent systems are powerful tools when it comes to the analysis of the collective and dynamic behavior of a large number of distinct "types" of decision-makers. The emerging patterns of behavior are difficult to capture. In most cases, they are even intractable for standard decision-making approaches or game-theoretic models. The aim of this paper is, thus, to give an insight into the basic structure of the multi-agent system of the INCA-project, to present some preliminary simulation results and to discuss further steps and prospects. The remainder of the paper is organized as follows: In the next section, we give a brief account on the concepts of cross-border resilience and culture and provide a short introduction on multi-agent systems. After that, we introduce the INCA simulation framework, describe the basic structure of the multi-agent system for disaster resilience, and we present first simulation results. In the last section, we briefly discuss the preliminary insights and the prospective potentials of the model.

CROSS-BORDER RESILIENCE, CULTURE AND MULTI-AGENT SYSTEMS – A BRIEF ACCOUNT

Cross-border resilience, culture and communication

Resilience is an integrative concept, which became prominent in science and on the political agenda. It encompasses two main ideas: a response to stressful events and the sustainability of systems when coping with stressful events (Reich et al. 2010). At a geographical level, the United Nations define resilience as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions" (UNISDR 2009).

The capacity of a region to withstand disasters depends on five factors (Boin et al. 2011): disaster risk assessment, disaster risk mitigation, disaster preparedness, disaster response, and disaster recovery. Risk assessment refers to the identification, analysis, and evaluation of potential disaster risks and vulnerabilities. Risk mitigation and prevention refer to actions that reduce the vulnerability to disasters. This includes measures that reduce causalities, disruptions, and exposure to damages as well as measures that provide passive protection. Disaster preparedness refers to measures that bolster emergency response capabilities, including warning systems, evacuation routes, supply chains and communication procedures (decision-makers must implement these measures before a disaster occurs). Disaster response refers to measures taken immediately before, during, and after a disaster to save lives, to eliminate or at least to minimize damages. Disaster recovery includes short-term activities, that restore vital support systems as well as long-term activities to rebuild physical, social, and economic infrastructures.

Regional disaster resilience relies on the interaction of public, private, and non-profit organizations among themselves and on the interaction between these organizations and the community. These interactions face a significant amount of obstacles - especially in cross-border regions. Therefore, it is mandatory to assess the specific characteristics of borders. In general, geographic borders are "line[s] on a map" (Agnew 2008). They not only separate geographic areas, but also political systems, economic systems, cultures, values and norms. Geographic borders are not always tangible: they can be natural structures (mountains, rivers, seas, etc.), artificial structures (walls, meridians, etc.), or mental borders between different cultures (Guo 2015). Although cross-border regions have been empowered in the past, their vulnerabilities to disasters remain. Especially, in times of increasing natural and man-made disasters, it becomes ever more important to improve disaster resilience across borders (Adrot et al. 2018).

Cultural differences may have an impact on people's collective behavior and thus on the disaster resilience in cross-border regions. In 1871, Tylor, a social anthropologist, defined culture as the "complex whole which includes knowledge, belief, art, morals, law, custom, and any other capabilities and habits acquired by man as a member of a society" (Tylor 1871). In 1953, Jacques, a sociologist, proposed one of the first definitions of organizational culture. According to Jacques (1952), organizational culture is the "customary and traditional way of thinking and doing of things, which is shared to a greater or lesser degree by all its members, and which new members must learn, and at least partially accept, in order to be accepted into service in the firm". Since then, scholars identified different cultural factors of variability. This includes, inter alia, uncertainty avoidance, long-term versus short-term orientation, individualism versus communitarianism, achievement versus ascription, sequential time versus synchronous time, degree of the importance of the context in communication, task based versus relationship based trust building, or different forms of time management (e.g., Hofstede et al. 2010, Trompenaars & Hampden-Turner 2012, Meyer 2015).

A classical definition of *communication* is: "the definition of a *message* by a *sender* with some *intentions* transmitted to *receivers* by the mean of a communication *channel* where *noise* can affect negatively the performance of the communication process" (Shannon & Weaver 1949). With the concept of *feedback* (Wiener 1948) the role of sender and receiver can be interchanged and positive or negative feedbacks amplify or attenuate the communication process. Sender and receiver shared a *context* and a *code* for generating and understanding *messages* (Jakobson 1965). Hymes (1974) extends the model by considering various attributes as the *setting and the scene* (when and where the communication process takes place), the *ends* (referring to purpose, goals and outcomes of the process) the *act sequence* (corresponding to the form and the order of the process), the *keys* (describing tone, manner or spirit of the exchange of messages), or the *norms* (related to social rules governing the communication process). Newcomb (1953) associates communication with social relationships and derives the hypothesis that communication process supports the equilibrium between the sender, the receiver, and a topic. In the context of cross-border communication, it is necessary to extend these models by dimensions as language or culture for the sender and the receiver.

Multi-agent systems

Multi-agent systems are computational models, developed for the simulation of actions and interactions of autonomous agents in order to assess their behavioral impact on a particular system. The concept of an agent is central to this approach. An agent is an encapsulated computerized entity that is situated in an artificial environment. It is capable of carrying out flexible, autonomous actions in that environment in order to meet its design objectives (Jennings 1999). Agents represent heterogeneous groups of discrete individuals, which are autonomous, self-directed, and able to interact. Furthermore, agents can store resource attributes, they are adaptive to their environment, and they have goals that drive their behavior (Macal 2009). The program code itself represents the processes that the modeler thinks how they exist in the real world (Macy & Willer 2002). Multi-agent systems provide concepts, methodologies and tools for specifying, designing, and engineering software for autonomous and/or distributed acting entities. This allows the simulation of complex individual and social behavior.

Various decision frameworks for disaster management, such as the decision support system VESTA, developed by Kamissoko et al. (2014), already exist. They take into consideration that decision making in the case of an emergency is more complex than under "normal" circumstances while focusing on vulnerability calculations. Multi-agent systems are suitable for disaster management analysis because they allow decision-makers to analyze complex dynamic situations without global information by simulating different types of agents with various characteristics. In the following, we outline some existing agent-based models for a disaster context: Joo et al. (2013) compare various evacuation strategies for warehouses in the event of a fire. Aldewereld et al. (2011) analyze efficiency differences between individually operating and hierarchical organized emergency management teams. Fikar et al. (2017) simulate the impact of transport disruptions. Moreover, Crooks & Wise (2013) analyzed the Haiti earthquake of January 2010 by using crowdsourced GIS data. The authors explored how people react to the distribution of aid as well as how rumors relating to aid availability propagate through the population. In their model, agents are equipped with an energy level, which allows them to move only predefined distances without refilling their energy. These energy levels represent the health of an agent and therefore simulate human needs, such as food, water, and rest. Cross-border coordination problems and the potential of the integration of spontaneous volunteers were not analyzed in the literature yet.

THE SIMULATION FRAMEWORK

We developed a basic simulation framework based on a multi-agent system in order to study characteristics of cross-border disaster resilience. This framework consists of four components:

- A methodological *guideline*: This component provides support functionalities to users as defining the context of their simulation, defining the required data set for their simulation, defining their simulation sessions, and visualizing as well as analyzing their simulation results.
- Simulation *editor*: This component provides editing and visualization functionalities to users for the definition of input parameters for the simulations. Parameter sets describe cross-border characteristics, disaster scenarios and resilient management use cases (e.g. search and rescue).
- *Simulator*: This component provides functionalities for conducting simulation sessions of use cases. By modifying key variables, individual and collective behavior is generated and visualized as well as consequences of agents' decisions-making processes and tasks.
- Results *visualization* and *analysis support system*: This component provides functionalities for the visualization and interpretation of simulation results and for generating simulation reports.

The model is implemented using the multi-agent system toolkit *Repast Simphony*. This toolkit is written in the *Java* programming language and belongs to the *Repast Suite*, a family of free and open-source agent-based modeling and simulation toolkits (North et al. 2013). The definition of the multi-agent system is based on the *Gaia* methodology for agent-oriented analysis and design (Wooldridge et al. 2000). *Gaia* is a conceptual framework, which allows specifying and designing models and software using the multi-agent system paradigm.

Aims of the multi-agent system

The multi-agent system aims to support the simulation of individual, collective, and organizational behavior in the context of disaster resilience management. It considers effects of the presence of a border, such as cultural biases, communication problems and regulatory issues. Furthermore, the presence of the border can affect technical skills of emergency operations (such as search and rescue or evacuation) and non-technical skills (such as decision-making processes, tasks planning and realization, communication and coordination processes, conflict management, stress and fatigue management, or situation awareness). The simulation illustrates a borderland territory with two countries separated by a physical border - a river - with only one passage – a bridge - as a connection between the two countries. This passage can be opened and closed to control the exchanges of health infrastructures or the mobilization of volunteers. Furthermore, the model considers variation in the health status of the victims. Depending on this status, the victims' diagnostic, transport and care will require specific competences and technological requirements. A set of performance indicators related to the efficiency of tasks and to the quality of the management of victims is implemented to study impacts of the variability of borderland resilience and the performance of cross-border crisis management operations. Additionally, effective coordination of spontaneous volunteers in the cross-border setting will be analyzed.

Multi-agent system design

The model considers three types of agents: *passive agents* that have properties but do not behave autonomously, *reactive agents* that perform roles when receiving signals from other agents or from the environment and *self-finalization agents* that behave autonomously and intentionally according to their objectives and to events occurring in the environment. Passive agents are characterized by a set of attributes, which can be modified by the actions of reactive and self-finalizing agents. Reactive agents are characterized by a set of attributes and a set of roles triggered by signals coming from the environment of other agents. The consequences of the execution of specific roles depend on the agent's attributes, on the attributes of the environment, and on other agents' reactions. Self-finalizing agents have belief attributes (related to their environment or other agents) and cultural attributes (related to individual, collective, organizational, and national specificities influencing their behavior). They dispose of knowledge and the ability to perform tasks. A specific set of roles can be performed under conditions associated to their identity or organizations they belong to. The following classes of agents are realized:

Victims are instances of passive agents. A variable describes their health and state of injury representing three levels: extremely injured, slightly injured, or not injured. This state variable is initialized by a uniform distribution over an interval corresponding uniquely to the level of injury. It constantly decreases over time except that compensating measures are taken, such as getting food or receiving a specific medical treatment. If the value is equal to zero, the agent dies (see Crooks & Wise 2013). Depending on their health status, agents can move or have to be transported to a hospital. Furthermore, dynamics in the decrease of energy levels are subject to the agents' attributes. For example, the health status of special needs and elderly persons decreases faster than the health status of young adults.

Volunteers are instances of self-finalizing agents. They adapt their behavior according to their energy status and motivation (on an "altruism"-spectrum starting with "no specific motivation to help" via "search and rescue of relatives and acquaintances" up to "search and rescue of unknown citizens"). So far, two kinds of volunteers are specified: Those who engage in terms of neighborhood help ("volunteers") and those without any motivation to help ("no volunteers"). The effectiveness of their engagement depends on external events occurring in the environment, on their abilities, and on the interference with other agents.

Ambulances are instances of reactive agents. They receive the instruction to search, diagnose, transport, or eventually treat victims. They are characterized by a status of occupation, a target, transport capacities (restricted by both - a maximum number of victims and a maximum distance), and a technical status (traditional versus advanced health management capacities).

Hospitals are self-finalizing agents. Hospitals have a fixed location and a set of capacities including available competencies, medicine, specialized material, and bed capacities. The latter variable varies depending on the number of victims arriving at one hospital. Subject to the evolution of these variables, the hospital can decide to cooperate with other hospitals.

Search and rescue coordinators are self-finalizing agents. Their target is to allocate ambulances and volunteers in the most efficient way to search and rescue victims and to transport them to hospitals. The feasibility of the solution results from the consideration of dynamics in the environment (e.g. opening of the border, increase of the number of victims, availability of hospitals). However, hospitals' reaction time can increase (e.g. due to a delay of available information updates or due to stress), which can result in difficulties of the emergency coordination.

Multi-agent system roles and protocol

The list of roles and protocols of the multi-agent system was established in accordance with the *Gaia* methodological framework. An initial list of roles has been identified related to the management of victims, the management of volunteers, and with respect to cooperation between health organizations:

- Roles associated to victims' management are: coordinate search and rescue, search of victims, diagnose victims' health status, transport victims, and treat victims. These roles include organized search strategies initiated by a coordination center, professionals and volunteers with medical or logistical competences, and equipment for transport and care. This also includes spontaneous volunteers searching, providing first aid, and transporting victims to hospitals.
- Roles associated to the management of volunteers are: register volunteers, assign tasks to volunteers, coordinate with professionals, and monitor volunteer activities.
- One role is associated to cooperation between health organizations that reach their maximum capacity: transfer victims from one organization to another.

Associated to these roles, a set of protocols are implemented which define exchanges between individual agents and between individual agents and organizations:

- The purpose of the "search for victim"-protocol is to structure the organized search and rescue process of a group of victims. This protocol is initiated when rescue agents receive a message related to a set of victims in a given area, which is subject to coordinated search and rescue procedures. Agents in charge of victim search, transport, and treatment are part of this protocol. Input of the scenario is a group of victims with diverse levels of affectedness (injuries or illness) in a given area. Output is the same group with a final level of affectedness. During the course of actions, there is communication between agents about the identification of victims, about the results of their health and injuries diagnostic, and about the used or available transportation modes.
- The purpose of the "volunteer management"-protocol is to organize the realization of a set of tasks by a group of professionals and volunteers. The protocol is initiated when search and rescue tasks require volunteer support and volunteers are available. Participants are professionals-agents and volunteer-agents which all follow the standard rescue procedure (search, diagnose, transport, care). The input is a group of tasks to perform. The output is the same group of tasks assigned to agents (professional or volunteers). The course of actions is composed of requesting availabilities for personal and volunteer agents, assigning suitable tasks to them by considering their competences and preferences and taking decisions to achieve a final schedule of tasks. These decisions include the possibility to assign tasks to a group consisting completely of professionals, to a group consisting completely of volunteers or to a group mixing professionals and volunteers together. Additionally, a precise schedule of tasks within the groups has to be communicated.

PRELIMINARY SIMULATIONS

The multi-agent system is designed to study the behavioral and organizational implications of cross-border cooperation for crisis management and disaster resilience in response to a long-lasting power blackout. Due to this objective, the simulation has a high level of abstraction and the root cause of the disaster - the long-lasting power-blackout - is modelled indirectly. Focusing the health dimension of the model, we are primarily interested in the number of victims specified by their degree of injuries and by the time required to guarantee an adequate treatment. Since these states are not predictable, we apply scenarios to achieve a robust treatment strategy. Hence, the simulation captures the degree of injuries by the mentioned energy levels and the time period within which a person turns to a victim, differentiating between short-term victims and victims who are affected over a longer time period. In the real world setting, short-term victims are for example persons trapped in an elevator or persons having an accident due to traffic light failures. Over time, the number of victims will grow for example due to the lack of water and food supply. These specific triggers are not explicitly represented in the simulation due to the level of abstraction. The number of short-term victims is difficult to forecast from the point of view of civil protection agencies whereas vulnerable groups of society (e.g. special needs or elderly people) represent a more stable group of potentially affected victims.

The multi-agent system is implemented using the *Repast Simphony* toolkit. So far, a cross-border region with two bordering countries is modelled. The countries are separated by a physical border: a river with only one bridge across. Three cities are located in the modelled territory, two on one side and one on the other side of the border. Each city has one hospital and there are five ambulances available at each hospital. We assume a uniform distributed population for the rural area. Additionally, a uniform distributed population with a higher population density is given for each city. It is assumed that a disaster occurs, which randomly affects the population equally on both sides of the border. The simulation starts by the exogenous event of a power-blackout but technical details leading to the failure are not within the scope of the model. Hence, the system is initialized (T0) and agents take one out of three possible states of injury: extremely injured (red colored agents in *Figure 1*), slightly injured (violet colored agents in *Figure 1*), or not injured (white colored agents in *Figure 1*), which is uniquely indicated by the actualization of the energy variable. Thereby short-term victims are modelled. With each discrete time step, the time-dependent variables of agents and environment are updated. Decreasing levels of energy thereby model an increasing number of victims over time. Agents who are not injured can decide to volunteer. Depending on their motivation, they either bring neighboring persons in need to a hospital (if they do so, they get a yellow color in the picture of *Figure 1*) or they do not volunteer (then their color remains white). The white arrows in *Figure I* illustrate the correspondence of a victim with an ambulance or voluntary helper. In a first set of simulations, two states of the border are implemented: the border can either be closed (with no access from one side to another) or opened (allowing volunteers and ambulance to cross the border). *Figure 1* illustrates the dynamics of the model. The picture on the left shows a situation of search and rescue with suppressed cross-border activities. Ambulances on each side of the border collect victims in star-shaped routes around the hospitals. Here, the movement range of agents is concentrated on a limited areal. The picture on the right shows the same model with the only modification that cross-border collaboration is allowed. Agents can pass the border at one fixed point (a bridge over the border river) so that the cross-border activities concentrate around this point. The access to the neighboring areal increases the overall variation of distances and directions.

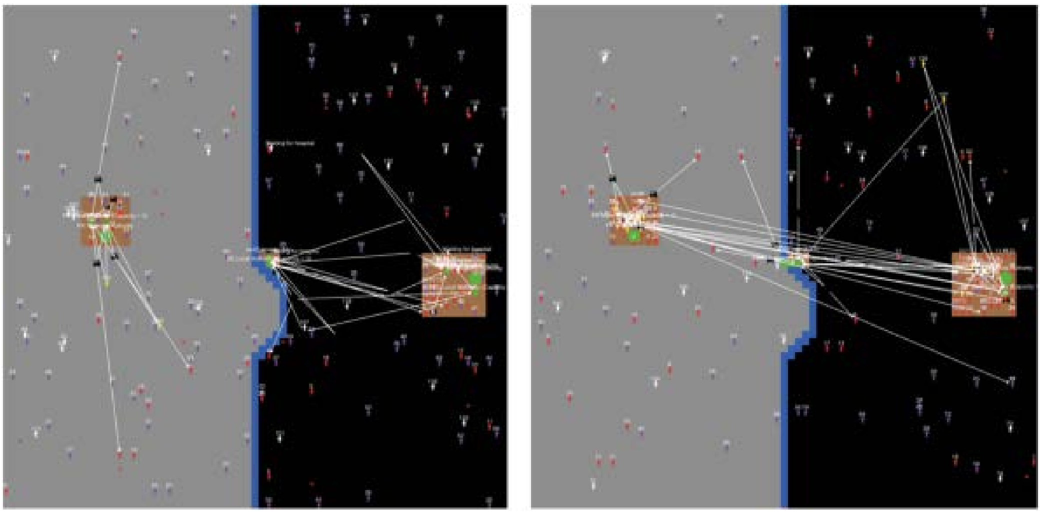

Figure 1. Illustration of the dynamics comparing cross-border cooperation disabled and enabled

The variation in the health status variable of the victim-agents is registered through the variable tracking functionalities provided by *Repast Simphony*. *Figure 2* presents the increasing number of dead agents (due to limited capacities in health facilities) as well as a decreasing number of volunteers (due to fatigue and decreasing resources) over time. The number of extremely injured people decreases in the first period due to the activities of health facilities, but increases later since minor injuries that are not treated increase to extreme injuries (due to limited capacities, health facilities have to prioritize). The red curve indicates the number of slightly injured agents. It increases at time T30 since agents fall into this category after they were released from the hospital. The subsequent decrease is caused by minor injuries which are not treated and therefore extend to extreme injuries.

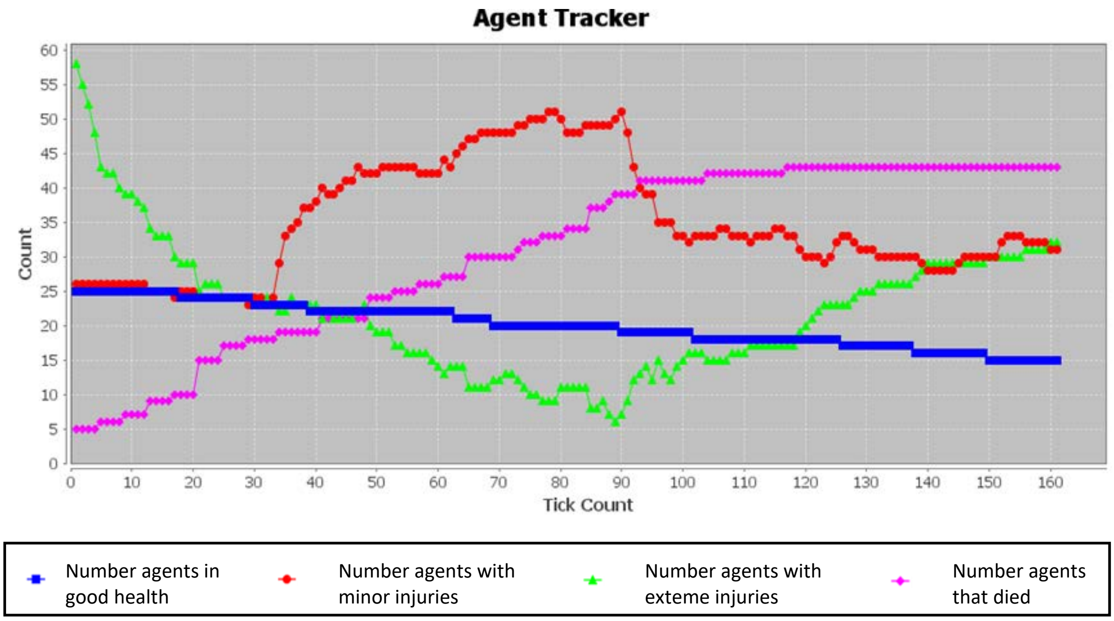

Figure 2. Illustration of the dynamics of the agents' status

This first round of simulations demonstrates the potential of the basic model to describe and analyze collective and partly coordinated rescue activities in a cross-border region. The first realizations are characterized by strong assumptions, such as perfect information flows and optimized actions. Ambulances and volunteers know the available capacities of the closest hospital and can bring victims on the shortest path to the best suitable hospital. In case of an open border, the perfect information flows and optimized actions spread to the whole area without facing any difficulties in terms of language, culture or law. In a more realistic scenario of a power-blackout, long-distance communication via telephone or mobile phone is strictly limited which will complicate the coordination procedures. Hence, we address different scenarios in the agent-based model in order to derive suitable procedures. The external validity of these assumptions will be checked, too.

FURTHER STEPS

Considering culture in the communication process

The ongoing process aims at the implementation of inter-agent's communication strategies. To describe the nature of communication, we use a set of key concepts deducted from a literature review as indicated in the corresponding section. These key concepts offer a structure to the model of communication, which will be extended for our considered cross-border studies by personal traits of the sender and the receiver. Bowles & Gintis (2004) analyzed trust and exclusion in ethnic networks, analyzed communication difficulties between individuals of various trait types, and derived a trust equilibrium. In order to transfer these ideas, a network will be implemented such that each agent is represented by a node. Two nodes are connected by an edge, if the two agents corresponding to these nodes know each other. The relationship of two agents can be indicated via weights on the connecting edge between these agents. Additionally, the model yields the possibility to equip each agent with a personal vector representing the "character" of the agent. In our context traits as ethnicity, language and cultural characteristics are of special interest since these characteristics will either complicate or simplify communication. Differences in the personal vector of the sender and the receiver can result in delayed information via misunderstandings and even lead to complete failure of communication. The more similar these personal vectors of the sender and the receiver are, the easier and more reliable communication will be. Hence, the expected probability of successful communication increases. The case of perfect communication - which is already implemented - corresponds to identical trait variables in the personal vector. In order to quantify a "degree of similarity" in this context, the authors will apply the concept of *expected communication difficulty* defined by Bowles & Gintis (2004). It is planned to study the impact on communication for various trait types. Another challenge is the assessment of the communication efficiency. The concepts of good and bad communication need to be investigated and a qualitative scale has to be developed that allows the visualization of communication performance.

Increasing degree of realism and complexity of the model

With an increasing degree of realism - and thus complexity - of the model it is important to up-scale the technical capacities of the model simultaneously. For that purpose, a set of refinements and extensions needs to be defined.

The first set of refinements and extensions relates to the model itself:

- The geographical model can be more realistic. Spatial, topological, and demographic dimensions could be enhanced as well as critical infrastructures interdependencies. However, this requires the selection of an example region in a first step.
- Furthermore, the diversity and complexity of the border can be increased with respect to several aspects. Different typologies of borders have to be considered by the model as well as – which is one of the main upcoming tasks - the sociological dimension of the cross-border region.
- It is possible to give a more detailed description of the disaster itself. For example, the dynamic features of the model provide the opportunity to considerate complex disaster scenarios that comprise phases like propagation and escalation.

A second set of extensions relates to the software:

- A far-reaching but highly interesting extension is the definition of interfaces with cross-border regions, disasters and simulations editors. For this objective, the software should be able to integrate editors, that provide relevant input models. Furthermore, the software has to be able to import models with a standardized language.
- A specific interface to monitor simulations can be defined. The simulation above includes a very basic set of target values and key performance variables which can be extended to more sophisticated performance indicators such as vulnerability measures or resilience indices. With an increasing number of variables, it becomes more practical to develop an associated simulation interface that allows these variables to be modified.
- A specific interface could be developed for the visualization of the results as well as an interface presenting the tracked variables.

SUMMARY AND OUTLOOK

Enhancing the understanding of disaster resilience of a cross-border region is a challenging task. In this paper, we gave an overview of the multi-faceted concept of cross-border resilience and presented a preliminary draft of a multi-agent system which is designed to depict and analyze the behavioral dynamics of key actors during a crisis situation. The model has been designed and implemented using the *Repast Simphony* toolkit. The outlined simulation focused on rescue operations carried out by volunteers and professional rescue units. First insights with respect to the evolution of different types of victims, their degree of affectedness and the motivation of volunteers – both with and without a separating border – were discussed.

It is quite clear that this basic version is still based on a very high a degree of simplification which is unavoidable for a first set-up. In principle, it is a good practice to follow the "from simplicity to complexity"-rule for modeling tasks in order to keep track of the model's mechanisms from the very beginning. However, it is an ongoing work and the model will be refined and continuously approached to the relevant properties of the behavioral characteristics of agents as well as the driving factors of the "real" environment. In this respect, a number of refinements, extensions and technical requirements were listed. As mentioned above, the dimension of culture (e.g. on an organizational and country level) as well as the specific characteristics of crisis communication in all interesting directions (within and between organizations, among volunteering helpers and between organizations and volunteers) will play a key role in the future.

While focusing on culture, the authors of this contribution also seek to shed light on an issue which is often overlooked when analyzing cross-border phenomena: In cross-border regions, the borders do not just have a separating function creating an obstacle for cooperation. Cross-border regions are not just separated by culture but they also created their own culture and "cross-border identity", which is sometimes even rooted more deeply than the respective "national cultures" (Adrot et al. 2018). Therefore, the multi-agent system has to be complemented on an empirical ground, which has to be accomplished by both intense social research and data acquisition. In this regard, the research agenda of the INCA-project also comprises surveys, interviews, and experiments.

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