Overview, design concepts, and details (ODD) protocol for the agent-based model

Supplement to:
Unravelling the influence of human behaviour on reducing casualties during flood evacuation

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1. Overview

The study "*Unravelling the Influence of Human Behaviour on Reducing Casualties during Flood Evacuation*" presents an explicit Agent-Based Model (ABM) developed in the GIS Agent-based Modeling Architecture (GAMA) platform. This software has its own comprehensive Java-based domain-specific language called GAML and is freely available at https://gama-platform.github.io/. The model is original of this paper and has not been previously published.

This appendix shows the Overview, Design concepts, and Details (ODD) protocol presented by Grimm *et al.* (2006, 2010) as a common framework for ABMs and Individual-Based Models (IBMs) description. The ODD protocol is subdivided into seven elements in sequence: Purpose, State variables and scales, and Process overview and scheduling that are part of the block Overview; Design concepts inside of the block Design; and finally, Initialization, Input and Sub-models that are part of the block Details. The overview block contains the context and general information; the design block consists of the strategic considerations; and finally, the technical details are embedded into the details block.

2. Purpose

The purpose is to explore the effect of people's behaviours, lead-time of the flood warning and time of the flood onset in the flood evacuation process. The objective is to provide the Civil Protection members and emergency planners with a tool to design flood emergency plans under a variety of plausible scenarios. Currently, one of the greatest concerns in the design of these plans is the accountability of people's behaviour, hazard and environment conditions to ensure a smooth evacuation. In this regard, an ABM is a comprehensive modelling framework suitable to assess the role of the three above mentioned factors in altering the efficient movement of evacuees towards the shelters increasing the number of casualties.

3. State variables and scales

The model focus on a small region of Umbria (Italy) that covers the municipalities of Ciconia, Sferracavallo, Orvieto Scalo, Orvieto, and Fontanelle di Bardano with an extent of approximately 63 Km^2. This region suffered the last 200-year flood event in 2012, after which a levee system was built and inaugurated in 2017. This model is made of low-level entities characterized by low-level variables. In GAML language entities are called agents which collectively form a species. There are eight entities: one entity made by the inhabitants of Orvieto Scalo and Ciconia, and seven entities part of the environment including the buildings, temporary shelters, shelters, rivers, roads, flood boundary and flood event.

All inhabitants are part of the species “people” and have assigned two low-level variables that define their socio-demographic characteristics: employed and having a child. When aggregated, inhabitants create a population of 1000 individuals.

The model world has a unique agent from species global that triggers the main process (i.e. start flood and send warning). This model world contains the buildings, temporary shelters, shelters, rivers and roads. The flood boundary and flood are intermittent emerging only when the flood event takes place. There are 2171 buildings, 9 temporary-shelters, 12 temporary shelters and 1586 bidirectional roads. The temporary shelters differ from the shelter in its location and purpose. Temporary shelters are at the convergence of flooded roads where civil protection members ensure that no individual crosses the river.

Variables and methods of the species have been summarized in a Unified Modeling Language class diagram (UML) found in Figure 3 of the manuscript. This data has been collected from the Civil Protection Department of the Region of Umbria, OpenStreetMaps, the literature and the authors' judgement.

4. Process overview and scheduling

Individuals are the highly complex entities of the model. According to its socio-demographic characteristics, they perform a daily routine that starts approximately at 7:00 a.m. until approximately nine hours after. They move towards their destination using a road network. The GAML function “goto” is used for this purpose.

During the day or night, a flood event might occur disrupting the inhabitant's daily routines. Once the flood warning is issued, each inhabitant reacts with one of these four behaviours: normality bias, straightforward, sympathy or indifferent behaviour. The straightforward behaviour characterizes individuals who evacuate immediately after receiving the warning. The normality bias behaviour corresponds to individuals who evacuate some time after the flood warning is issued. Normality bias behaviour has imbedded an altruistic behaviour because some inhabitants may decide to pick up their children from the school before heading all together to the shelter. Inhabitants with sympathy behaviour follow another agent evacuating ahead. Finally, the inhabitants with indifferent behaviour not evacuate when received the warning. Once the behaviours are assigned, the inhabitant creates a “map” with the distances to the shelters on the same side of the river where the agent stands.

To start the evacuation process, the triggers are: (1) obeying the flood warning (for straightforward and normality bias behaviours); observing the flood event (for any type of behaviour); and, (3) following another agent evacuating ahead (for sympathy behaviour).

An evacuee moves the shelter using the “goto” GAML function. The evacuees with normality bias behaviour who decide to pick up their children move firstly to a school or a temporary shelter (if the school is the other side of the river where the inhabitant is standing) before heading to the shelter.

At the end of the simulation, the inhabitant has one of these three statuses: evacuated, no evacuated or drowned. When the inhabitant reaches the shelter, its status becomes evacuated. If an inhabitant finishes its daily activities without complying with the flood warning and without being affected by the flood, its status turns into “no evacuated”. Finally, an agent is considered to be drowned if it is covered by 1.5 m of water at any time within the simulation. Once the agent has one of these three statuses, its interaction in the simulation finishes.

This model is time-step dependent with two fixed schedule actions, sending the warning and the flood onset. The time step, also called cycle, is 1 minute. All the simulations start at 7:00 a.m. and finish 15 hours (900 cycles) after the flood onset.

5. Design concepts

Objectives: this design concept brings up the objectives of the agents. The initial objective of the individuals is to perform their daily routines. When they decide to evacuate, their objective change to reach a shelter. They choose with an 80% probability the closest shelter, and with a 10% another shelter.

Emergence: refers to the system-level phenomena that truly emerge from individual traits and to the phenomena that are merely imposed (Grimm *et al.* 2006). Bias in behaviours (straightforward, normality bias, sympathy and indifferent behaviours) is imposed as proportions of agents. The behaviour of individuals is represented by theoretical rules described as probabilities, for example, the probability to pick up the children (50%) and the probability to choose the correct shelter (80%). Other emergence imposed by the model rules come from the hydraulic model that defines flood extent and water depths at locations in this extent.
The emergence arises in the selection of destination that varies between individuals, and the interaction between them on their way to that destination. Traffic jams may emerge when an important number of individuals with sympathy behaviour follows the agent ahead.

Sensing: refers to the internal knowledge and sense capacity of environmental variables that the agents have and consider in their decisions. Individuals know their socio-demographic characteristics and consequently the daily routines to perform. Moreover, individuals sense a flood warning issued by the local authority and sense an approaching flood at a distance of 100m.

Interactions: there are two interactions modelled explicitly: the individuals interacting with each other when driving; and individuals with sympathy behaviour following another individual evacuating ahead.

Stochasticity: the daily routines and behavioural parameters are determined by probabilities and randomness. For example, selection of destination and time of departure to perform the daily routines is not equal among agents. Agents choose with a high probability (80%) the closest shelter assuming that are familiar with their environment, and when evacuating, agents may stop to pick up their children from the school with a probability of 50 %. The selection of probabilities are our smart guesses as Vorst (2010) suggests that happen for most evacuation models with a Human Factor.

Adaptation: appeals to the adaptive attributes of the individuals in response to changes (Grimm et al. 2006). The individuals adapt their driving speeds based on the congestion on the roads. At the same time, individuals can recompute their path on the road network when they encounter a flooded road. Also, they adapt to the flood warning by changing their daily schedule to move to shelters or to pick their children from school. These adaptations seek to increase their evacuation success.

Observation: there was no availability of field or empirical data to parameterize some variables such as the evacuation behaviours. This data has been gathered from disaster psychology literature. The data analysed from the model is the time in which the inhabitants reach the shelter and the time and location where the inhabitants drowned. Results are exported in CSV format.

6. Initialization

This subsection refers to the creation and initialization of the environment and entities at the start of the simulation. The spatial elements of the municipalities were uploaded in shapefile format and inhabitants' data in CSV format. As an exception, the flood event was uploaded as shape and transformed into a grid (50m x 50m) updated every 10 minutes (or cycles).

For visualization and spatial calculations, each entity is assigned with a geometry (shape). The initialization of global variables such as the ones defining the flood onset or flood warning depends on the scenario, and therefore are not always the same.

7. Input

The dynamics of the model are driven by the flood event. Flood maps were generated using a 2D hydrodynamic model built-in the Hydrologic Engineering Centre's River Analysis System (HEC-RAS) software. Hydrographs corresponding to a 500-year flood event are the input data for the hydrodynamic model.

8. Submodels

There are two models and both of them relate to traffic modelling. The first model addresses the movement of agents. Agents follow the meso-scale traffic model of "Underwood-Forward Random Model" proposed by Banos *et al.* (2017)

$$u = u_f \, \mathrm{e}^{\left(\frac{k}{k_0}\right)} \quad (1)$$

where u_f is the free-flow speed in a road with no traffic, k is the current concentration of the road, and k_0 is the maximum capacity of the road.

The second model is a geometric correction applied to the road network. The road network for this study was downloaded from OSM and it contained only the centreline geometry. To apply "Underwood-Forward Random Model", the network was modified to contain two parallel lines, one in each traffic direction, by drawing a parallel line to the existing centreline from OSM. A similar method was used in Bhamidipati *et al.* (2016).

References

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