**The ODD protocol**

This model description follows the ODD (Overview, Design, Concepts and Details) protocol by Grimm (2010,2006) to facilitate the reproducibility of agent-based models.

1. **Overview** 
   1. **Purpose**

This purpose of this agent-based model is to understand the micro-level processes contributing to the emerging yet limited diffusion of adaptation practices among transit agencies. It uses the empirical setting of transit agencies adapting to extreme weather events through resilience-enhancing capital investment against extreme weather impacts.

* 1. **Entities, state variables and scales** 
     1. **Agents**

The model contains two types of agents: transit agencies and solutions. The grid is separated into four quadrants representing the four Census regions in the US. Transit agencies are distributed to their corresponding region represented on the grid. From the very beginning, each of transit agencies are attached to a solution which copes the immediate impacts of extreme weather events. Adaptation solutions are randomly distributed across the grid, with a higher efficacy value than the coping solutions. Agents are heterogenous in their capacity, the efficacy of the coping solution they are attached to, their natural environment and the level of accepted risk. The agent attributes are given in Table 1.

The model also contains three types of links: 1) among agencies in the same region; 2) among agencies located in difficult regions; 3) among agencies and the regional office from Federal Transit Administration. The links do not have attributes and are only used in agencies’ search for adaptation solutions.

five types of agents: transit agencies, solutions, opportunities and problems. The main entities in the model are transit agencies. Agencies have a set of state variables relating to their experience with extreme weather, their perception of risks given the weather experience, their capacity to implement certain solutions. The solution agents represent the alternative solutions available to the agencies through their search or innovation process. They are characterized by cost of implementation, efficiency for problem solving as well as a dummy coded type variable to distinguish adaptation-based solutions from other solutions. The problem agents represent the weather-induced problem an organization faces. Characterized by the level of difficulty, the problem is a function of its past exposure to and impact from extreme weather events. The opportunity agents capture the rare occurrences of weather disasters, which have the potential to open a window of opportunity for the confluence of solutions, agencies and problems for problem solving. Finally, the link agents have one attribute category to distinguish network ties with agencies in the same region and agencies from different regions.

All agent attributes are provided in Table 1, including the description and parameterization of each state variable.

Table 1. Agent attributes

|  |  |  |
| --- | --- | --- |
| **Variable** | **Description** | **Initial value** |
| **Agencies** |  |  |
| Weather Intensity | Intensity of weather conditions |  |
| Resilience | Capacity to absorb and withstand weather shocks without incurring impacts |  |
| Capacity | Capacity based on resource endowment and system characteristics to implement a certain solution |  |
| Extreme Weather Frequency | Number of extreme weather events |  |
| Impact per weather event | The impact of each extreme weather event on an agency |  |
| Cumulative weather impact | The cumulative impacts from multiple extreme weather events |  |
| Risk perception | Represents the extent to which an organization perceives the risk related to extreme weather |  |
| Cumulative risk perception | Risk perception cumulated over a certain period of time |  |
| **Solution** |  |  |
| Efficiency | Represents the suitability and effectiveness of a solution for problem solving |  |
| Cost | Represents the cost involved in implementing a certain solution |  |
| **Problem** |  |  |
| Difficulty | Represents the inherent complexity of the problem |  |
| **Links** |  |  |
| Category | Used to distinguish types of network ties |  |

**1.2.2 Environment**

The landscape is represented as a grid of four cells, each cell representing one of the four Census regions in the United States. The organizations are distributed in the four regions drawing on the 2016 survey data. The agencies are linked by two networks: 1) networks with agencies in the same region; 2) networks with agencies in other regions.

This model includes a few global settings that influence the number of initial solutions distributed over the modeling space, the damage each extreme weather event can possible cause, the max resilience level of each agency to determine the level of impact per extreme event, an organization’s memory length to filter out older memories, the scanning range which determines an agency’s scope of search for alternative solutions for problem solving.

**1.2.3 Temporal dimension**

The model is run 20 years with each tick representing a month.

**1.2.4 Exogenous drivers**

The main exogenous drivers in this model are extreme weather events, defined as the events that deviate from historical norm, exceed the local, regional or national threshold and generate impacts. The frequency of the extreme weather events is agency-specific, the data being drawn from the 2016 national survey on transit agencies. With rare chances, there are major extreme weather events leading to weather disasters.

* 1. **Process Overview and Schedule**

Each time tick represents 1 month. Simulations are run for 240 ticks for 20 years. At each time step, the following processes occur in the given order:

1. Check current weather intensity. If the weather intensity goes beyond a certain level, the weather is modelled as extreme weather. The simulation starts the next tick if no extreme weather occurs.
2. Track weather impact. When extreme weather occurs, an agency suffers from weather impacts, the level of which is moderated by its resilience. The higher the resilience, the lower the impact. The minimum impact is zero when an agency’s resilience
3. Perceive the risk. Each extreme weather event is accompanied by an organization’s update of its risk perception.
4. Calculate cumulative risk perception over a defined period of time. An agency’s risk perception builds up.
5. if perception goes beyond a certain threshold, search for solution
6. When searching for an alternative solution, the agencies randomly select from the four strategies: 1) Search nearby areas for a solution; 2) Search solutions from their network ties from the same region; 3) Search solutions from the network ties regardless of their geographical location; 4) Innovate on their own; 5) learn from industry leaders; 6) learn from the majority (but this won’t be obvious until everyone has implemented solution)