Simulating and Analyzing Crowdsourcing Impacts in Flood Management: A Geo-spatial Agent-Based Approach

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Abstract. Crowdsourcing is becoming essential to facilitate disaster management. It can help to gather or check information and delegate collective physical tasks (alerting, rescuing, sheltering, food distribution…) to volunteers. In this context, the management of volunteers, with possible uncertain behavior, cannot be improvised, for both security and efficiency reasons. Therefore, it is necessary to provide officials with tools to anticipate and prepare coordination with volunteers. For that purpose, this paper proposes a geospatial agent-based simulator to visualize, measure and analyze the influence of crowdsourcing in natural disasters management. More precisely, this tool allows the authorities to visualize a crisis situation (actors, environment) and its evolution throughout time and space, improve their situation awareness and explore several what-if scenarios so as to ease coordination with official responders. Moreover, task assignment is implemented according to the contract net protocol to select the volunteers according to their variable characteristics: availabilities, positions, skills… This paper describes the design and implementation of this simulator, which is based on a conceptual model representing the environment, agents' behaviors and their interactions. We also demonstrate its use through a real-world case study based on a flood that took place in 2018 in Trèbes, a French town. We demonstrate with quantitative indicators the positive impacts of crowdsourcing on this crisis management. This simulator could be easily reused for other natural disaster situations.

Keywords: Agent based Modelling and Simulation · Crowdsourcing · disaster management

1 Introduction

Context. Nowadays, the number of natural disasters (floods, fires, earthquakes, tsunamis…) as well as their impacts are increasing worldwide, notably due to climate change. In Europe for example, in 2021 summer floods affected Germany, Belgium and Turkey and caused the death of hundreds of people and more than 10 billion euros of property damage. Nowadays, during the response phase of such crisis, the authorities cannot handle these events alone anymore. Citizen volunteers (i.e. contributors) are commonly included in crisis management activities such as rescuing, hosting, alerting people, providing materials and food, or gathering and checking information on the field [1, 5].

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In this context, the management of volunteers, with possible uncertain behavior (availability, motivation, movement…), cannot be improvised, both for security and efficiency reasons. Indeed, coordination is necessary for limiting redundant actions, avoiding collisions, or synchronizing them. Besides, it is important that contributors follow explicit and well-defined protocols (to be engaged and also during tasks allocation) to avoid misinterpretation of orders and therefore reduce risks. Since preparation drills in the field are costly and time-consuming, it becomes necessary to provide officials with simulation tools to anticipate, test and prepare volunteers coordination policies, calibrate the number of volunteers (number, distribution…) and measure the overall impact of their actions on the quality of the disaster management process (reduce the number of victims and damage, improve reaction time, increase citizens and responders awareness…). Moreover, the acceptability of digital solutions by officials requires coordination policies to be experimented, visualized, discussed, and adapted in *a shared and user-friendly information space* that shows the geospatial context in which the crisis occurs, and the scope of damage.

Given these observations, *the goal of this work* is to design and implement a simulation framework to simulate, visualize and analyze the impact of crowdsourcing in natural crisis management. It should make it possible to test and elaborate in an interactive way, coordination policies while taking into account the following requirements: the variable behavior of the contributors, their interactions with the officials, and the geospatial representation and evolution of the disaster phenomena in its environment.

Existing work about crowdsourcing applied to disaster management (see [1, 2, 5] for a review) features several limitations. They mainly focus on optimization aspects (task allocation, information accuracy improvements) without measuring the global impacts of crowdsourcing on crisis management and the possible risks and vulnerability attached to it. In addition, as noticed by [8], most of them rely on idealized models that do not consider uncertainty due to the variability of human behavior. [12] specifies an interesting approach to formalize and integrate motivation in an agent-based simulation devoted to model the spontaneous volunteers' convergence phenomena but it provides neither a comprehensive approach nor a geo-spatial setting for its execution, as discussed in Sect. 2.

To the best of our knowledge, no work provides an interactive framework simulating contributors' behaviors and visualizing the geo-spatial environment, its evolution and the global effect of crowdsourcing on the crisis resolution.

Contributions. To overcome these limitations and thanks to interviews with officials involved in crisis management, we developed a geospatial simulator for visualizing, measuring and analyzing the impact of crowdsourcing for disaster management. Our work follows an agent-based modeling and simulation (ABMS) approach [4] allowing to capture the complexity of the crisis universe: the different actors (contributors, citizens and officials) with their variable and parallel behaviors, their interactions protocols and the representation of the evolving environment. It also allows officials to conduct what-if scenarios (exploratory, predictive or normative) interactively.

Our simulator is designed to be used by the authorities in charge of the crisis response to prepare coordination plans, or to react to an imminent flood in their locality. In such situations, hydrologic and meteorological data to predict the dynamic of the flood represented in the simulation. Based on output indicators and the dynamic visualization of the map, representing the flood's impacts on the population and the infrastructures, authorities are then able to evaluate different scenarios and determine the most adequate contributors' configuration.

More precisely, *the contributions of our work* are as follows:

- *A conceptual model* representing the agents (citizens, contributors, official responders), their interactions and the dynamic environment (river, flooded areas…) in which they evolve. Task allocation is represented by the contract net communication protocol [11].
- *A simulator implementing the previous model* with the Gama multi-agent platform [4] that allows spatial visualizations of the simulations based on GIS real-world data. Our user interface also allows to try different what-if scenarios, and visualize different output metrics.
- *A set of experiments* applied to a real case study validates and demonstrates the interest of our approach. It is about a flood that took place in the Southern French City of Trèbes in October 2018. In our experiments, contributors have three possible tasks: informing citizens to increase their awareness of the event, helping them to shelter and closing roads to help traffic regulation.

The remainder of the paper is organized as follows. Related works, about crowdsourcing and ABMS applied to disaster management are discussed in Sect. 2. Our conceptual model is described in Sect. 3. The simulator interface and its context of use are presented in Sect. 4. The experiments and validation are presented in Sect. 5. A discussion about our work concludes the paper in Sect. 6.

2 Related Work

The concept of Crowdsourcing is gaining widespread popularity to complete cooperatively complex activities. Besides research interests, crowdsourcing also has a practical relevance notably in information technology, business, education, health and more recently disaster management [1].

In the context of *disaster management*, numerous crowdsourcing tools and platforms (Ushahidi, Tweet4Act, CrowdTasker, RE-ACTA, Staying Alive, GDACSmobile…) have been developed and several of them have been used during one or several steps of the crisis life-cycle (mitigation, preparedness, response or recovery) see [1, 2, 6] for a review. [2] presents lessons learned from an exercise using a combination of two tools (Crowdrasker and GDACSmobile). Tools are either *information-oriented*, by providing means to gather, aggregate or check information, or *task-oriented* by delegating to volunteers collective physical tasks in the field (alerting, rescuing, sheltering, food distribution…). Our simulator is task-oriented and could be used at different steps of the life-cycle: to prepare coordination plans, organize an imminent reaction with what-if scenarios, or replay past events to better understand what happened. Its objective is to improve the coordination of volunteers in a geo-spatial context: physical distribution and task allocation (informing the population in their houses or in the streets, helping them to shelter).

While geo-spatial crowdsourcing [7] has been addressed in the literature, existing works mainly concentrate on optimization aspects (task allocation, information accuracy improvements) without considering the disaster context and linking the solutions to their possible consequences in terms of risks and vulnerability. In addition, as noticed by [8], most of optimization methods rely on idealized models that do not consider uncertainty accurately due to the *variability of human behavior*: actions and movements based on interactions and the dynamic environment state, availability, position… At the opposite, Agent-based modelling brings two interesting features, used in our simulator, that better reflect reality: goal-oriented behavior (e.g., saving population, sheltering…) and high-level interactions between agents with protocols (e.g., matchmaking, contracting protocol). In addition, *the interactivity* provided by our simulator is a key and original feature to associate decision-makers (authorities) to the incremental building of the crowdsourcing configuration. Indeed, we believe that the acceptability of the solution could be improved by providing a visual information space to decision makers and by enabling them to launch what-if scenarios based on their knowledge of the domain and the specific situation.

Regarding the ABMS approach, [13] defines 25 attributes that feature and influence the behavior and coordination of agents representing spontaneous unaffiliated volunteers. It also classifies these attributes into three groups: individual, social and environmental attributes. Even if we didn't take into account all these attributes (e.g. motivation, group affiliation), our agents are able to perceive their environment, coordinate and interact with others, and decide by themselves the actions to perform (e.g. decide to shelter or not, and where). Adding attributes to our model will not change the overall agents architecture and reasoning (see Sect. 3). [12] aims at understanding through simulations the spontaneous volunteers' convergence phenomena according to their motivation and information sharing. The motivation is formalized using the Theory of Planned Behavior (TPB) while our agents have a simple probability-based decision process for accepting or refusing to perform a service. However in [12], authors do not measure the real impacts of their work on the rescue of individuals and their awareness of the situation. They do not formalize either the interaction protocols between stakeholders as we do with the contract net protocol, to coordinate volunteers. Moreover, we provide a more comprehensive approach, taking into account agents, their interaction protocols, their organizations and the environment. Our simulator is also more realistic thanks to a spatialized agent-based model and an interactive interface, more useful for decision makers.

Regarding *ABMS and GIS coupling*, several simulators have already been proposed for floodings [2], bushfires [10], tsunamis [9] but they do not address crowdsourcing (impacts) which remains a key requirement from an official crisis responders' point of view.

3 Agent-Based Model for Crowdsourcing Management

We will present hereafter our agent-based conceptual model for crowdsourcing management in the context of flooding. This model represents the concepts involved and their relationships: agents, the environment, interactions between agents and the environment.

Here, only the environment is specific to flooding while the other concepts are invariant and crisis independent.

We first present the structure of the different entities involved in our model and their relationships, and then the behaviors of the active entities, namely agents, and their interaction protocol. Agents exhibit an autonomous and intelligent behavior that captures uncertainty and improve realism: i) they perceive their surrounding environment, and so can be aware of the situation ii) they decide of their actions (move, shelter, help…) and iii) they communicate with one another through protocols. Part of the model has been elaborated thanks to interviews, we conducted with crisis managers.

Structure of the Entities

The model in Fig. 1 represents, with a UML class diagram, the following aspects:

i) the environment (Building, RescueCenter, RoadSegment, River) and its dynamic state (FloodSituation);
ii) the agents (Citizens, responders Actors: Contributors and Officials) that are able to move, to perceive their environment and act;
iii) the services (tasks) that Actors can provide (skills) and possibly realize.

More precisely, let us detail each class:

- ***Building*:** A building may be affected by a flood, and may host one or several people when its type is residential.
- ***RescueCenter*:** represents a safe public building that will not be affected by the flood, where people can shelter.
- ***RoadSegment*:** corresponds to a portion of a road. It can be used by citizens to move from and to different locations, and may be submerged by a flood.
- ***FloodSituation*:** defines a flooded area at a specific moment. It starts at a predefined time and affects the infrastructures of a predefined area.
- ***River*:** describes a watercourse as a line from where the flood starts and is mainly used for visualization purposes on the map. This entity does not have any activity nor interactions with other agents.
- ***Agent*:** defined by the common attributes and behaviors of the human agents of the model. They notably have a location, a perception radius and they can move according to a speed value.
- ***Citizen*:** regular inhabitant (not involved in crowdsourcing activities), living in the case study area, who may decide to shelter during the flood according to his/her awareness state about the flood. A citizen inherits the attributes and behaviors from agent.
- ***Actor*:** abstract class describing the common attributes and methods of contributors and officials involved in the crisis response. Like a citizen, an actor inherits the attributes and behaviors from agent. An actor can offer several services: close a road, help citizens by sheltering and informing them (at home or in the street).
- ***Contributor*:** an agent contributing to crowdsourcing crisis response activities according to his/her skills and current state.
- ***Official*:** an official person representing the authorities (e.g. professional rescuer, police officer) and taking part in crisis response operations. As for contributors, an official is a subclass of the actor class.

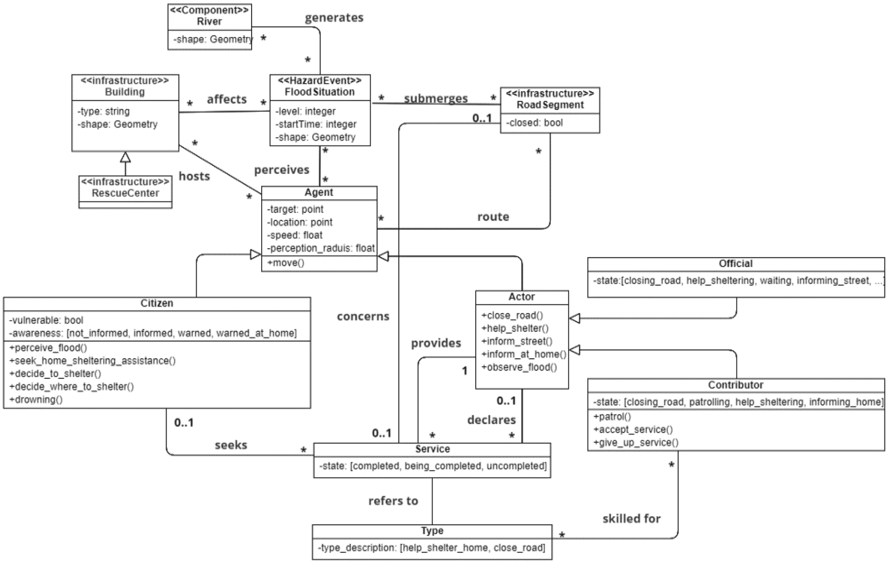


Fig. 1. UML class diagram of the model

- ***Service*****:** describes an assistance task sought by a citizen or a general community (e.g. close a road). A service requires a specific skill, depending on its type, for the completion of the task. Its state could be: "completed", "uncompleted", "under completion"
- ***Type*****:** describes the type of a service.

Agents' Behavior

We will present hereafter the behavior of the active agents: citizen, contributor and official.

Citizen States and Behavior. Figure 2 represents the evolution of a citizen's state according to his/her flood awareness. Initially, a citizen is not informed about the flood. Citizens get the strongest level of awareness when they are warned at home by contributors (who physically visit them at home), and get the lowest level (*informed*) when they perceive the flood by themselves. They become *warned* when they are informed of the flood by phone (at home by officials), or in the street by officials or contributors. According to their level of awareness of the flood, citizens decide to shelter with different probabilities represented by the following parameters:

- $\text{Shelter}_{\text{informed}}$: is the probability of an *informed* citizen to shelter
- $\text{Shelter}_{\text{warned}}$: represents the probability of a *warned* citizen to shelter
- $\text{Shelter}_{\text{warned at home}}$: is the probability of a *warned_at_home* citizen to shelter

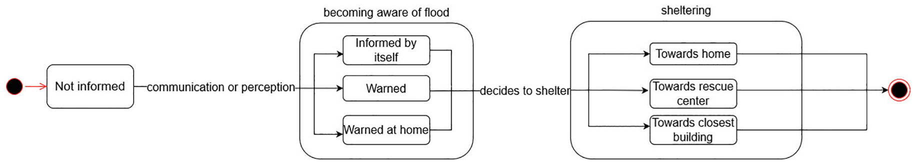


Fig. 2. Citizen state diagram

Once a citizen has decided to shelter, he/she chooses the nearest sheltering location (home, rescue center or other safe buildings).

Contributor States and Behavior. The states are summarized in Fig. 3. Initially, a contributor is patrolling in the area using random successive destinations. This state consists in the following on-field activities: observing the flood, creating a *close_road* service if a road is submerged, and informing citizens in the street about the flood. Once the predefined time for informing citizens at home has been reached, a predefined proportion of contributors starts a walking tour to inform the citizens directly at home. When contributors have finished their home informing tour (they have visited all the buildings to inform in the flood-prone area) they recover their initial *Patrolling* state. While they are informing citizens at home or patrolling, contributors can interrupt their activity to accept a service: *closing road* or *help sheltering*. When the service is completed or if the completion failed, contributors recover the original state they were in before accepting the service.

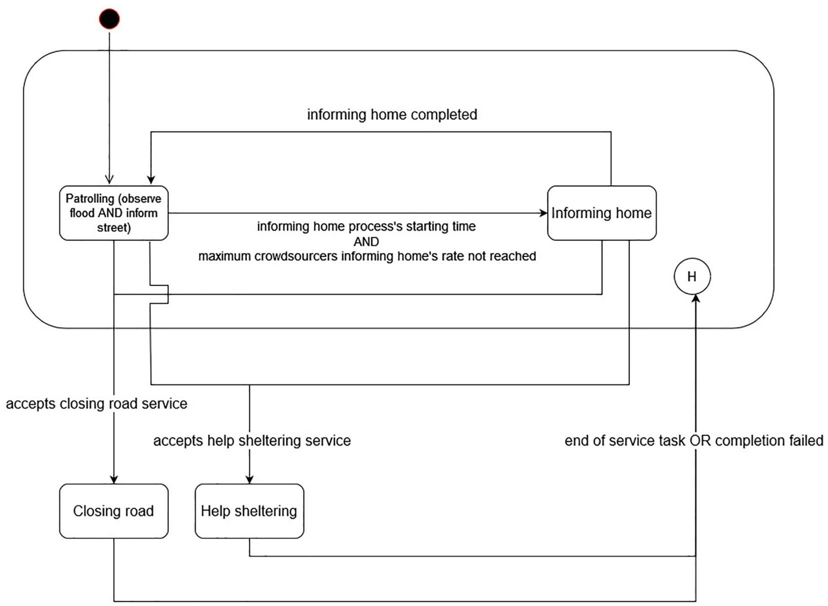


Fig. 3. Contributor state diagrams

Official States and Behavior (See Fig. 4). The initial state for officials is to be waiting for interventions. When the predefined time for informing citizens at home has been reached, officials who have this role start to phone to citizens at home to inform them of the flood. This informing citizens at home process is quicker than the volunteers' informing home process. However, officials are less likely to reach citizens on the phone and thus inform them. Similarly, to the informing home process, when the predefined time for informing citizens in the street has been reached, officials having the corresponding role start informing citizens in the street. They remain in this state until the end of the simulation.

When officials are waiting, they can be allocated task services to complete. Unlike contributors, officials have no choice to accept or refuse a task service and must accept it. When the task is performed, officials recover their waiting state.

At any time (in any state), officials keep observing the flood. Unlike volunteers, officials' flood observations are not performed on the field. One observation comes up randomly among flooded roads every 15 min and results in the creation of a *close_road* service for the observed flooded road. This process aims at reproducing the way authorities are being informed of field situation by the population in real situations.

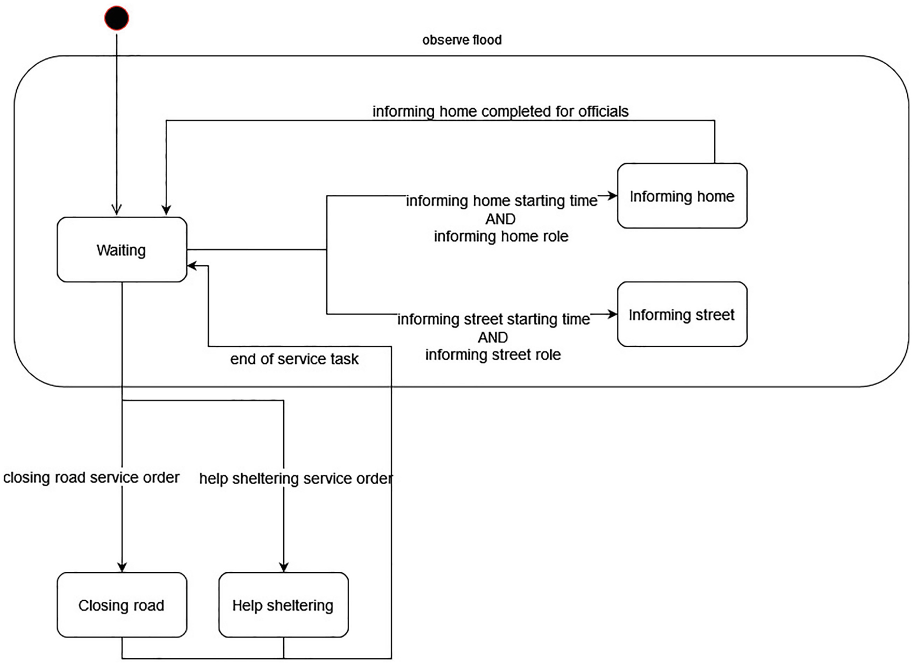


Fig. 4. Officials state diagram

Task Allocation Protocol

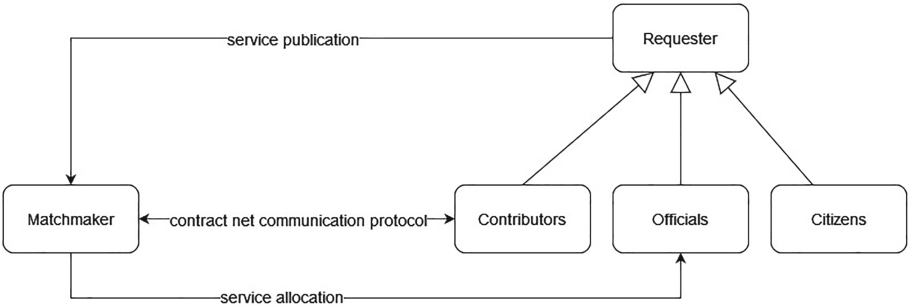


Fig. 5. Service publication diagram

As described in Fig. 5, services are created and published to the matchmaker by contributors, officials and citizens, who are represented by the requester class, The requester class is not implemented in the model and is represented on the diagram only to facilitate its reading. When a service is published, the matchmaker tries to allocate it either to officials (in priority), i.e. through an order, or to contributors through the contract net interaction protocol (see Fig. 6). The matchmaker class corresponds to the manager agent of the Gama model, which is basically the main program of the model orchestrating simulations.

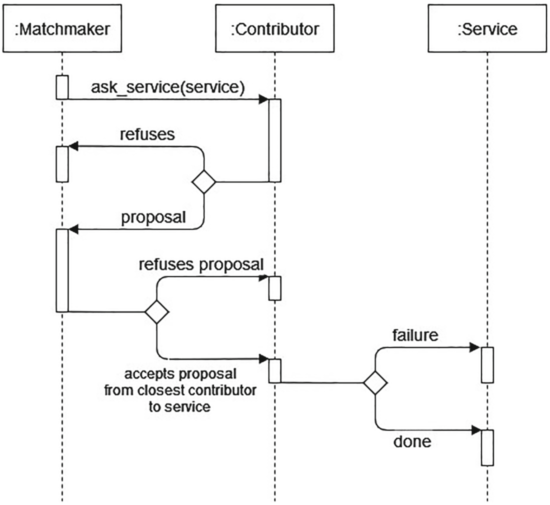


Fig. 6. Sequence diagram of the contract net interaction protocol used to allocate services to contributors (adapted from [3]).

The services allocation process uses the contract net interaction protocol (defined by [11]) and depicted in Fig. 6 (UML model adapted from [3]). The principle is that the manager (here matchmaker) sends the specification of a task (service) to several agents (here contributors), waits for proposals from some of them and then chooses one of them to whom the task is subcontracted. In our context, at each time step of the simulation, the matchmaker sends requests to contributors. The service specification contains the type of service and its location. Each Contributor may accept to perform a service depending on his/her availability, on whether or not the location is safely accessible (without having to cross flooded areas) and on a service acceptation probability. When the matchmaker receives the responses from contributors for a given service, he/she allocates the service's task completion to the contributor who is the closest to the service's location. The elected contributor then performs the service which results in its completion or failure.

4 The Simulator Engine and Interface

4.1 The Simulator Engine

The main program initiates the simulation with the creation of all the agents of all the different classes of our model (see Fig. 1). When the simulation is launched, at each timestep, all the agents automatically compute the methods representing their behaviors (e.g. the "drowning" or "perceive_flood" methods for citizens) known as reflex methods in the Gama terminology. The execution of the reflex methods is sequential and follows the creation order of the agents performed at the initialization.

4.2 The Simulator Interface

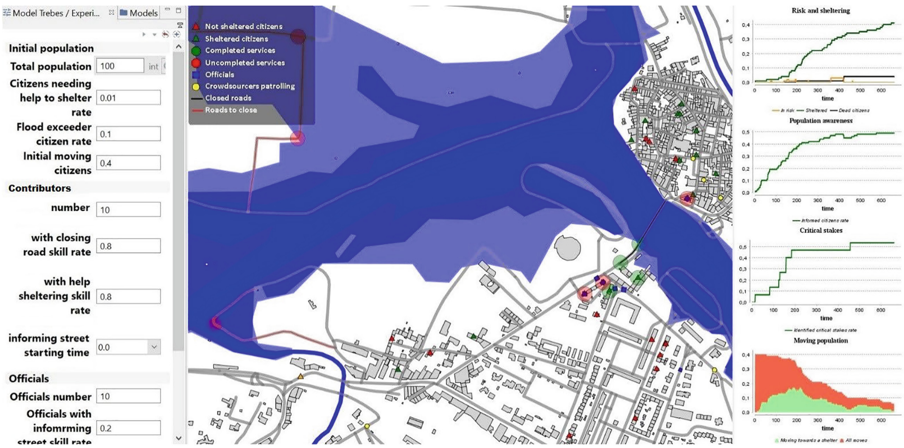


Fig. 7. Interface of the crowdsourcing-based flood management model under the GAMA platform with input parameters (left hand side), real-time chart indicators (right), and dynamic map of the case study area with simulated agents (contributors, citizens, officials) in the middle.

The interface allows to visualize the environment of the studied area (road network, buildings, rivers), the spread of the flood, the location and state of citizens (e.g. level of awareness about the flood, sheltered or not), the location and state of contributors and officials (movements and activities they are involved in) and of services (completed, being completed or uncompleted) (Fig. 7).

Input Simulation Parameters. The main input parameters, specified at the initialization of the simulation and used to define the initial population are for each type of actor, as follows:

- *Population (citizens):* total population, percentage of citizens needing help to shelter, percentage of citizens initially moving.
- *Contributors*: total number, percentages of them offering the following services: "closing road", "sheltering", "informing citizens at home"; maximum rate of contributors informing citizens at home; starting time for informing citizens at home.
- *Officials:* total number, percentages of officials involved in the following services: "informing citizens in the street", "Informing citizens at home"; starting time for informing citizens in the street; "starting time for informing citizens at home".

Output Indicators. The indicators used to evaluate the different crowdsourcing scenarios are the following:

- *Dead and sheltered citizens graph:* represents the evolution of the percentage of sheltered and dead citizens
- *Population awareness graph:* represents the evolution of the percentage of citizens aware of the flood, whether they are *informed*, *warned* or *warned at home.*
- *Percentage of identified critical stakes graph:* this indicator is used to give an insight about authorities' situation awareness. In our experiments critical stakes are defined by 12 vulnerable citizens that need help to shelter and 3 strategically chosen roads (crossing or near the rivers) that need to be closed. A critical stake is considered as identified/discovered when an associated service is created either to close the corresponding road or to help the corresponding vulnerable citizen to shelter.

5 Validation and Experiments

5.1 The Trèbes Case Study

As mentioned before, our model is evaluated using real world data from a flood that took place in the Southern French town of Trèbes in October 2018 where 6 deaths and consequent material damages were recorded. The flood that occurred in Trèbes was caused by a rainfall event. The water level started to rise on the 14th of October at approximately 11:00 pm and reached its maximum level at 5:25 am on the 15th of October.

The data of the simulation scenario are based on feedback report of the Trèbes event. As we focus on the study of the response phase of the crisis management and in order to reduce computational time of simulations, we consider a relatively small time frame (3 h and 45 min), starting at the beginning of the flood (when the flood threshold is reached), and terminating 30 min after the maximum water level has been reached. In addition, we launched our experiments with a reduced but representative population, 1000 citizens, instead of the approximate number of 5500 inhabitants living in the area.

For the other inputs, real data of the Trèbes event are used:

- The IGN (National Institute of Geographical Information) BD TOPO® database provides GIS data representing different aspects of the study area (buildings, roads, and rivers);
- the feedback report provides the dynamics of the flood, i.e. the evolution over time of the areas covered by the flood (provided through shapefiles);
- Approximation based on data from the national statistics bureau of France INSEE (National Institute of Statistics and Economic Studies) provides us demographic and sociological values for parameters such as the number of vulnerable people (provided through input simulation parameters).

5.2 Experiments and Results

Scenarios. To demonstrate the advantage of using crowdsourcing for flood crisis management, two scenarios, defined by the absence or presence of contributors, are studied. The first scenario, abbreviated as "*without CS*" (without crowdsourcing) only involves professional rescuers, called *officials,* in the response effort while the second one, referred to as "*with CS*" involves both contributors and professional rescuers. All the actors are randomly geographically distributed.

The two scenarios are evaluated with the same population characteristics, synthetized as follows:

- Number of citizens: 1000
- Rate of citizens needing help to shelter (rate): 1%
- Rate of Citizens not reacting to the flood: 10%
- Rate of initially moving citizens: 40%
- Number of vulnerable citizens: 12

The scenario without crowdsourcing consists in 50 officials involved in the response effort. 10 of them have an informing-home role and 10 others have an informing-street role. Both groups start their activities, informing home and informing street, at the beginning of the simulation.

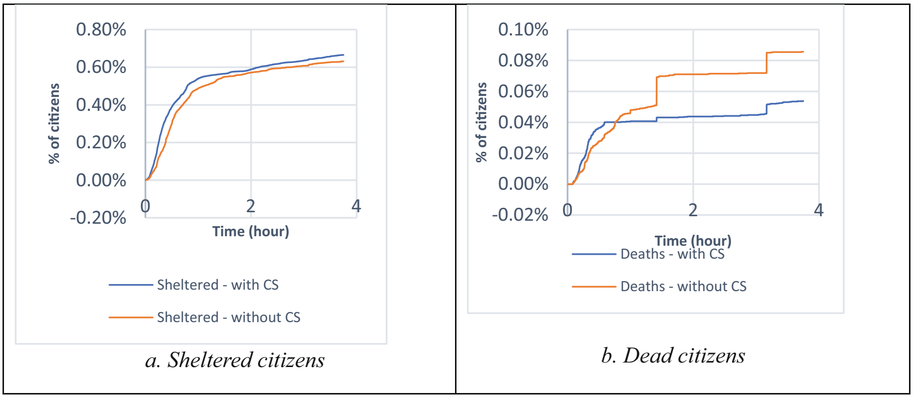
The scenario with crowdsourcing consists in the same officials' configuration as the latter one and involves 100 contributors. 80% of the contributors have the capacity (skill) to close a road and to help citizens to shelter at home. A maximum of 20% of them can be allocated the informing activity of citizens at their home. As for officials, this activity starts at the beginning of the simulation.

For each scenario, we launch five simulations and aggregate the results to obtain the average values of each indicator. We then compare the two scenarios by superposing the obtained average graphs for each indicator.

Scenarios Analysis

Influence of Crowdsourcing in the Percentage of Sheltered and Dead Citizens. From

Fig. 8a, we can draw the following observations. The presence of contributors allows to shelter more citizens and more rapidly. After 47 min, 50% of the population is sheltered with crowdsourcing, while 1 h and 6 min are needed (19 more minutes) to reach the same proportion without crowdsourcing. The final rate of sheltered citizens also tends to be relatively higher with crowdsourcing with 66.5% (665 persons) of the population sheltered, compared to 63.1% (631 persons) without crowdsourcing: this represents 34 additional persons sheltered thanks to crowdsourcing. This difference could be higher if contributors started their service before the arrival of the officials, which is sometimes the reality since contributors are most often citizens of the impacted area.



a. Sheltered citizens *b. Dead citizens*

Fig. 8. Sheltered and dead citizens

The total number of deaths (cf. Fig. 8b) represents 5.4% of the population with crowdsourcing and 8.6% without. In other words, the presence of contributors allows to save 32 persons in comparison with the scenario involving only professional rescuers.

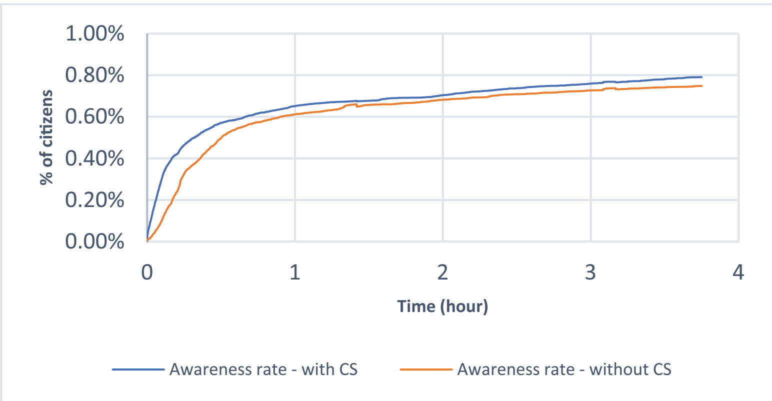


Fig. 9. Population awareness evolution

Influence of Crowdsourcing in Population Awareness. The analysis of Fig. 9 reveals that the presence of contributors enhances the diffusion of flood-awareness: more citizens are aware of the flood more rapidly. 50% of the population is aware of the flood after 19 min with crowdsourcing, while 30 min are needed to reach the same rate without crowdsourcing. The final number of aware citizens is also slightly higher in the crowdsourcing scenario, with 42 more citizens being aware.

In both scenarios, the final number of citizens aware is higher than the final number of sheltered citizens: for the crowdsourcing scenario 790 (79.0%) citizens are aware while 665 (66.5%) are sheltered; for the officials-only scenario 748 (74.8%) citizens are aware whereas 631 (63.1%) are sheltered. This corresponds to 125 (12.5%) and 117 (11.7%) citizens who are aware but not sheltered at the end of the simulation respectively in the crowdsourcing and the officials-only scenario. This difference highlights two elements. Firstly, the sheltering of citizens process is not immediate (some citizens can be aware and engaged in a sheltering process, but not yet sheltered). Secondly, although citizens are aware, they might not decide to shelter according to their sheltering decision probability (see description of *Fig. 2. Citizen state diagram*).

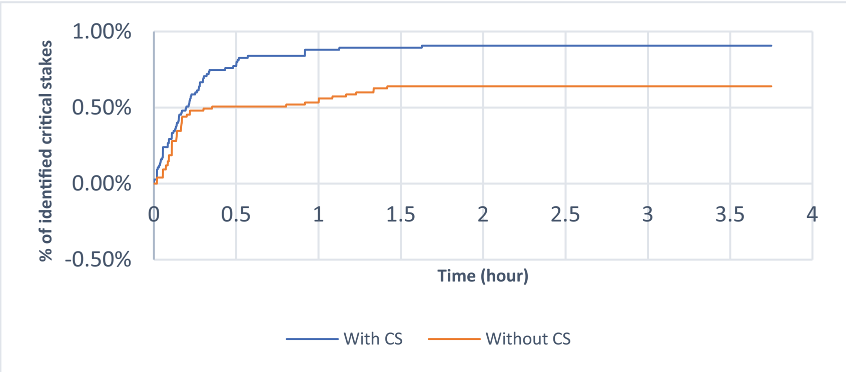


Fig. 10. Critical stakes identification

Influence of Crowdsourcing on the Identification of Critical Stakes. Figure 10 enlightens the positive impact of crowdsourcing on the authorities' situational awareness. Indeed, on-ground information (critical stakes in this case) is gathered quicker and in a higher volume. 50% of the critical stakes are discovered after 12 min with crowdsourcing, whereas the same proportion is reached after 21 min without their contribution. In average 90.7% of the critical stakes is discovered with the help of contributors, while only 64.0% without their help.

6 Conclusion and Discussion

In this paper, we have proposed a new approach aiming at developing a generic agent-based model to simulate and measure the impacts of crowdsourcing in flood crisis management. The main interest of our simulator is to provide a visual and shared information space on top of which decision makers can simulate and visualize floods interactively and incrementally elaborate a coordination policy thanks to what-if scenarios.

We used a real-world case study to evaluate our model and launched *several* experiments that underlined the interest of using crowdsourcing in flood crisis management through output quantitative indicators. The results have showed that the presence of contributors allows to increase the level of the populations' flood-awareness and the number of sheltered citizens. Moreover, sheltering activities were speeded up. In addition, a reduction in the number of dead citizens was observed and the authorities' situational awareness was improved both in terms of the number of stakes discovered and the discovering speed.

In future work, we would like to represent additional realistic characteristics and psychological factors in the population, such as: family links, motivation, emotion, etc. Additional interaction protocols (vote, negotiation…) could also be included to allow the authorities to select the most appropriate one according to the situation.

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