Proceedings of the 2015 Winter Simulation Conference
L. Yilmaz, W. K V. Chan, I. Moon, T. M. K. Roeder, C. Macal, and M. Rosetti, eds.

Participatory Simulations of Urban Flooding for Learning and Decision Support

Jonathan M. Gilligan

Earth & Environmental Sciences
Vanderbilt University
Nashville, TN, 37235-1805, USA

Corey Brady

School of Education & Social Policy
Northwestern University
Evanston, IL, 60208, USA

Janey V. Camp

Civil & Environmental Engineering
Vanderbilt University
Nashville, TN, 37235-1831, USA

John J. Nay

School of Engineering
Vanderbilt University
Nashville, TN 37235-1826, USA

Pratim Sengupta

Department of Learning Sciences
Werklund School of Education
University of Calgary, Alberta T2N 1N4, CA

ABSTRACT

Flood-control measures, such as levees and floodwalls, can backfire and increase risks of disastrous floods by giving the public a false sense of security and thus encouraging people to build valuable property in high-risk locations. More generally, nonlinear interactions between human land-use and natural processes can produce unexpected emergent phenomena in coupled human-natural systems (CHNS). We describe a participatory agent-based simulation of coupled urban development and flood risks and discuss the potential of this simulation to help educate a wide range of the public—from middle- and high-school students to public officials—about emergence in CHNS and present results from two pilot studies.

1 INTRODUCTION

The complex nonlinear interactions in CHNS can produce unexpected emergent effects, which can cause well-intentioned attempts at risk-mitigation to backfire and increase vulnerability instead of decreasing it (White, Kates, and Burton 2001). Considerable attention has been devoted to educating the general public and decision makers in government and the private sector about the complexities of CHNS. Interactive simulations can be powerful tools for teaching and learning about complex systems (Dorner, Nixon, and Rosen 1990), and participatory agent-based simulations, in which human participants can interact with large numbers of automated agents representing social and physical components of the environment, seem especially promising (Wilensky and Stroup 1999).

2 PARTICIPATORY SIMULATION MODEL DESIGN

We developed a simulation of cities at risk of river flooding. Our model simulates cities along a flood-prone river. The model combines human actors, who can build flood walls to protect their cities, with a simulated real-estate market based on Filatova et al. (2009). Flood waves are launched stochastically, and our model incorporates dynamic hydrology to account for the way flood walls affect the propagation of flood waves.

Each participant manages a city along the river. Each manager collects taxes proportional to the value of occupied property and may draw on that revenue to build flood walls. Simulated agents participate in real-estate markets in which the demand for property depends on agents' income and risk aversion and the local property density and history of flooding. When flood walls prevent high-frequency low-magnitude events, demand for property inside those walls can rise nonlinearly with time if relationships between population density and demand create positive feedback. However, this can raise the risk of catastrophic flooding as development within the floodwall increases the value of property at risk to floods that overtop the wall. This phenomenon has been observed historically and has been widely discussed with respect to New Orleans among other cities (Meyer 2006). Urban development also increases flood risks by increasing the amount of impervious surface, which causes rainwater to flow faster and to remain on the surface rather than infiltrating into the ground. Adding flood walls in one city also affects nearby cities because restricting flow onto the floodplain increases the height of the floodwave both upstream and downstream.

The characteristics of the model (landscape topography, river geometry, and distribution of agents' income, risk aversion, intertemporal discounting, and desire to live near a city center) can be modified to simulate different growth scenarios. Our model operates on two different time scales, with time moving rapidly (one simulated year takes less than one second in the laboratory) most of the time, but then slowing dramatically when a flood event occurs to allow the participants to experience how it interacts with the built defenses. Time in the simulation also stops every 20 years to allow participants to make new decisions about building flood walls and to interact with each other as they see their actions affecting each other's cities.

The model is implemented in NetLogo/HubNet and is available at https://github.com/pratim/Floodpartsim.

3 PILOT STUDY

We conducted one pilot study with a group of pre-service teachers studying human geography. After participating in the simulation, the subjects demonstrated that they had learned key concepts of risk tradeoffs and unintended consequences that can accompany flood-control measures. During the simulation, they exhibited strong emotional responses, including hope, fear, and sense of loss. This emotional engagement differs from experiences with participatory simulations of purely natural systems and with non-participatory simulations of CHNS. We conducted a second session in which the participants were expert engineers. We will present the results of these experiments and the prospects for using such models for pedagogy from middle school through university, for improving public understanding of flood risks, and for supporting reflection and decision-making by planners and public officials.

ACKNOWLEDGEMENTS

This work was supported in part by NSF Early Career Award (ACI 1150230).

REFERENCES

Dorner, D., P. Nixon, and S. D. Rosen. 1990. "The logic of failure". *Phil. Trans. Royal Soc. B* 327:463–473.

Filatova, T., D. Parker, and A. van der Veen. 2009. "Agent-Based Urban Land Markets: Agent's Pricing Behavior, Land Prices and Urban Land Use Change". *J. Artif. Soc. and Soc. Sim.* 12:3.

Meyer, R. J. 2006. "Why we under-prepare for hazards". In *On risk and disaster: Lessons from hurricane Katrina*, edited by R. J. Daniels, D. F. Kettl, and H. Kunreuther, 153–174. Penn.

White, G. F., R. W. Kates, and I. Burton. 2001. "Knowing better and losing even more: the use of knowledge in hazards management". *Global Environmental Change B* 3:81–92.

Wilensky, U., and W. Stroup. 1999. "Learning Through Participatory Simulations: Network-based Design for Systems Learning in Classrooms". In *Proceedings of the 1999 Conference on Computer Support for Collaborative Learning*, CSCL '99. Palo Alto: International Society of the Learning Sciences.