Overview, Design, and Details. Protocol to describe the stylized Agent-Based model of the MEGADAPT project

Introduction

This document provides a detailed description to use the NetLogo implementation of the stylized example of the MEGADAPT model. The model simulates the coupling between the decision-making processes of institutional actors, socio-political processes and infrastructure-related hazards. We describe details of the theoretical implementation, including its purpose, and objectives (Grimm et al., 2006), and we define the hypothetical multi-attribute landscape, the description of the procedures and its scheduling, and the initial conditions of the landscape and location of neighborhoods.

The model simulates the decisions of residents and a water authority. Neighborhoods are located in a landscape with topographic complexity and two problems: water scarcity in the peripheral neighborhoods at high altitude and high risk of flooding in the lowlands, at the core of the city. The role of the water authority is to decide where investments in infrastructure should be allocated to reduce the risk of water scarcity and flooding events in the city, and these decisions are made via a multi-objective site selection procedure. This procedure accounts for the interdependencies and feedback between the urban landscape and a policy scenario that defines the priorities that the authority places on four criteria (see the main document).

Neighborhoods respond to the water authority decisions by protesting against the lack of investment and the level of exposure to water scarcity and flooding. Protests thus simulate a form of feedback between local-level outcomes (flooding and water scarcity) and higher-level decision-making. Neighborhoods are located in a landscape with spatially-correlated topographic variability, that is, a landscape with hills and valleys, where neighborhoods at high altitude are more likely to be exposed to water scarcity and lack infrastructure, whereas neighborhoods in the lowlands tend to suffer from recurrent flooding. The frequency of flooding is also a function of spatially-uniform rainfall events. Likewise, neighborhoods at the periphery of the urban landscape lack infrastructure and suffer from the chronic risk of water scarcity.

How does it work?

Every 10 time-steps, defined as a decision cycle, the problem of whether each neighborhood is suitable for infrastructure investment is solved by the water authority using a multi-criteria evaluation.

Then, by sorting neighborhoods according to a distance metric, the procedure selects the number of neighborhoods that maximizes the return on investment and meets budgetary restrictions. Budget conditions are represented by the number of neighborhoods the authority can respond to in a single time-step given budget constraints. Investment in maintenance or construction of new infrastructure modifies the conditions for the provision of potable water and sewer systems in the selected neighborhoods.

Overview

Model objective

The model is inspired by the empirical model developed in the MEGADAPT project (http://megadapt.weebly.com/). The goal of the project is to understand how the decisions of dominant actors of the Mexico City water governance system influence socio-hydrological vulnerability. The objective of this model (https://github.com/sostenibilidad-unam/abm2) is to understand how the vulnerability patterns of an urban environment subjected to risk and exposure associated with water are influenced by the decision-making process of a central authority that manages water-related infrastructure. We focus on the feedback that emerges between the decisions of the water authority and a socio-political factor defined as resident protests, which is driven by their exposure to flooding and scarcity.

Agents, patches, and state variables

There are two types of agents in the model: 1) neighborhoods that experience hazardous events (specifically, scarcity of water and flooding) and 2) a central agent representing a water authority (WA) that has the goal of reducing the risk of hazards by investing limited resources in repairing and creating new pieces of infrastructure in the landscape. These decisions are made by evaluating the state of the system using a multi-criteria decision method.

The topographic configuration of the landscape can be set to three types: a closed watershed with a lower valley in the center and a radial increase in altitude towards the edges; a gradient, in which case it creates a landscape with longitudinal but not latitudinal changes in altitude; and a landscape with many hills, in which case the model selects at random four patches of high altitude and creates valleys using the function diffuse In the Netlogo library. Urban neighborhoods can be supplied with potable water or sewer infrastructure, which in turn reduces the risk of water scarcity and episodic events of flooding. The water authority can take two actions: it can repair the local infrastructure in the neighborhood to reduce flooding or to supply water, and it can create new infrastructure.

Process overview and scheduling

When the model is initiated, the landscape and the location of the neighborhoods are set using the "Create-Landscape" and "Create-District-Infra" procedures. The "GO" procedure activates the sequence of procedures to simulate the dynamics of the system: (ticks in NetLogo). First, the "To-Rain" procedure generates a climatic event drawn from a probability distribution and converted to a standardized scale of risk factors between 0 and 1. The second procedure to be activated is "Hazard". This procedure determines the probability that a flood occurs in each neighborhood and calculates the exposure.

The next procedure, "Vulnerability", updates for every neighborhood and is the accumulated exposure to both issues (flooding and scarcity). The "To-Protest" procedure determines if protests emerge in the neighborhoods, and it computes the level of social pressure, which is defined as the accumulation of protests in a neighborhood over time. The level of social pressure is directly proportional to the level of exposure, the investments made by the water authority, and the tolerance of the residents to exposure. The procedures needed for the water authority agent to calculate the suitability assessment are "Surveillance" and "WA-decision". The "Surveillance" procedure retrieves the attributes of the landscape that define the criteria needed for the water authority to invoke the suitability analysis. The "WA-decision" procedure standardizes the criteria and calculates the metric of decisions to select neighborhoods. This metric is calculated for each neighborhood based on the value of the criteria, the priorities, and the value functions. Once the metric is calculated for each neighborhood, an optimization procedure is invoked to select the neighborhoods for investment. After the neighborhoods that will receive investments have been identified, the water authority modifies the value of the attributes of the landscape (age and provision) according to the actions taken (maintenance of, or provision of new, infrastructure).

Finally, the "Update-global-and-reporters" procedure updates the indicators of performance, and the procedure "Update-infrastructure" updates the condition of the infrastructure that defines the risk factor related to infrastructure conditions.

Design

Basic Principles

The principles that dictate the actions of the water authority are built on defining and calculating a metric of decisions with theoretical foundations in multi-criteria decision-making theory and analyses (MCDA). The aim is to utilize the machinery of MCDA tools to include systematically multiple agents affecting and being affected by climate related hazards (flooding and potable water shortages).

Emergence

Spatial patterns of infrastructure condition, and subsequent risk and social pressure areexpected to emerge because of the feedback between investments, socio-political processes and decisions. The variables expected to show emergent properties are, the age of the infrastructure, the socio-political pressure, and the level of exposure.

Observation

Institutional agents observe the attributes of the landscape associated with the MCDA model (policy). These agents observe attributes of the landscape associated to the criteria of the multi-criteria model. These criteria includes, the average number of protests per neighborhood, the level of inequality in exposure, the average age of the infrastructure, and the number of neighborhoods with functional infrastructure Similarly, socio-political agents observe the level of exposure and the actions of the socio-institutional agents in their local spatial unit.

Interactions

Residents are linked to the water authority by demanding actions via protesting. The water authority responds to the protesters by considering social pressure as a criterion. The policy implemented will determine the importance the socio-institutional agent gives to social pressure, through the value of the criteria weights.

Scheduling

In each time-step (tick), the exposure is calculated for each neighborhood, followed by the protests of the socio-political agent, and finally, the socio-institutional agent executes the action of maintenance. Every 10 time-steps in a simulation correspond to a single decision cycle. In each decision cycle, the water authority invokes the suitability assessment and the site-selection procedures that will define the neighborhoods selected for investment until a cycle is completed.

Stochasticity

Climatic events are random realizations obtained from a log-normal distribution. The frequency of flooding is associated with the magnitude of the climatic event. Protests are created when the tolerance surpasses the value of a random variable simulated using a uniform distribution.

Details

Initialization

Neighborhoods are placed randomly in the landscape with a probability inversely proportional to their altitude in the landscape. In addition, the age and provision of infrastructure are proportional to the neighborhood's altitude. Specifically, the probability that a neighborhood j has infrastructure provision decreases with altitude:

$$\rho_{jvt=1} = \begin{cases} 1\ if\ X > \gamma_j \\ 0\ otherwise \end{cases},$$

where ρ_{jv1} tracks the presence or absence of infrastructure system v in neighborhood j at time $t = 1$ γ_j is the standardized score (obtained through a decreasing linear function) of the elevation at neighborhood j, and $X \sim U([0, \breve{\sigma}])$ is a random number from a uniform distribution. Parameter $\breve{\sigma}$ controls the provision of infrastructure to neighborhoods at high altitude. In addition, the model initiates assuming an aged infrastructure that decreases in age in neighborhoods at high altitude to represent differences in age as the urban landscape grows. Formally,

$$\lambda_{jvt=1} = \tau_I(1 - \gamma_j),$$

where λ_{jv1} is the age of infrastructure system in neighborhood j at time $t = 1$. τ_I is the maximum initial age, and γ_j is the standardized score obtained through a decreasing linear function of the elevation.

These initial conditions aim to create landscapes inspired by the Mexico City landscape, also present in many other megacities of the developing world. These are areas with highly-densified cores with aged infrastructure, and with a less populated periphery that often lacks infrastructure provision.

The user can choose the initial condition of the infrastructure, from a new ($\tau_I = 10$) to an old system ($\tau_I = 100$). The user can also choose between three types of landscape: one with many hills, as used in the main document, one with a gradient, and one with a watershed.