Agent Models of Catastrophic Events

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Abstract. The study of complex phenomena, such as the interplay between human and natural systems, requires models. To allow for an orderly study of the effects of individual actions the model must comprise different scales of granularity, individuals and aggregates. In a joint research project between IIASA (Austria), DSV (Sweden) and the Hungarian Academy of Science, the flooding problem of Upper Tisza in Hungary is investigated. From a flood management perspective, different possible mitigation strategies and strategies for distribution of the financial responsibility, are investigated. Multi-agent based simulations are used to investigate the feasibility of different strategies, with a focus on different insurance programs. The simulation model is implemented in Matlab and offers possibilities for scenario generation as well as for strategy optimisation.

Introduction

Recently multi-agent based simulation models have become popular for investigating the relation between micro- and the macro-level of complex systems (see e.g., Bonabeau et al. 1999). The direct connection between human behaviour and climate changes is hardly challenged, as illustrated by the results presented in the recent report from the National Academies (Committee on the Science of Climate Change 2001) requested the Bush administration to question the Kyoto treaty. Global warming caused by the increased greenhouse-gas emission results in more frequent and more severe natural catastrophes, such as flooding. For instance, the number of natural disasters in the decade 1988-1997 was five times greater than in the decade 1960-1969. As the number of catastrophes increases, human and financial losses are escalating; in the period 1988-1997, major natural disasters cost US$700 billion (MunichRe 1998). The increased concentration of populations and vulnerable assets in high-risk areas are the main reasons for the increase (Loster, 1999). The key problem for policy makers is to find ways to improve resilience and to protect society effectively against increasing risk (Ermoliev *et al.*, 2000). For instance, more efficient land-use can be achieved by using flexible insurance conditions as an incitement to make people choose safe areas for their homes. A problem with using a financial instrument such as insurance is that flooding is by the insurance industry normally considered uninsurable, due to problems of adverse selection, moral hazard, and difficulties in estimating the risks involved. Moreover, with escalating losses, many insurers are reducing their catastrophic cover. Recent advances in computer modelling of catastrophic events have increased interest in insurance policies, however (Evans *et al.*, 2000).

Since it is impossible to analytically estimate the result of different scenarios within reasonable time limits, due to the complexity of the system and the large amount of stochastic variables, the use of simulations is investigated.

By explicit modelling of all involved individuals, a level of granularity that is out of reach for mathematical modelling can be obtained. The possibility to model interactions between individuals, their environment, and feedback of the resulting macro-structures to the micro level of the individual decision-makers, are key advantages of an agent-based approach to simulations. This makes agent-based modelling suited as an inductive analysis tool for understanding fundamental processes across a variety of applications (Axelrod, 1997). Our model presents an insurance policy problem pertaining to the Tisza region in Hungary, a relatively poor part of Europe, often hit by floods. The agents are of two different types, individual property owners and aggregates (insurance companies and government).

In the next section, we will introduce some background on modelling complex systems. Next, we present our simulation model. Following this is a presentation of the results. Because this is work in progress, we close with indications of further research necessary.

Modelling Complex Systems

From a systems analysis perspective, disastrous events are usually seen as resulting from complex interactions between different systems, such as physical, social, economic, etc. For instance, the probabilities for a flood to occur in a river, as well as the consequences of that same flood, are related to systems of economy, ecology, meteorology, and hydrology. These systems are in turn influenced by the conditions in the river system, and uncertainty is inherent, requiring explicit modelling. It is impossible to predict the amount of precipitation, the humidity of the soil, the level of inflation, etc. These stochastic variables can at best be represented as exogenous parameters in the model, and their dependencies investigated. For instance, rain data from the meteorological system affects soil absorption, measures that are important to the hydrological system. Even though there is sufficient data on a regional level, this is insufficient for *ex ante* loss estimations, pertaining to particular locations. However, a wealth of geographical data on climate, soils, land cover, and groundwater flow is available through remote sensing, incorporated in geographical information systems (GIS). GIS tools can produce highly detailed maps. Taken alone, such tools are insufficient for complex decision support, as the GIS models typically do not account for spatial interdependencies (Keyzer & Ermoliev, 1998). The integration of data acquired from a GIS system with a simulation tool makes dynamic simulations possible, however, and we will exploit this fact in a MAS setting. Our hypothesis is that our simple models of interaction on the individual level through simulations will provide important information on the stability and flexibility of our earlier obtained solutions.

The Basic Model

A geographically explicit dynamic model was developed, the chief purpose of which was to investigate the possibilities for a national Hungarian insurance program. The model contained the information in Table1.[1] For the sake of brevity, we do not go into detail on methodological aspects, but refer the interested reader to earlier report (Brouwers, 2000; Ermolieva, 1997; Hansson 2000). The model was implemented in Matlab, and all simulations were executed on a single personal computer. Detailed simulation data and colour graphics can be found at www.dsv.su.se/~lisa.

[1] Discretionary income is disposable income less essential purchases for food, clothing, shelter, and transportation. Basically it is the money you have after paying your living expenditures to either save or blow. Payments on credit card bills for vacations, and consumption other than living expenditures are paid for out of discretionary income.

Agents

- Insurer Agent

Wealth
Wealth transformation function (Risk reserve + premiums – compensations)
Pattern of coverage, and premium size
Goal function (risk willingness, level of profit)

Objects

- Individuals (only represented trough the property value - aggregated per grid square)

Wealth (property value)
Wealth transformation function (wealth – damages + compensation – premiums)
The property values for each grid represent the insurance market customers.

Data

- Property data (per grid square)

Monetary value

- Land data (per grid square)

Slopes

- Flood data

Strength of flood (exogenous)
Height of water level (exogenous)

Structural Measures

- Levees

Height and location

Interdependencies
How the flood is affected by the levee
How inundation of neighbouring land is affected by the slopes
How property values are affected by the flood

Table 1. Information represented in the basic model.

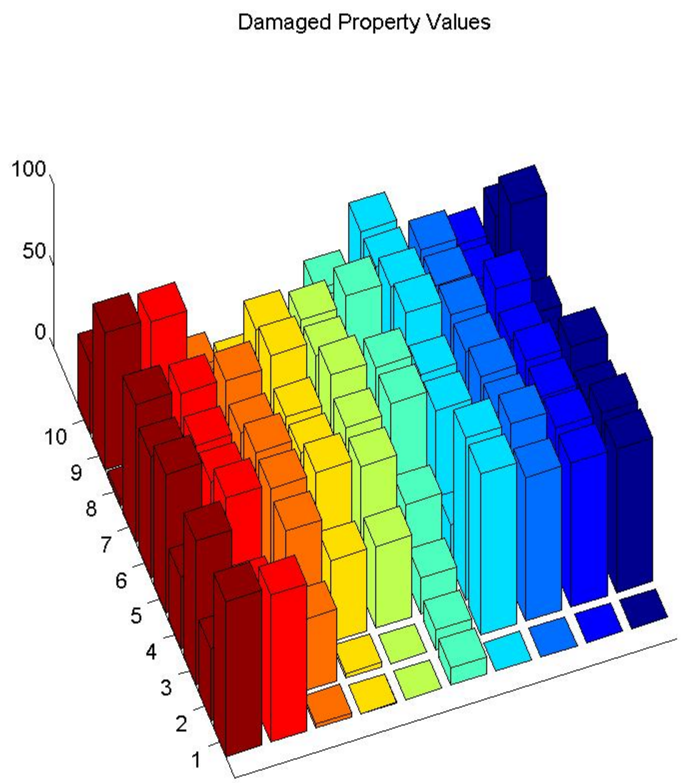

Fig. 1. Damaged property values in a particular region, as represented in the simulation tool.

As an example, a snapshot of a simulation on damages on property values is shown in Fig-1. The model consists of interacting modules. A detailed description is given in (Brouwers, 2000). The economical losses in each flooded square of the grid are estimated. Each round of simulation represents one month, so twelve rounds represent one year. For each round, the Monte-Carlo simulator picks new random values for the exogenous variables.

The role of insurance is a complement to structural measures. There is an economic optimum to the degree of protection available from structural measures, where the cost of building more (greater protection) is higher than the additional benefits. Here insurance covers the residual risk. In general, a mix of the structural and non-structural mitigation measures is required for an optimal solution (Retiano, 1995).

The goal for the insurance agents is to maximise wealth and to minimise risk of insolvency. In our simulations, the property values were updated every month depending on losses and compensations from flooding. Each year, the wealth of the insurer agents was updated based upon received premiums and paid compensations.

The insurance agents' goal is to maximise wealth by varying the 'pattern of coverage' (over a time period of 50 years). Coverage is defined as the fraction of the property value that is insured, and is measured in each square of the grid. The following assumptions were made.

- The initial coverage pattern was 50 per cent for each contract
- The size of the premium was 1 per cent of the property value covered, each year

Simulation Results

The results showed that both the insurer agent and the aggregated individual agent avoided insolvency. The expenditures for the government were high, due to large compensation of uninsured losses. The optimised pattern of coverage reflected the level of flood risk directly. In safe squares, 100 per cent coverage was offered while the coverage for riverside squares approached 0. We also performed a number of simulations where different heights of the levee were tested. A high levee is expensive to build and maintain for the government, however the increased protection was reflected in the optimised pattern of coverage. When extreme floods occurred, and the high levee was destroyed, the insurer went insolvent, as the claims were too high. Contracts were not treated separately for each individual customer, but were aggregated, and as a result no consideration was taken to the vulnerability of each individual customer agent.

Conclusions and Future Research

The system dynamics have been modelled in a simple fashion. Diversity among agents has not been analysed, other than with respect to geographical distributions. Asynchronous message passing has not been implemented, and flocking behaviours and mutual mimetic contagion have therefore not been studied.

That said, the above shortcomings should be seen as directions for future research. We want to extend the model to include individual agents in order to test if the increased granularity brings more insight. We have presented certain aspects of an ambitious case study, involving dozens of researchers (in Hungary, Sweden, and Austria), working in an interdisciplinary fashion over a three-year period.

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