Microsimulation Models for Disaster Policy Making

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Abstract

Two executable simulation models for answering policy questions were designed and implemented. The first for a flood management case, and the second for a disease transmission case that is currently underway. The flood simulation model differs from earlier natural disaster simulation models in several respects. It represents explicitly the geographical location and the economic strength of each household. It is also equipped with a graphical user interface, making it possible to design policies interactively, and to test their outcomes. If policy options are compared, the simulation results can automatically be transformed into decision trees. The flood simulation model shows that a micro-level representation makes it possible to investigate the distributional effects of policy changes. Novel features of the disease transmission model include the use of (anonymized) data representing nine million individuals, the inclusion of important parts of the contact patterns, and the explicit representation of places. The disease transmission model shows that the incorporation of social structure allows for a more realistic representation of disease spread than do models that assume homogenous mixing. Using this model, it is possible to conduct experiments of significant policy relevance, such as investigating the initial growth of an epidemic on a real-world network. Together, the two cases demonstrate the usefulness of a spatially explicit micro-level representation for policy simulation models in the area of disaster management.

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List of Papers

The following papers are included in the dissertation:

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- Brouwers, L. and Hansson, K. (2001). MicroWorlds as a Tool for Policy Making. In Canas, J., editor, *Proceedings of the 1st International Workshop on Cognitive Research with Microworlds*, pages 139–146.
- Brouwers, L. and Verhagen, H. (2003). Applying the Consumat Model to Flood Management Policies. In Muller, J. and Seidel, M., editors, *4th Workshop on Agent-Based Simulation*, pages 29–34, Ghent. SCS-European Publishing House.
- Brouwers, L., Ekenberg, L., Hansson, K., and Danielson, M. (2004). Multi- Criteria Decision-Making of Policy Strategies with Public-Private Re- Insurance Systems. *Risk, Decision and Policy*, 9(1):23–45.
- Brouwers, L. and Påhlman, M. (2005). Consensus by Simulation: A Flood Model for Participatory Policy Making. Submitted for publication: Special Edition of the *Journal of Risk Research.* Flood Risk Management: A Model-based Stakeholder Approach.
- Brouwers, L. (2005). MicroPox: A Large-Scale and Spatially Explicit Microsimulation Model for Smallpox Planning. In Ingalls, V., editor, *The Proceedings of the 15th International Conference on Health Sciences Simulation*, pages 70–76, San Diego, USA. SCS.
- Brouwers, L. and Liljeros, F. (2005). The Functional Form of an Epidemic in a Real-World Contact Network. Submitted to the *Journal of Artificial Societies and Social Simulation (JASSS).*

A number of papers also constitute parts of my research, even if they are not included in this dissertation:

- 2005
  Linnerooth-Bayer, J., Vári, A. and Brouwers, L. Flood Risk Management and Insurance in Hungary: A Model-Based Stakeholder Approach. Submitted for publication: Special Edition of the *Journal of Risk Research*. Flood Risk Management: A Model-based Stakeholder Approach.

- 2003
  Ekenberg, L., Brouwers, L., Danielson, M., Hansson, K. ,Riabacke, A. and Vári, A. Flood Risk Management Policy in the Upper Tisza Basin: A System Analytical Approach–Simulation and Analysis of Three Flood Management Strategies. Interrim Report IR-03-002, Intl. Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

- 2002
  Brouwers, L. Flood Risk Management Policy From an Insurance Perspective. *Licentiate Thesis*. 02-008, ISSN 1101-8526, ISRN SUKTH/ DSV/R–02/9–SE, Dept. of Computer and Systems Sciences. Stockholm.

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- 2001
  Boman, M., Brouwers, L., Hansson, K., Jansson, C-G., Kummeneje, J. and Verhagen, H. Artificial Agent Action in Markets. *Journal of Electronic Commerce Research*, 1:159–168.

Table of contents

Chapter 1

Introduction

The research problem that this thesis strives to answer is whether a micro-level representation is a useful feature of spatial simulation models for disaster policy making. Two cases are presented, a flood case and a disease transmission case.

1.1 Motivation

In public policy making, models that represent each individual explicitly are often used for investigating the effects of policy changes that concern the pension system, the labor market, or subsidies to the unemployed, for instance. The distributional effects can be analyzed at a detailed level or aggregated by, for example, sex, geographical region, or age-group [53]. Models of this kind, so called microsimulation models, are not common in disaster policy making. In this area, there is a need for loss estimation models that represent persons and places explicitly.

Insurance and reinsurance companies use different loss estimation models to keep track of their risks. The risk, from the insurer's perspective, is the compensation to policyholders (persons who buy insurance). Policyholders claim compensation for events at a random time in the future.

The amount of compensation depends on the terms of the insurance agreement and the nature of the event. Difficulties in quantifying dependent risks of such “low-frequency with high-consequences” events complicate accurate pricing of insurance premiums. Traditional actuarial models for calculating the correct premium do not work properly in the case of natural disasters, as the events (compensation to policyholders) are highly correlated in time and space [29, 27]. If the insurers could quantify risk at a detailed level, insurance premiums could be based on local risk instead of on property value or regional risk. Existing computerized disaster models simulate the physical characteristics of natural disasters and project their effects on property, using aggregated data for larger regions, or zones. Governments and municipalities need detailed zoning and coding maps that state where houses may be built, and where the risk is too high. It is in the interest of the government that the public disaster policies are fair and that the distributional effects of new policies can be investigated beforehand. A government deciding whether to terminate economic compensation to owners of flooded houses in high risk areas would do well to investigate how many and which houses this affects before implementing the policy change. This detailed information cannot be retrieved from aggregated models.

Simplified models are often used to investigate the transmission of infectious disease. These deterministic models assume homogeneous mixing and thus random interaction, meaning that all persons have the same number of contacts and that all persons are equally likely to meet. They are often expressed in a number of coupled differential equations that describe the dynamic flow between the fraction of susceptible persons in the population and the fraction of infected persons. Models of this kind, and elaborations of them, work well for representing highly contagious diseases. However, for moderately infectious diseases, these models have shortcomings [57]. The main drawback is that the number of contacts in a real-world network varies greatly, and that persons with many contacts tend to interact with persons who also have many contacts.

1.2 Problem

Is a spatially explicit micro-level representation a useful feature of simulation models for disaster policy making?

1.3 Objective

The objective of this thesis is to show that a spatially explicit micro-level representation is useful for policy simulation models. More specifically, the research objective is twofold:

1. Micro-level representation in flood simulation models:
   Show that a spatially explicit micro-level representation is useful for flood risk management.
2. Micro-level representation in disease transmission models:
   Show that a micro-level representation of persons and places is useful for infectious disease control.

1.4 Theoretical Foundation

Since the two words often appear together, the phrase *modeling and simulation* has come to describe the integrated activity around the construction of models of real-world systems and their computer simulation. The modeling part focuses on the relationship between real systems and models, while the simulation part focuses on the relationship between computers and models [77]. For the purposes of this thesis, modeling and simulation is the method of developing a model of a real-world system, realizing the model in an executable computer language, and performing experiments on the computerized model in order to learn something about the real system. The features of reality considered most relevant to the process under study are captured and represented as carefully as possible in the model, while the other features are left out. The results of simulation may or may not say something about the real world—it depends on how well the model was designed, how it was translated into a computer program, how the simulation experiments were performed, and finally, how the results were interpreted.

One way of classifying the different simulation approaches is to divide them into the two main categories of discrete-time simulation and continuous-time simulation [77, 12, 61]. When a discrete-time simulation model is executed, time advances periodically: time is divided into steps of equal length and jumps from one step to the next. In continuous, or continuous-time simulations, the system evolves continuously as time progresses smoothly. The model is often described by differential equations in which time is the independent variable. If the differential equations are stochastic, then it is undoubtedly correct to refer to the model as a simulation model. However, if the equations are deterministic, then it can be argued that the model is solved rather than simulated [12]. Diffusion processes and macro-economic models, are examples of continuous models where focus is on the flows in the systems.

Simulation models are also commonly categorized as either time-driven or event-driven [60, 12] In a time-driven simulation model, each time step is executed when the simulation program is run. The simulation represents real time linearly, each time step in the real system is represented by one time step in the model system. In an event-driven simulation, the events are placed on a time axis, a time-ordered event list, or a queue. The time axis is divided into a number of time steps of equal length. In a simulation run, the execution "jumps" to the next time step where there is an event placed on the time axis. The empty time steps are simply ignored, time in the model model is not linear to time in the real system. New events can be scheduled along the time axis during runtime, and events can also be removed from it.

More pragmatically, simulation models may be considered by the purpose of the simulation. According to Axelrod [4], the most common purposes of simulation include prediction, performance, training, entertainment, education, proof, and discovery. A similar classification has been proposed by Nance and Sargent [60], who present five different objectives of simulation studies: system analysis, education and training, acquisition and system acceptance, research, and entertainment. Computer-based simulation games are becoming increasingly popular since many families now have high-speed computers at home. The Sims™and SimCity™are examples of games in which the daily social lives of virtual persons are simulated. Flight or car simulators are games that allow the user to fly or drive a virtual vehicle. The use of simulations in education has also increased, as many schools equip their classrooms with computers, and companies use simulations to train their staff, c.f. overview by Ören and Güven.[1]

THE HISTORY OF SIMULATION

The use of simulation methods has a long history. Before the invention of digital computers, analog simulators such as wind-tunnels were used. The real-world system was described in terms of differential equations and physical models that obeyed the equations were constructed to test whether the descriptions were adequate. When general purpose computers became available in the late 1960s, the simulation method gained wider acceptance. Early efforts were made towards a General Simulation Program (GSP) [72], in which common functions required for simulations were grouped. The GSP not only provided a simulation language, but it also represented a first effort to capture the specific simulation structure. The first generation simulation program languages were developed in 1960–1965; the General Purpose System Simulator (GPSS) [38] and the simulation programming language Simula [62]. The second generation emerged in the late 1960s, including GPSS II, Simscript [13], and Simula 67.

Nance gives an overview of the evolution of discrete-event programming languages [61]. Åström describes the development of continuous simulation models [3]. The history of discrete-event simulation models has been described by [31, 60]. Today there are many freeware and commercial simulation software packages (see two recent surveys by Swain[2] and Kennington[3]). Many large simulation models are, however, implemented in standard procedural or object-oriented general-purpose programming languages like C or C++. Bratley *et al.* have critiqued three of the major simulation languages, Simscript, GPSS, and Simula. According to the authors; these languages

[1] `www.site.uottawa.ca/~oren/sim4ed.htm`
[2] `www.lionhrtpub.com/orms/surveys/Simulation/Simulation.html`
[3] `www.topology.org/soft/sim.html`

are badly designed and not state-of-the-art. Simscript suffers from an uncontrolled syntax; the block-structure of GPSS makes it unable to represent problems that are not natural to represent in flow diagrams; and although Simula is based on excellent ideas, the impenetrable complexity of the language makes it hard to understand. Bratley *et al.* concluded their survey by noting that ([12],p. 229):

> "... for any important large-scale real application we would write the program in a standard general-purpose language, and avoid all the simulation languages we know. The reason is simple: we would not be comfortable writing simulation programs (or any others, for that matter) in a language whose behavior we are not able to understand and predict in detail."

In the early days, simulation was mainly used to understand and improve system performance in the areas of management science and operations research. The field of system dynamics evolved from work in control and feedback systems [32]. System dynamics describes the internal behavior of systems, that is, how parts in the system influence each other. Its focus is on interrelations rather than causal dependencies. The area has had a significant effect on business and academia, where system dynamics is used increasingly by system ecologists, computer scientists, and sociologists, among others.

Models of Social Systems

System dynamics can be used to model social systems. According to Forrester [32], social systems are "multiloop nonlinear feedback systems". Since the main goal of the models in system dynamics is to consider the system as a whole, the unit of analysis is populations. The changes that occur in the model are typically described by a set of differential equations, and the effects can only be analyzed at an aggregate level.

The word *social* should here be understood as closely related to societal, that is, relating to human society and its members; a social system includes humans who interact. According to Epstein and Axtell ([24], p. 1),

> "...many crucially important social processes are complex. They are not neatly decomposable into separate subprocesses—economic, demographic, cultural, spatial—whose isolated analyses can be aggregated to give an adequate analysis of the social process as a whole."

The point made by Epstein and Axtell is important and motivates a micro-level representation when social processes are modeled. Epstein and Axtell [24] also pointed out that social sciences are a difficult case because controlled experiments on how individual, or micro-level, behavior affects the system as a whole are hard to conduct. Simulation models, unlike deductive models, allow for representation of the dynamic social process, not only for its outcome. Social processes are hard to represent in traditional mathematical economic modeling, because the method has a number of limitations: the impossibility of equipping the different agents (or actors) with different decision models is referred to as the *limitation of multiagency* [15]. In mathematical models, it is sometimes difficult to represent effect of time, for instance, how an action by one or more agents today affects the behavior of another agent later.

Micro-level Representation

In several areas there has been a need to simulate the social processes at a more fine-grained level than at the level of population. Microsimulation is an early attempt in this direction and agent-based simulation is a more recent one [11]. The economist Guy Orcutt [64, 65] presented early ideas in the direction of micro-level representation in his article "A new type of socio-economic system" from 1957 [63]. Microsimulation models can be seen as a reaction against the dominance of the aggregate models of economy and society, which still dominate in economics and in the social sciences. Microsimulation models have mainly been used in the area of economic policy making the last two or three decades to investigate the distributional effects of implementing new pension reforms, tax reforms, and other macro-economic changes. Klevmarken described microsimulation for policy analysis as follows ([53] p. 1),

> "Microsimulation aims at statements about the distribution of some endogenous variables (for instance, the distribution of incomes) defined on a population (for instance, the population of Swedes in a particular year), given certain policy assumptions (for instance assumptions about tax rates) and initial conditions."

He has also pointed out that micro-models allow for heterogeneous behavioral responses to applied policies, an important step away from the simplifying assumption of average economic behavior that is used in most economic models [52]. The use of microsimulation models has been considered attractive, since they can capture the inherent heterogeneity among the individuals, that is, they do not aggregate individuals into homogeneous groups, but rather emphasize variability at the individual level. One drawback, however, is that the models are complex to implement and to adjust. Most models include a representative sample of the population, in the range of 1000–200 000 individuals. The SVERIGE model used in the epidemiological application in this thesis is unique since it comprises the entire population of Sweden (close to 9 million) [45, 46, 70], rather than just a sample. The CORSIM [14] model, which simulates the US population, and DYNASIM [64], the dynamic simulation model for Canada, are examples of well-known and large-scale microsimulation models that have proved successful. Dupont *et al.* present a detailed overview of dynamic microsimulation models from the United States, Europe, Asia, and Australia [20]. The microsimulation paradigm has not yet made the leap into other domains; models are still mainly developed to analyze microeconomic and social policy, such as pension reforms. An exception is the use of microsimulation models in road-traffic modeling [1], where the micro-units are vehicles instead of persons or families.

Other approaches to capturing the micro-level interaction when social processes are modeled include agent-based simulations. The cellular automaton can be seen as a predecessor of the agent-based models, and this technique has successfully been used to model such social phenomena as social segregation [69]. The homogenous representation of the individuals is quite limited, and in other areas a richer representation is desired. For this purpose, other, so-called *agent-based* techniques, might be better suited. The concepts of agents and multi-agent systems become popular in the

1990s [50]. Software agents, so called *softbots*, evolved to become more and more sophisticated as they were equipped with mechanisms for reasoning, decision making and communication (see [11, 18] for surveys of the use of agents in in the social sciences). The field of agent-based social simulation (ABSS) uses simulations to investigate social mechanisms (see for instance [5, 24, 36] for the fundamentals). Within this field, the use of ABSS in policy making has been given special attention by a number of researchers [19, 49, 68, 36, 35]. The majority of these models investigate policy issues related to climate change and sustainable development. Gilbert [36] proposed that social simulation should be called *process-centered* analysis. He pointed out that systems of non-linear equations are hard to solve when they involve interaction between processes at the micro- and the macro-level. Axtell presented three situations in the social sciences for which the use of agent-based simulation is motivated [6].

The first situation occurs when the computer is used as an aid to solve equations that are already known to be solvable. The model is solved either by automating the analytical solution process or by using Monte Carlo techniques to simulate the solutions numerically. Chattoe also commented on this when he argued [15] that economists tend to use the term *simulation* when they really mean the act of using a computer to solve a pre-existing mathematical model automatically. Agent-based simulation models are also useful for mathematical problems that can be formulated mathematically but for which no solution is known. The use of agent-based models can help one to understand the problem; the users can change parameter values interactively and inspect the effects, and the dynamical process can be studied. Even if no solution is obtained, the simulation may reveal other useful information about the problem.

The last situation is when it is too hard, impossible, or too time-consuming to formulate the problem as mathematical equations. Agent-based simulations represent a possible way to study these problems systematically. This can apply in a situation where the agents behavior is comprised of rules at both the micro- and the macro-level, and when the rules at both levels include stochastic elements. An example is the dynamic simulation of the supply and demand for disaster insurance in a spatially explicit model [26]. The simulation model incorporates catastrophic events as well as a micro-level representation of property values, insurance premium costs, and the size of insurance claims over time. The inclusion of stochastic processes at the micro-level (amounts of claims and premiums) as well as at the macro-level (the occurrence of natural hazards), plus the existence of spatial and temporal dependencies (the claims are co-located in time and space), makes this problem analytically intractable.

Axtell pointed out that microsimulation models and agent-based models differ in one important aspect. Microsimulation models represent the effects of overall changes in the system, like policy changes, to each and every unit (person or family or company). However, the behavior of the smallest units is described at an aggregate level, which is why the microsimulation approach is more "top-down" than agent-based modeling. This remark also partly explains why there are few large-scale agent-based simulation models in which the agents are autonomous, proactive, and communicative. It is indeed challenging to implement executable models that include individual decision-making models for each agent if the model holds more than a few agents.

Spatially Explicit Models

Many processes in a social system are spatially located, that is, they are linked to specific geographic locations. The spread of disease, for instance, occurs when persons are close to each other. The concept *spatial* could be extended to network topologies in general, such as computer networks or chat communities. However, for the purpose of this thesis, spatial refers to geographic space, as the focus is on disasters that strike at places in the real world and affect persons and buildings in a geographical vicinity. The size of the vicinity varies with the type of disaster. Berger *et al.* [10] state that a model is spatially explicit if location is included in the representation. Here, this definition is sharpened by stating that a micro-model is spatially explicit if location is included in the representation of each micro-unit.

Torsten Hägerstrand, who invented the research field *time geography* in 1953 [40], focused on the importance of representing space when analyzing social phenomena in his research. He described the concept of individual-based simulation models in which the dimensions of space and time restricted the number of possible actions of an actor. He used the term *station* to refer to points in the two dimensions where many individuals meet, places where many actors are co-located at the same time. Hägerstrand highlighted three types of constraints that limit the possible actions of an actor: capacity constraints, coupling constraints (only one activity at time occurring at one location), and steering constraints (macro-level regulations and laws). Hägerstrand's ideas are still not fully explored, but they provide a theoretical basis for spatial microsimulation [11]. The interactive microsimulation model HÖMSKE [47] largely builds on ideas from time geography, including the concepts of stations and constraints on possible actions. The paths of the individual actors in the time-space dimension form a web of trajectories that meet and separate, reflecting the choices made at the individual level, leading to actions that are influenced and constrained by the social reality. As expressed by Hägerstrand in a lecture given at the University of California at Berkeley in 1984 [41],

> "...When space and time are seen together then, suddenly, a new world opens up for investigation. The static map becomes transformed into a plaited weave of trajectories of room-occupying entities which come into being, meet, stay in touch, part, and disappear."

Another research discipline that deals with processes of a temporal-spatial nature is ecology. Randy Gimblett has surveyed the use of computer simulation models in natural resource management applications [37], from the use of cellular automata in landscape dynamics modeling to the use of Object-oriented techniques and the incorporation of Geographic Information Systems (GIS) in individual-based modeling approaches. He points out that the vast majority of the models include the biophysical interaction but exclude the human dimensions of ecosystems. Standard GIS software does not offer the possibility to update the attributes of a cell in the spatial raster dynamically, Gimblett points out that this inability to incorporate time-dependent data hinders the application of GIS in simulations of spatially explicit ecological phenomena, a technological limitation that needs to be addressed. Gimblett also points to the potentials of using individual-based simulations coupled with GIS as decision support in the area of policy making where the natural and the social systems are interconnected.

DISASTER MODELS

Simulation models are used to simulate disasters. The goal of the activity is to quantify the risks of the insurance company to make good re-insurance arrangements. A number of modeling companies offer tailored disaster simulation models to the insurance industry.[4] Ermoliev *et al.* have applied innovative adaptive stochastic optimization techniques to design insurance portfolios that spread the risks better [28, 25]. By operating in different geographic areas, the insurer reduces the overall risk. A diversified portfolio consists of contracts with clients in high-risk locations as well as in low-risk locations. This method makes it possible for insurers to offer insurance to properties in high risk areas.

The use of a micro-level representation in models for disaster planning is rare. Work by Cogneau and Grimm [39] exemplifies novel approaches in combining catastrophe modeling with a micro-level representation where the macro-level process here is an AIDS epidemic in Côte D'Ivoire, and the micro-level representational attributes are income and poverty.

Daniel Bernoulli is considered the first person to apply mathematical models to guide public health policies concerning infectious disease epidemics [16]. In 1760, he calculated the fraction of the population that must have immunity to smallpox (caused by the *variola* virus) to prevent an epidemic. Immunity is the result of, either surviving the disease, or, a successful *variolation*, meaning that a mild version of the variola virus is introduced to the patient by inocculation. More recently the related virus *vaccinia* is instead used, and the method is now generally referred to as *vaccination*. In 1906, Hamer [43] lay the foundation to the so called "mass action principle" by stating that the course of an epidemic depends on the rate of contact between susceptible and infectious individuals. The principle asserts that:

> "...the net rate of spread of infection is assumed to be proportional to the product of the density of susceptible people times the density of infectious individuals ([2], p. 7)".

[4] AIR `www.air-worldwide.com`, EQECAT `www.eqecat.com/`, GenRe Catastrophe Modeling Group `www.genre.com`, ReMetrics `www.benfieldgroup.com/remetrics`, and Risk Management Solutions `www.rms.com/AboutRMS`

A well-known model of the spread of infectious disease in a population, is the compartmental SIR (Susceptible, Infected, Resistant) model, cf. [76]. The population is divided into three categories and differential equations govern the dynamic flows from Susceptible to Infected and from Infected to Resistant, cf. Anderson and May [2] and Giesecke [34].

An important measure in the study of epidemics is R_0, the basic reproduction ratio. This quantity describes the expected number of new cases of an infection caused by a typical infected individual in a totally susceptible population. The value of R_0 must be larger than 1 for an epidemic to take off, if it is lower than 1 the disease dies out, and if it equals 1 the disease becomes endemic. The concept was initially used as a measure of the critical (spatial) density of mosquitoes; if the ratio of mosquitoes to humans is kept below a certain threshold, the malaria parasite cannot sustain. Heesterbeek [44] describes the historical evolution of the concept R_0 in demography, ecology, and epidemiology. It is, however stressed by Giesecke [34] that it is an average value. If there are large variations in the number of infections in different subgroups in the population, the average value R_0 does not provide much information.

Models in Policy Making

From a societal perspective, the consequences of a potential disaster are hard to estimate. This has become evident after the large number of recent natural and man-made catastrophes; tsunami, flooding, terrorist attacks, and outbreaks of highly infectious diseases. The problems connected to risk quantification make it difficult to design and adopt realistic preparedness and response-programs for emergencies, at a regional as well as at a national and international level. Scenario-based methods have long been used for assessment of the likely impact of applying new policies in situations where uncertainty about the future prevails.

Up to the time of the second world war, scenarios were only used in military applications like war games, as described in an introduction to the area by van der Heijden [73]. Herman Kahn [51] brought the technique to the civil domain, first at the RAND Corporation and later at the Hudson Institute. The term *scenario* was adopted by Kahn to underline the connection to movies, his predictions should only be seen as stories to explore and not as accurate predictions. Each constructed scenario is a potential version of the future, and the scenarios differ with respect to a few key assumptions. The Intergovernmental Panel on Climate Change (IPCC) used different climatic scenarios for which the assumptions on the demographic, economic, technical, social and environmental development varied [48]. Peterson *et al.* [67] overview the main steps that are taken in scenario planning and provide examples of where the method has been used. Simulation models are most useful in the later stages of the process, when the scenarios are tested, and the policies are formulated and evaluated.

Spatially explicit agent-based simulation models are also used as tools to support role-playing games in the area of ecosystem management. CIRAD is a French development-oriented agricultural research organization serving the tropics and subtropics, it promotes a companion-modeling approach which is based on their in-house developed agent-based simulation tool Cormas.[5] The use of role-playing games and agent-based models (not only based on the Cormas framework) for support in negotiation processes has been carefully surveyed by Barretau [8, 9].

Exploratory Modeling

Lempert and Schlesinger have argued against the use of subjective probabilities for representing the future, and so, instead of restricting the number of possible future scenarios to a handful as is done in scenario-based planning, they have proposed a method called *exploratory modeling* [56]. It was defined by Bankes [7] to mean the search over an ensemble of models, where each model is the representation of one plausible future. Exploratory modeling was compared with the related method *sensitivity analysis* [56]. In sensitivity analysis, it is first assumed that the model and the data are correct, then the optimum policy is calculated, and finally it is investigated how sensitive the policy is to the assumptions. In exploratory modeling, on the other hand, it is first recognized that the model cannot predict the future, and then a search for the policy that performs well across a broad range of possible futures is conducted. Lempert and Schlesinger proposed

[5] `cormas.cirad.fr/indexeng.htm`

the use of modern computer technology and exploratory modeling in policy making, in this example regarding climate-change issues ([56], p. 3):

> "Rather than find the optimum strategy based on a single set of subjective probabilities, researchers can now systematically and analytically evaluate alternative policies against a wide range of plausible futures and, thereby, directly address the real task that faces climate-change decision-makers – crafting strategies that are robust in the face of an unpredictable future."

1.5 Method

The methods for addressing the research problem are explorative and case-based, and the choice of methods is to a large extent the result of the context in which the research has been conducted. We have adopted a systems perspective. In this tradition, a system is considered as an organized, integrated whole made up of diverse but interrelated and interdependent units. To develop a model representation of the system, we took the following steps:

1. problem definition and identification of the main features of the system
2. development of a model representation of the system
3. realization of the model in an executable computer language
4. verification and validation of the model and the computer program

We used an exploratory modeling method in both cases to represent different future scenarios. In the flood case, the uncertain characteristics of the future were the water level in the river channel and the distribution of insurance contracts. It would be hard to find an analytical solution to this problem, as the model included ten different possible scenarios (nine flood failure scenarios and one with no flood) that were simulated over a period of 10 to 30 years; see Article B for a description of the number of possible future scenarios. In the disease transmission model, the uncertain features were the daily routines of people (for instance whether a person goes to work, stays at home, or travels) and how the disease affects a person. The stochastic nature of the two simulation models requires that simulations be performed many times to test the robustness of the policies.

The Flood Management Case

The Upper Tisza flood management study was initiated to investigate the use of a model-based stakeholder approach for identifying a new flood management policy option that was robust and acceptable to all (or most) stakeholders. Within this project, a flood simulation model (see Articles B and E), was developed to support the participatory decision process.

In Hungary, the government is traditionally responsible for minimizing flood risk and for compensating flood victims. The frequency and intensity of flood disasters in Hungary appear to be increasing. It was pointed out by Pecher *et al.* [66] that from 1877 to 1933 the average period between disastrous floods on the Tisza River was 18 years. Between 1933 and 1964 it was only three to four years, and since 1998, record-breaking flood levels have occurred annually. Since the costs of mitigation and compensation are rising, and the political climate has become more market-oriented, the Hungarian government needs to shift part of the disaster liability to individuals in an effective and acceptable way. In Article A and in the forthcoming article by Linnerooth-Bayer, Vári, and Brouwers [59], the background to the flood risk problem in Hungary is described in greater detail. Article F, "Consensus by Simulation", describes the use of the model as an interactive tool in a stakeholder workshop and presents the graphical user interface (GUI).

It was explicitly stated that the project would apply a participatory approach. A number of steps were taken to promote active stakeholder involvement in the project. First, we investigated the flood risk conditions and existing mitigation and loss-sharing alternatives, cf. [58, 74]. The purpose of these open-ended interviews (24 subjects) was to extract mental models of active stakeholders[6] to be used as input in the disaster simulation

[6]Representatives of the central, regional and local government agencies, farmers and entrepreneurs, nongovernmental organizations (NGO) activists, and insurance companies

model. A public survey[7] was also conducted to investigate the public opinion on flood risk policy management issues [75]. We distinguished between three different world views, implying three competing policy paths; state protectionism, individual responsibility, and holistic development. According to cultural theory [71], public policies must be based on all three world views, otherwise the policies will be unstable. We thus designed and implemented in the simulation model three policy options that corresponded to the world views. The options differed mainly in economic responsibility and level of solidarity. The effects of applying a policy option was presented from three different, and many cases conflicting, stakeholder perspectives: the government's, the insurance company's, and the aggregated effects for the property owners. The model was improved after feedback from the stakeholders.[8] We demonstrated the simulation model and interviewed the stakeholders, see [23].

Design of the Flood Model

The simulation model was programmed in Matlab, a mathematically oriented interpretive development environment, since early versions of the model built significantly upon previous Matlab simulation models [26, 17]. Advantages with Matlab include:

- it allows for easy inspection of variable values
- no compilation is required, thus changes in the program take effect immediately
- the built-in data-type matrices with many predefined operations
- the ability to visualize the variables (vectors and matrices) instantly

[7] 400 citizens from four geographic areas were interviewed.

[8] The model was presented to the following seven stakeholders: an officer of the Upper Tisza Regional Water Authority, the mayor of a city in the Bereg region (the neighboring river basin), the mayor of a village in the Szatmar area, the director of a regional Environmental NGO, the representative of the Szabolcs-Szatmar-Bereg County Chamber of Agriculture, a representative of the Association of Hungarian Insurers, and an officer of the Ministry of Interior National Directorate General for Disaster Management.

The features that make the language good for prototyping come at a price – performance is much slower than it would be in a general-purpose language like C or C++.

Large quantities of land-use data was available for the geographic area under study; it was represented as grid with $2\,500 \times 2\,500$ cells, each corresponding to an area of 10×10 meters. During the simulation, we only considered the cells that contained property (2 580); the other cells were filtered out. The properties, together with the families that lived in them, were the micro-level objects of the model. To keep the model clear and to avoid uncertainty, we decided to include only attributes that were of direct relevance to the policy experiments, even if we were tempted to include much more information. Since the policy options that were considered relevant in the model were financial in nature focusing mainly on insurance, the most relevant attribute was *property value*. Our detailed data on property values gave us a good picture of the spatial distribution of prices, even though the dataset was several years old. Other data, like income and amount of insurance premiums, was only available at an aggregate level by county. Therefore, we had to make educated guesses about the distribution of these data by consulting experts with local knowledge; the Hungarian Statistics Central Office (HSCO) presents *per capita* income data at a national as well as a regional level on the Internet.[9] The department of social statistics of HSCO advised us on how to best update property values in accordance with increases in consumer price indexes.

Verification and Validation: Flood Case

The verification process was inspired by the method proposed by Bratley *et al.* [12]. The first step was to verify the accuracy of the simulation program against known solutions. By fixing the values of the stochastic flood parameters in the program (the magnitude and location of the flood), as well as the insurance distribution so that all properties had the same level of insurance (full insurance or no insurance), it was possible to ensure that the outcomes for the different stakeholders agreed with our manually calculated outcomes at an aggregated level. The next step was to calculate the monetary balance for a few properties. This made it possible to verify the

[9] `www.ksh.hu/eng/`

results for these specific properties. If the results were erroneous (and the correctness of the input data was confirmed), We checked the simulation program manually by running the simulation program in debugging mode (line by line execution) until a point in the program was reached where the economic balance of the stakeholders was affected. Here, all calculations performed in the program were compared with the results of manual calculations. Since this method was rather time-consuming, it was only used when there were known errors for certain stakeholders.

The reliability of the simulation model was verified by repeating the simulation many times (1 000) for each of the three predefined policy options with either fixed flood probabilities or fixed insurance distributions (identical coverage for all property owners). The value of the stochastic element was logged for each simulated year.

In short, the three policy options were:

- A. Business as Usual (state protectionism)
  A continuation of current practices. Extensive government post-disaster relief, combined with voluntary, flat-rate (cross-subsidized) insurance.
- B. More Private Responsibility (individual responsibility)
  The government compensates victims by a lesser amount than in A. An additional, risk-based insurance is introduced.
- C. Public Disaster Fund (holistic development)
  The role of private insurers is reduced. A governmental disaster fund is created, financed by mandatory, flat-rate contributions from all property owners. The government subsidizes insurance premiums for low-income households.

The outcomes of the experiments were plotted and analyzed to confirm that the variance was a result of, and in accordance with, the value of the stochastic element.

To validate a simulation model is to confirm that it is a sufficiently close approximation to reality for the intended application [12]. The first step to fulfill this condition was taken during model development by presenting the model to seven stakeholders in Budapest and in the Upper Tisza. Each of the different policy options was applied, and the economic outcomes of the simulations were presented from three different stakeholder perspectives; the government, the insurance companies, and the property owners (aggregated for the entire Palad-Csecsei basin), cf. [23]. The feedback from the stakeholders resulted in modifications to the model. It also became clear that the model should be very easy to understand in order to gain acceptance. The executable simulation model was therefore extended with an option to present the output in form of standard decision trees in which the different policy options were the alternatives, as described in Chapter E.

Second, a number of experiments were conducted to statistically validate the inner functions of the model [23]. In general, validation of policy models is problematic as it is of little use to compare the outcomes with historical records; the effects of a policy change will take effect in the future. In the flood management case, the outcomes could not be validated against historical records on insurance patterns because such data was not available to us, nor did we have data on the size of the flood related costs for the government. The *usability* of the model was validated at the concluding stakeholder workshop, when the simulation model was used interactively, described in Article F.

INCORPORATING BEHAVIOR

In parallel with, but separated from, the flood management project, a number of experiments were performed with the flood simulation model. The motivation for these experiments was a scientific interest in the use of a micro-level representation in a disaster simulation model. The model was hence refined and modified to represent the decision-making process at the micro level instead of at the macro level. The refinement can be seen as substituting a black box with an explicit decision-making model for each micro-unit. The executable simulation model was reprogrammed accordingly. The reason why these extensions were not presented to the stakeholders in the flood management project was that we did not consider the merits of the model refinement great enough to compensate for the extra uncertainty that it would introduce. Given the fact that no statistical evidence or generally accepted scientific theories supported how these consumers make their insurance decisions, we were concerned that a micro-level representation of these choices would lead to long and potentially irresolvable discussions among the stakeholders.

To gain some elementary insight in the decision-making process behind the insurance choice, we posed a number of open-ended questions to the stakeholders after the model demonstrations. This material has not been published elsewhere, and is merely included in this thesis (Appendix B) to point out the qualitative steps that we took in the flood model design. The only conclusions that may be drawn from this very small survey (four respondents) is that it seems that social contacts play a role in the insurance decision (the decision of one stakeholder was influenced by discussions with relatives, and the relationship with an insurance agent affected the decisions of two stakeholders) and that trust in insurance companies is not high. Article D was inspired by this result.

The Smallpox Case

A geographically explicit micro-model for simulating the spread of smallpox in Sweden has been implemented and is now refined and extended. The aim of the project is to produce a simulation model that allows for testing and evaluation of competing policy options, such as, mass vaccination, ring vaccination, isolation, and contact tracing. The research is conducted at SMI. The persons who are, or have been, involved in the project are listed in Appendix A.

The goal of model implementation is to support decision makers in the identification of policy interventions against smallpox in Sweden that ideally are efficient, harmless to people, and economically and socially acceptable. The involvement of different stakeholders was not as central here as it was in the flood management case since no conflicting interests have been recognized so far. The actors who have a stake in this problem are the future policy makers; here the national Board of Health and Welfare (Socialstyrelsen), and SMI. There is also an expert panel connected with the project, consisting of persons with backgrounds in epidemiology, infectious disease medicine, and statistics. The members are listed in Appendix A.

This group advises the project on medical issues and on what policy options to focus on.

Epidemiological models are often used to estimate the course of an epidemic, and most models are elaborations of the fundamental SIR model. Since these models assume homogenous mixing among individuals, they have shortcomings when it comes to modeling diseases that are not highly contagious [57]. The contact patterns in a population can be represented in a network: the nodes are persons and the edges are contacts between persons. The potential for representing the contact patterns is one reason why the smallpox model uses a micro-level representation. Other reasons include the possibility to model behavior at a micro level, and to investigate the geographic patterns of epidemics.

Smallpox was chosen for the simulation for two reasons: media attention and transmission properties. Media interest in potential bioterror attacks has forced policymakers worldwide to examine their countries' emergency and preparedness programs. Smallpox is often cited as an example in a bioterror scenario because it is perceived to be easily transmitted, it has a high death rate, and the level of immunity in the population is low. The disease is primarily spread by close contact. According to data from historical outbreaks, the disease was transmitted between members of the same household in close to 80 percent of all cases [22]. These findings point to the importance of including reasonable estimations of the contact patterns.

Design of the Smallpox Model

The basic entities of the disease transmission model are *persons* and *places*. The underlying idea is that the model should be pable to represent places that are considered relevant for the spread of smallpox, that is, places where infected and susceptible persons are collocated. Since smallpox is primarily transmitted through close contact, the project members together with the expert panel decided to include the following types of places in the model: dwellings, workplaces, schools, kindergartens, hospitals, infection clinics, travel, and neighborhoods. It was decided not to include public meeting places like buses or department stores, since records from historical outbreaks show that transmissions here are very rare. The types of places

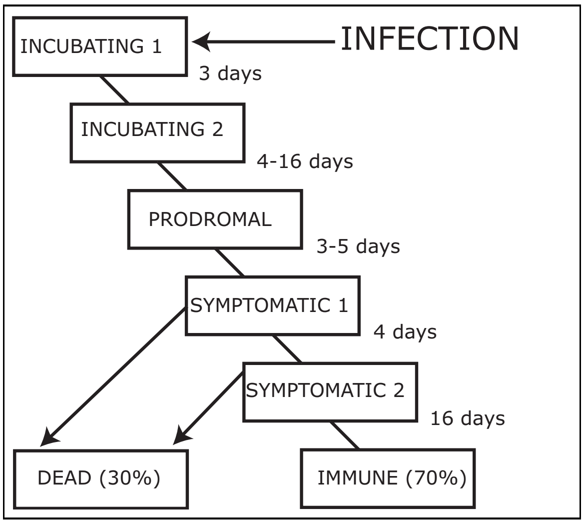

Figure 1.1: A general description of the how the disease (smallpox) was represented in the model.

that were to be included in the model implied a rather coarse-grained representation of time in units of hours. It was decided to only represent place changes in the morning and in the evening.

Representation of the Disease

Figure 1 displays the different stages of the disease; this division is similar to how the disease has been represented in the literature [30, 2] and in other smallpox models [21, 42, 33, 54, 55]. The duration of the different stages are not represented as parameters in the program as they are believed to be uncontroversial.

There is no general agreement on *how* infectious smallpox is and *when* an infected person can transmit the disease to others. Historical records show average numbers of infections from specific outbreaks, but as these records reflect the social context and the contact patterns of where the disease was spread, it is not certain that they would be the same for Sweden today. For that reason, we represented the values of infectiousness as parameters in the simulation model. Since the disease is more likely to spread through intimate contact than distant, we decided to distinguish the different types of contacts based on the type of place. Contacts in dwellings are generally more intimate than at workplaces, for example. To represent this in the model, one parameter stated the *transmission probability* for each type of place. The parameters *stage weight* tells how infectious a person is during this stage. Transmission of disease occurs twice every 24 hours in the model – one transmission in the daytime and one at night. In the articles presented in Chapter G and H a more detailed description of the transmission process is provided, together with listing of all parameters included in the model.

Incorporating Behavior

The daily behavior of persons in the model is not very complex. A summary of the possible daily activities are visualized in Figure 2. In the morning, each person first checks their health. If they are healthy they go to work, to school, or to kindergarten. Retired and unemployed persons stay home. Some people travel each day to places where they meet other travelers. Most persons make short trips; a few travel longer distances. Persons who are ill in the morning, either stay home from work or visit the emergency ward. All persons who are ill from smallpox will by the last day of the prodromal stage have visited the emergency ward. From there they are either taken directly to an infection clinic, or they are sent home with an incorrect diagnosis of influenza. On day two or three of the first symptomatic stage, all persons are sent to an infection clinic and stay there until they recover or die.

Simulation Program and Data

When the model was realized in a computer program, we separated the base functionality from the application program. The base functionality was handled by a discrete-event simulation engine, EVSIM[10], developed for analyzing the regional labor market in Sweden. EVSIM has been used

[10] EVSIM was implemented by Kalle Mäkilä.

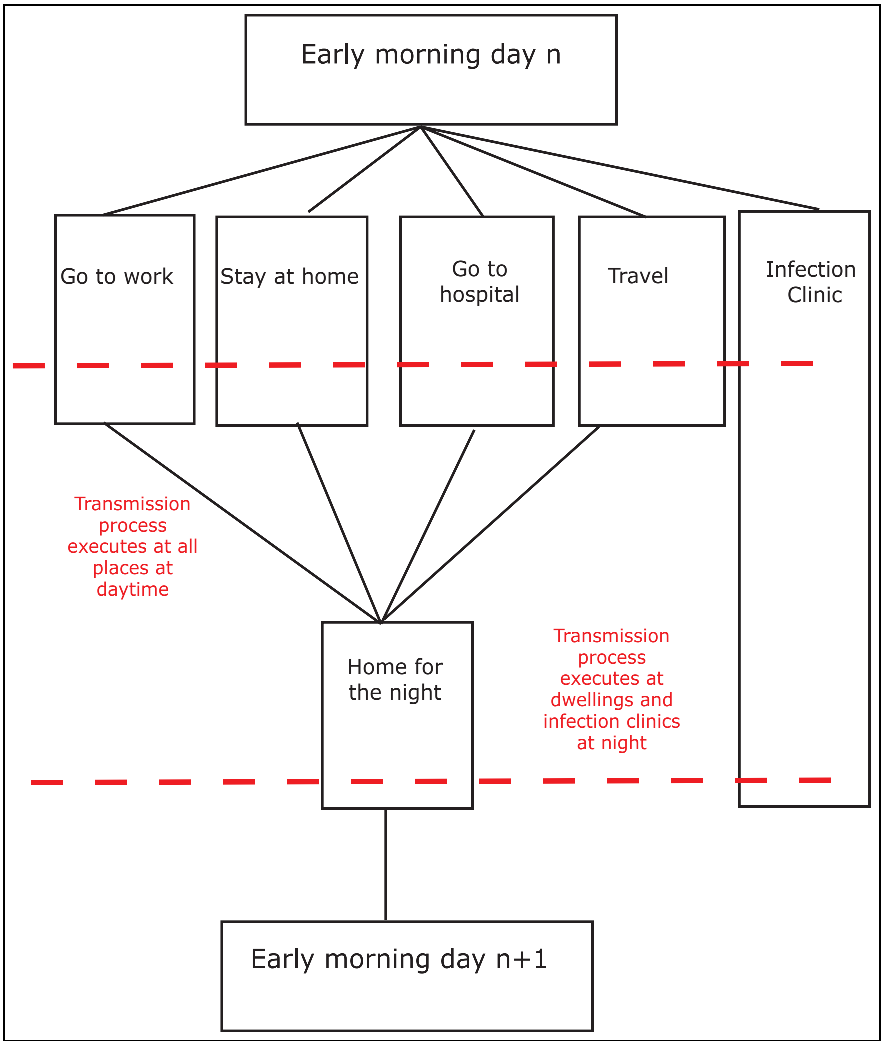

Figure 1.2: The daily routines for the simulated persons.

for several large-scale object-oriented applications [46, 45]. The simulation engine advances time on the time axis and manages objects and event handling.

The data set we used for this project is unique in that it represents the entire Swedish population in detail, close to nine million persons. The anonymized data contains information on family, age, sex, and location of dwelling and workplace for each person. It belongs to the Spatial Modeling Centre (SMC), in Kiruna, Sweden, and is provided to them by Statistics Sweden (SCB). Since we collaborated with SMC in this project, we were allowed to use a subset of this data set for this specific transmission model.

The simulation program is implemented in C++ in the Visual C++ environment, a choice motivated by the efficient memory allocation and good control of program execution.

Verification and Validation: Smallpox Case

Verification of the executable simulation model has been started but is not yet concluded. The first step was to verify that the behavior of the persons agree with the model description, see Figure 1.

For these activities the C++ debugging facilities were used to check the state (infectious or not infectious, and the stage of the disease if the person was infected) and location (place) of a small number of individuals during the entire simulation. By following the daily routines of these persons, it was possible to verify that the daily behavior and the evolution of the disease are correct. We also verified that the transmission process worked as it was supposed to, for this purpose the probabilities were increased to one, so that infections occurred at all possible types of places.

To validate that the basic model (without intervention measures) represents a smallpox epidemic in Sweden in a realistic way, the results will be compared with data from historical outbreaks, preferably outbreaks in Western societies from modern time where the contact patterns can be assumed to resemble the contact patterns in the Sweden of today. The basic reproduction ratio, R_0, in the range 3–6 has been used in similar models [21, 42, 33] and would therefore indicate that the results are reasonable.

The distribution of transmission events is also important; it is known that most infections historically took place in dwellings and within the close neighborhood. It is also known that many infections occurred at hospitals in modern societies [22]. Our preliminary estimations of how a reasonable distribution would look, is the following: dwellings 60%, neighborhood 10%, infection clinic 15%, hospital 5% , schools and kindergartens 5%, offices 3%, and travel 2%. The distribution will, however, be discussed with the expert panel.

The parameter values that affect the value of R_0 and the distribution of infections are the infectiousness per place, how infectious a person is in the different stages (prodromal, symptomatic 1, and symptomatic 2), and finally, how the individual behavior is modeled. If the model, for example, represents that persons go to work while they are highly infectious, then a large number of infections will take place at offices. Since the value of R_0 (which is an average value) in this simulation model can only be assessed after a large number of simulations, we need to find values of infectiousness that on average generate epidemics for which the value of R_0 and the place distribution is acceptable to the expert panel. An analytical method will be applied to estimate reasonable values for the infectiousness at the different places. A series of experiments in which there is only one infectious person in a totally susceptible population, and the value of infectiousness (probability) is set to one for all places, has been initiated. It has thus been possible to identify a worst-case scenario for a disease that is spread at the places represented in the model. The values of R_0 that were generated are naturally much too high; they will be transformed to produce (1) a reasonable value of R_0, and (2), a reasonable distribution of places.

It takes 35 seconds to execute one day in the simulation program when the entire population is included. Since several weeks may pass before the epidemic takes off, we are normally interested in simulations that last 100 days or more. An experiment consisting of 100 simulations in which new persons are selected to be the initial infectors each time, would take 97 hours. The simulation program is executed on a standard PC with 2 Gb internal memory and a 1.4 GHz processor.

1.6 Results

For flood simulation models, a spatially explicit micro-level representation is useful for risk quantification and for investigating the distributional effects of policy changes, especially when focusing on issues of fairness and equity. However, if a micro-level representation forces assumptions about how individuals will behave, the extra uncertainty might jeopardize confidence in the model. For disease simulation models, a spatially explicit micro-level representation is useful, particularly if the disease under study is transmitted through interpersonal contact.

The objectives stated in Section 1.3 were met in the following way:

1. Micro-level representation in flood simulation models:

   > "Show that a spatially explicit micro-level representation is useful for flood risk management."

   The article "Consensus by Simulation" (F), supports the view that a flood simulation model was useful in a participatory setting. The usefulness of an explicit micro-level representation could, however, not be confirmed within the flood management project. Nevertheless, the experiments described in the articles "MicroWorlds as a Tool for Policy Making" (C) and "Applying the Consumat Model to Flood Management Policies" (D) indicate the usefulness of a micro-level representation.

2. Micro-level representation in disease transmission models:

   > "Show that a micro-level representation of persons and places is useful to infectious disease control."

   The experiments described in the MicroPox article (G), show that the spatially explicit micro-level representation makes it possible to visualize the dynamic spatial growth of the simulated epidemic. The article also presents an analysis of the place distribution of infections that took place. This kind of information can be valuable for policy makers, for instance to decide whether or not to close down schools. Article H shows that the explicit representation of persons and places allows for studies of how the contact patterns in a population affects the growth of an epidemic. In the article, we have shown that a high level of clustering does not always reduce the initial speed of an epidemic to polynomial growth of the number of infected individuals.

1.7 Summary of the Articles

Article A: “Spatial and Dynamic Modelling of Flood Management Policies in the Upper Tisza” presents the insurance policy issue in Hungary framed in the context of flood-risk policy issues more generally. The report further discusses how a flood risk management simulation model should be designed, what data and relationships to include, and how uncertainty should be treated. An executable prototype model was implemented, and some initial experiments were performed.

Article B: “Simulation of Three Competing Flood Management Strategies—A Case Study” (co-authored with Karin Hansson and Love Ekenberg) was presented at the IASTED International Conference on Applied Simulation and Modelling (ASM 2002), Crete, Greece. It describes the model (no longer a prototype) and the policy experiments that were performed. Three policy options were simulated in the model, and the economical consequences of them were presented and analyzed from different stakeholder perspectives.

Article C: “MicroWorlds as a Tool for Policy Making” (co-authored with Karin Hansson) was presented at the International Workshop on Cognitive Research with Microworlds, Granada, Spain. The article describes experiments in which the decision-making was made at the micro level and presents disaggregated results that show the large variety of outcomes for the property owners.

Article D: “Applying the Consumat Model to Flood Management Policies” (co-authored with Harko Verhagen) was presented at the Agent-Based Simulation 4 conference in Montpellier, France. The article describes an extension of the flood simulation model, by using the Consumat approach to represent the decision model of the individual property owners. The results are compared with respect to wealth distributions in the case of Consumat agents and simple (non-Consumat) agents.

Article E: "Multi-Criteria Decision-Making of Policy Strategies with Public-Private Re-Insurance Systems" (co-authored with Mats Danielson, Love Ekenberg, and Karin Hansson) was published in the journal *Risk, Policy and Decision*. The simulation of three policy options are described, and the results are analyzed with a decision tool where the problem is represented as a decision-tree.

Article F: "Consensus by Simulation: A Flood Model for Participatory Policy" (co-authored with Mona Påhlman) is submitted for publication in a Special Edition of *Journal of Risk Research*, Flood Risk Management: A Model-based Stakeholder Approach. The use of the flood model in a participatory stakeholder setting is described, together with a presentation of the interactive features of the model.

Article G: "MicroPox: A Large-Scale and Spatially Explicit Micro-Simulation Model for Smallpox Planning" is the first publication from the disease transmission case. The design of the smallpox transmission model is presented together with an illustrative simulation experiment. The article was presented at the 15th International Conference on Health Sciences Simulation in New Orleans, USA.

Article H: "The Functional Form of an Epidemic in a Real-World Contact Network" (co-authored with Fredrik Liljeros) has been submitted to the *Journal of Artificial Societies and Social Simulation (JASSS)*. The article investigates how the structure of a contact network affects the initial speed of an epidemic.

Articles

Article A

Spatial and Dynamic Modeling of Flood Management Policies in the Upper Tisza

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Interim Report **IR-03-002**

Spatial and Dynamic Modelling of Flood Management Policies in the Upper Tisza

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Approved by

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Leader, Risk, Modeling and Society Project

January 2003

Abstract

Flood management policy has been the subject of an international joint research project with the Upper Tisza in Hungary as its pilot study area. Design specifications for a geographically explicit simulation model are presented. Potential flood management policies, based on surveys and interviews with stakeholders, are presented. Some experiments on an executable prototype of the simulation model are also reported on, where the consequences of flood management policies are investigated. Focus has been on financial policy measures, mainly insurance. Besides more traditional evaluation of policy scenarios, the model incorporates adaptive optimisation functionality. The report incorporates three contributions:

1. the insurance policy issue in Hungary is framed in the broader context of flood management
2. the structuring of a flood risk policy model, capable of simulating flood failures and estimating the economic consequences
3. reports from policy experiments performed on the implemented prototype flood risk policy model

Acknowledgments

I would like to thank Professor Yuri Ermoliev from IIASA's Risk, Modelling and Society Project, and Dr Tatiana Ermolieva from IIASA's Social Security Reform, for helpful advices and guidance during the Young Scientists Summer Program (YSSP) 2000. I am also grateful to Dr Joanne Linnerooth-Bayer for her inspiration and support during and beyond the YSSP. Finally I would like to thank Dr Marek Makowski for his kind assistance.

I am grateful to the Swedish Member Organization (FORMAS) and IIASA for financial support during the YSSP.

Contents

List of Figures

Spatial and Dynamic Modelling of Flood Management Policies in the Upper Tisza

Lisa Brouwers (lisa@dsv.su.se)[*]

1 Introduction

The research project "Flood Risk Management Policy in the Upper Tisza Basin: A System Analytical Approach" is funded by FORMAS (the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning), see the project proposal and the progress report [27, 25] for more information. The partners in the project are (1) the International Institute for Applied Systems Analyses (IIASA) in Laxenburg, Austria, (2) the Department of Computer and Systems Sciences (DSV), Stockholm University/KTH, Sweden, and (3) the Hungarian Academy of Sciences. It is carried out within the Risk Modelling and Society (RMS) project at IIASA, and seeks to:

1. Prepare a case study of the 1998 floods in the Upper Tisza basin, Hungary.
2. Gather data and perform interviews on the interests, views of fairness and concerns of different stakeholders to use as a foundation when constructing policies for Hungarian national flood risk management program.
3. Implement and test a catastrophe model of the area, which includes hydrological models of the flood, and interdependencies between policy strategies and the distribution and frequency of risk, cost, losses, and benefits.

The work presented in this report is a summary of the work that I performed at the YSSP (Young Scientists Summer Program) 2000, at IIASA. A flood risk policy model was structured, capable of simulating flood failures in the Palad-Csecsei basin of the Upper Tisza and produce geographically explicit distributions of property losses. An additional requirement wasw that it should be possible to test different policy strategies on the model: the economical consequences should vary with the policy strategy. An executable prototype model was implemented, based on the identified model structure. Some experiments were performed to validate the structure of the model.

I would like to emphasize that the work presented in this report builds heavily on earlier work performed in the Risk, Modelling, and Society (RMS) project at the

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IIASA. Yuri Ermoliev and Tatiana Ermolieva have contributed with expertise in the fields of mathematics and statistics for disaster management, see [10, 2, 8, 9, 11]. István Galambos has provided detailed information on the hydrology of the Upper Tisza river. A flow model of parts the Upper Tisza river and an inundation model for the Palad-Csecsei basin was made [34, 11]. Surveys and interviews with the stakeholders in Upper Tisza were made by Anna Vári and Joanne Linnerooth-Bayer [38, 39, 40, 18, 27, 25]. Linnerooth-Bayer has also investigated catastrophe management globally, and the use of insurance [4, 3, 23, 24, 26]. External sources of information has mainly been a report on the Hungarian flood control development, by the World Bank [37], information and statistics on natural disasters from MunichRe [30], writings by Yevjevich [41] on flood control in Hungary, and by Reitano [31] about flood insurance programs.

1.1 Aim

The aim of this report is threefold. A justification for each aim is given in the bulleted list items:

1. To frame the insurance policy issue in Hungary in the context of flood risk policy issues more generally.
    - A broad background is needed to understand the policy problem of today
2. To structure a flood risk policy model that is capable of simulating the flood failures, and to estimate the consequences of different flood risk management strategies for different stakeholders.
    - Due to large uncertainties and many possible states, it is not possible to analytically estimate the consequences of a certain strategy; instead simulation can be used
    - It is important that the model can represent different perspectives; a strategy might be beneficial to one stakeholder and not to another
    - Scenario testing can lead into numerous iterations, with small changes of the parameters before next round, an automatic adaption of the parameter-values would be useful
3. To implement a prototype of the model and perform some policy experiments on it.
    - The prototype model should illustrate the important features, identified during the structuring, and by performing tests on the prototype model, the structure can be validated

A fourth goal, which points out the direction of future work, is to demonstrate how the model can be made useful in a participatory decision making process. The stakeholders could interact with the model by running scenarios and changing parameters. This fourth goal will not be addressed explicitly in this report, but in later stages of the project.

1.2 Methodology

I have used a system-theoretic perspective in this explorative research. Initially, a broad understanding of the Hungarian policy problem was gained through literature studies and discussions with Linnerooth-Bayer, Ermolieva, Ermoliev, and Galambos. After this initial wide approach to the problem, a second phase of abstraction took place when the most important features of the problem were identified and a structure of the flood risk management model was made; the different modules, the data requirements, and the relations, were identified.

The most important features of the structured model were represented in an executable prototype model, implemented by myself and Karin Hansson. The prototype model was built in the mathematical programming language Matlab, and was based on earlier catastrophe simulation models made by Ermolieva [10, 2]. The prototype model integrated data from the different systems that were considered relevant to the problem; the hydrological system, the geographical system, the social system, and the economical system. A series of experiments on different policy strategies was performed on the prototype model, to test if the model structure was realistic.

During these initial phases I worked at IIASA, located in Laxenburg, Austria. I shared an office with Hansson why a close cooperation was natural. The vicinity of other project members also made an intense exchange of ideas and information possible. It is difficult to divide the contributions between myself and Hansson, and the following is a simplification: my responsibilities have been to integrate all data and relations into one executable simulation model, while the responsibilities of Hansson have been to identify and implement the different goal functions and wealth transformation functions of the stakeholders.

1.3 Disposition

Chapter 2 discusses climate changes in general and the possible consequences to the hydrological system. An introduction to the conditions in Hungary and the specific river basin is also given in this chapter. Chapter 3 describes different flood management strategies. Chapter 4 gives a picture of the Hungarian policy problem, with focus on insurance issues. In Chapter 5, the problem is described in terms of interacting systems, and from this a rationale for the Tisza model is given, and the functions to be included in the model are listed. The use of computer models in participatory decision making is discussed in Chapter 6. Chapter 7 discusses conditions for it to be useful as a tool for policy-makers. The different proposed modules of the Tisza model are described in Chapter 8, and in Chapter 9 some experimental results from the executable prototype model are presented. Chapter 10 includes the conclusions, and a brief discussion on future extensions of the model.

2 Background

2.1 Climate Change

There are strong indications that humans are gradually but definitely changing the climate of the earth. Emissions from fossil fuels and greenhouse gases are altering the atmosphere, leading to an uncertain future of global warming, see, e.g., Jepma and Munasinghe [19]. The increased atmospheric concentrations of greenhouse gases lead to increases of global mean temperatures. The problem that usually is referred to as the "greenhouse effect" has developed since the Industrial Revolution. Emissions from the combustion of fossil fuels create a blanket of gases around the atmosphere of the earth. The heat of the earth does not escape properly through this layer of gas, with an increased temperature as result. Global surface temperatures have increased about 0.6°C since the late 19^{th} century, and about 0.2 to 0.3°C over the past 25 years, according to data from U.S. National Climatic Data Center, 2001.

The global warming will affect the hydrological cycle. This occurs because a part of the heating will go into evaporating larger quantities of water from the surface of the earth. The atmosphere is also capable of supporting greater amounts of water vapour. In general, an increase in the proportion of extreme and heavy precipitation events would occur where there is enough atmospheric instability to trigger precipitation events. This intensification of the hydrological cycle means more flooding with an increase in extreme precipitation events (cf. [20]). In a report, following meteorological parameters were stated as being the most important for flooding (cf. [35]):

- Precipitation (type, intensity, and volume)
- Temperature
- Wind speed
- Season of year

Although the impacts of sea level rise and associated coastal flooding have been more widely discussed, global climate change could also change the frequency and severity of inland flooding, particularly along rivers. It is also possible that increased flooding could occur in areas that do not become wetter. This is illustrated by four examples:

1. Earlier snowmelt could intensify spring flooding.
2. The need to ensure summer/drought water supplies could lead water managers to keep reservoir levels higher and thereby limiting the capacity for additional water retention during unexpected wet spells.
3. Warm areas generally have a more intense hydrologic cycle and thus more rain in a severe storm.
4. Finally, many areas may receive more intense rainfall.

2.2 Natural Catastrophes

The number of great natural catastrophes has risen, by a factor of three in the time period 1950–2000, see Munich Re [30]. Economic losses, after being adjusted for inflation, have risen by a factor of nine. According to Loster [28], the three main reasons for this dramatic development are:

1. The concentration of population and values in high-risk zones.
2. The greater susceptibility of modern industrial societies to catastrophes.
3. The accelerating deterioration of natural environmental conditions.

There are also more and more indications of a climate-related accumulation of extreme weather events. In Figure 1, the number of great natural catastrophes is

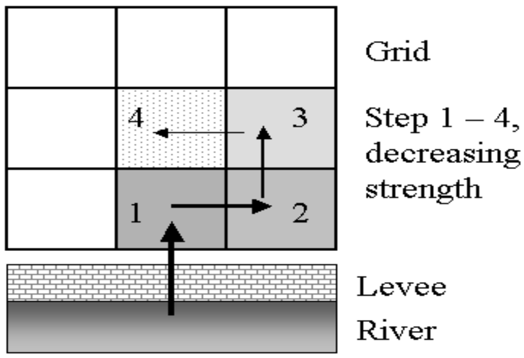

Figure 1: Number of great nature catastrophes 1950–2000,data from MunichRe.

compared over the decades, and a dramatic increase is revealed. Munich Re [30] considers a natural catastrophe to be great if the ability of the region to help itself is insufficient, why interregional or international assistance proves to be necessary. When the number of catastrophes is increasing, the financial losses escalate as well, see Figure 2.

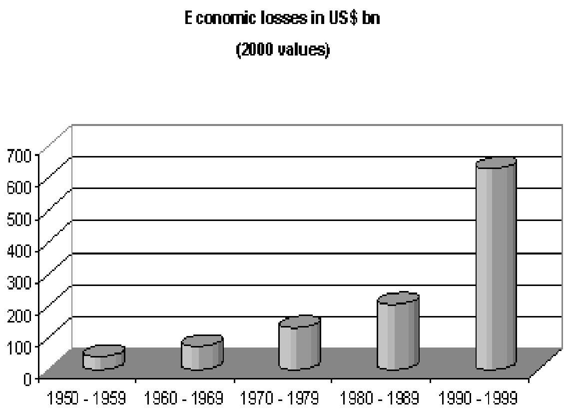

Figure 2: Economic losses from natural catastrophes world-wide, data from MunichRe.

A key problem for policy makers is to find ways to improve resilience and to protect society effectively against the increasing risk [8]. Questions of accountability and liability for preventing and absorbing the financial losses are on the political agenda in most countries.

2.3 Hungary in General

Hungary is a country where as much as 20 per cent of its 93 000 square metres of territory are at risk for flooding. The Upper Tisza region is one of the largest, natural riverside systems in Central Europe. A concentration of capital and people in risk prone areas result in increasing economical losses [23]. Due to agricultural activities and deforestation in the flood plains upstream, the water carrying capacity of the flood channels is deteriorating. Sedimentation also raises the terrain level of the unprotected flood plain. According to Kozak and Ratky [21], these factors result in ever-increasing flood levels.

2.4 The Tisza River and Upper Tisza Area

The Tisza is the second largest river in Hungary. It is a slowly flowing river with a gentle slope, famous for its beauty. Its water is a very important resource to Eastern Hungary. The entire stretches of the river Tisza is 800 km, the parts in Hungary sum up to 597 km. Through Upper Tisza, the river stretches for 235 km. It collects the waters of the Eastern half of the Carpathian basin. The source of the river is at the foot of the Magyar-Havasok Mountains, situated in Ukraine.

The study area for the Tisza project is Pilot Basin no 2.55, the Palad-Csecsei basin, see Figure 3. The basin lies on the eastern part of Hungary. Boundaries of the flood plain: from North and West the River Tisza, from East the Creek Batár and Creek Palád, from South the River Túr. The area of the pilot basin is 107 km^2, and it is located in the Szabolcs-Szatmár-Bereg County, see Figure 4. The number of persons living in the pilot basin accounts for only 2 per cent of all inhabitants in the County, an indication on how small the pilot basin is. The generality of the findings of this study can therefore be questioned. The reason for choosing such a small area for a case study was that we had detailed data available only for this area.

As much as 38 per cent of the land in the County is at flood risk. Because of few lakes in the Carpathian Mountains, the contrast between the maximum and minimum level of water is large; the level can increase by as much as 12 metres, see [36] for more information. When the flood waves arrive on the Tisza River, the speed can be extremely high, giving little time for preparation. The lack of lakes is also the explanation to the three annual floods. The first flood occurs in early spring, the second in early summer, and the third in the autumn. Apart from the minor or moderate annual floods, extreme floods occur every 10–12 years. During the last years the extreme floods appear to have become more frequent [40].

A 627-km long primary levee system protects the area from floods together with a secondary line along 94 km of the river. The nature is to a large degree untouched, as much as 4.3 per cent of the county, 25 500 ha, is nature conservation area with rare fauna and flora. The region is also famous for its historic importance. Archaeological findings prove that the region was inhabited already in the Neolithic period.

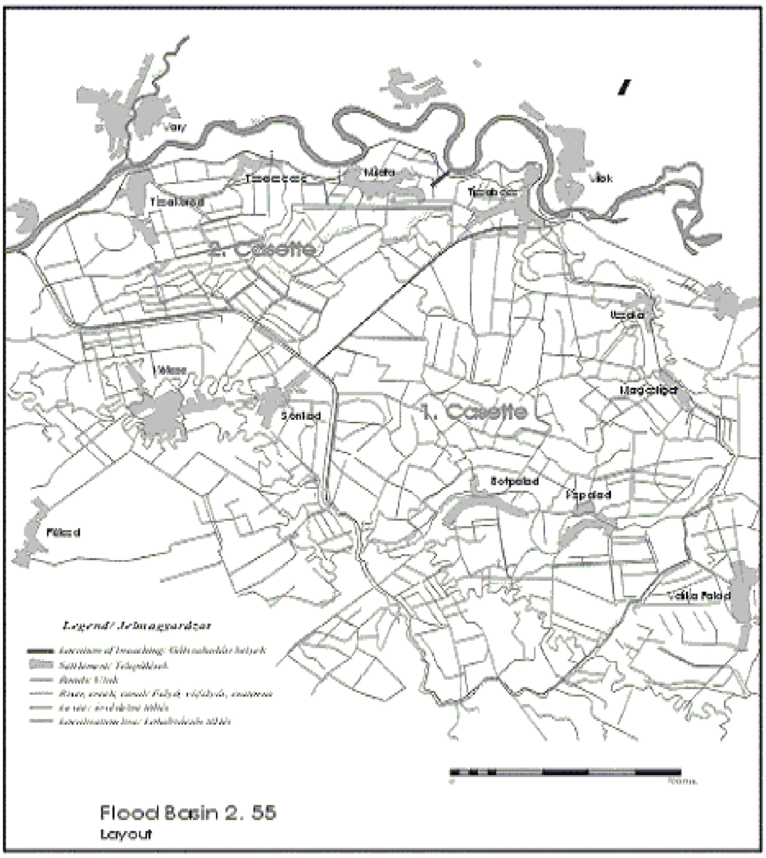

Figure 3: Basin 2.55, the study area for the Tisza Project, figure courtesy of VITUKI

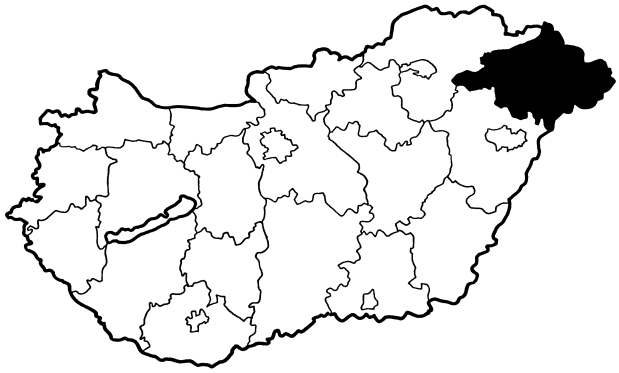

Figure 4: The County Szabolcs-Szatmár-Bereg.

It is a poor area, especially the rural areas along the river. Here, the population is very much dependent on the income from agriculture, which is not enough to support the local population. The distance between the small settlements and the cities is large, and the road connections are in a bad state. Many farmers are forced to sell their land, forests, and equipment due to economic difficulties. The situation is further aggravated by a number of severe floods in recent years. Since 1970, major floods have occurred in 1993, 1995, 1998, 1999, 2000, and in 2001 [18].

Statistics show that the region is one of the poorest in Hungary, and has a smaller agricultural production than most other regions. In 1998, the Szabolcs-Szatmár-Bereg region had the lowest average yield among Hungary's all 27 agricultural regions, for wheat, barley, as well as for potatoes, see Table 1.

Product	Position (27 regions)
Wheat	27
Rye	22
Barley	27
Maize	21
Sugar-beet	7
Potatoes	27
Grapes	23

Table 1: National rankings of the Szabolcs-Szatmár-Bereg region with respect to average yield, 1 means highest production among all regions and 27 means lowest. The figures were collected from the Hungarian Central Statistics Office [22], and reflect the year 1998.

About 200 000 people, located in 118 settlements, live in the Szabolcs-Szatmár-Bereg county. The gross domestic product per capita, expressed as percentage of the national average, was 57 in 1998. This county had the lowest GDP of all counties in Hungary, 567 000 HUF as compared to 1 858 000 HUF in Budapest, or 30.5 per cent of the GDP in Budapest. The number of unemployed was the highest in the country, 11 per cent. The beautiful areas along the Tisza would suggest a great potential for tourism and water sport activities, but this is not the case. Poor infrastructure is one explanation of why the tourism and recreation sectors are still weak here, and the cyanide spill in 2000 did not make the situation better for the young tourism industry. Greenpeace [14] among others has produced an in-depth report about the spill.

2.5 Hungarian Flood Risk Management

Flood risk management can be divided into pre-flood and post-flood actions. The pre-flood actions aim at reducing the risk for floods to occur, or to minimize the damages by moving houses out from the area for instance. Mitigation and response belong to this category. Post-flood actions include recovery and loss-sharing.

Flood protection in Hungary has a long history, and mitigation has been the dominating strategy. On January 1st, 1001 the Christian Hungarian Kingdom had already started regulating river flows and constructing protection structures against floods that endangered life and property. From documents dating back to the 13th century, it shows that it was the responsibility of the society to control floods and to minimize the risk of flooding. This view still holds, the interviews held in Upper Tisza [39] showed that most people feel that the government should compensate the victims if a levee fails. This has also been the policy, the government has a responsibility both to protect and compensate.

The technical and economical development in the 17th century made a more modern flood control approach possible. This was urgently needed as 4 000 000 ha (more than 40 per cent of the total territory of Hungary) used to be inundated when the Tisza flooded.

Before the regulations, it used to flow through the deeper parts of the Great Plains freely, causing severe damage to the arable-land agriculture. In order to increase the productivity in the region, the public appeal for river regulation grew. During the second half of the 18th century and the first half of the 19th century, activities like mapping, data gathering, planning, and designing provided the bases for flood control. The most urgent development goals for Hungary were formulated by count Istvan Széchenyi. Flood control and regulations of rivers were given top priority. Széchenyi started a national river regulation and flood control program on the Tisza River in August 1846. The plans designed within this program were almost entirely implemented during the last one and half century, as reported by Hankó [16]. During this time, Hungary became the scene of Europe's largest river controls. Large portions of land that earlier were flooded by the Tisza, were transformed into arable land. The result of these efforts is an extensive system of levees, controlling 3 860 km of the river.

3 Flood Management Strategies

Flood risk management strategies can be structured into pre-flood strategies and post-flood strategies, this is one of many possible categorisations of the different strategies:

1. Pre-flood strategies
    - Mitigation
        - Structural measures
            - Levees, dikes, dams, and reservoirs
        - Non-structural measures
            - Change location: relocate properties to less vulnerable places
            - Change land use: coding, zoning, proofing, and re-naturalisation
    - Adaptation
        - Loss Sharing
            - Flood insurance: Public, Private, and mixed (public/private)
    - Response
        - Preparedness (early warning)
        - Awareness and training
2. Post-flood strategies (recovery)
    - Bear losses (self-help)
    - Share losses
        - Governmental funds
        - Insurance
        - Charity
    - External aid (international)

Mitigation: Structural Measures

The most ambitious flood control measures within this group are levees, dikes, and flood-walls. Apart from assisting in flood control these structures also provide for irrigation, recreation, and hydroelectric power.

Levees are embankments along the course of a river. Many rivers produce levees naturally during floods when the overflowing river deposits debris along the bank. Gradually this builds up and contains the stream into the channel. Artificial levees are constructed in much the same manner. They may be temporary, as when sandbags are used during flooding, or permanent when the banks are raised to keep the river in its channel during times of increased water flow. Levees protect the surrounding countryside from floods by holding more water in the channel. They also aid in navigation by deepening the channel. A flood-wall is very much the same as a levee, but built out of concrete or masonry, instead of sand. Dikes are similar to flood-walls in all respects except that they usually refer to holding back large standing bodies of water, such as an ocean. A system of dikes prevents the North Atlantic Ocean from flooding the Netherlands.

Mitigation: Non-Structural Measures

The most typical feature of the measures belonging to the group of non-structural measures, is that they do not alter the physical characteristics of the river. These measures instead aim at changing the consequences of floods. For the last fifteen years, there has been a change in focus away from structural mitigation to non-structural mitigation measures. In industrialised countries, one possible non-structural solution is re-location. Families and businesses are moved out of the flood plain. This method is not commonly used, as there are many problems related to moving people. Even if such a policy would be economically rational, it is not often liked by the people living in the flood plain, why it is politically incorrect in most countries. In a land area with a given risk of inundation, regulations prescribe what can be done. It might for instance be forbidden to build certain types of industries in areas with a high risk of inundation. Because of the cost and environmental impacts of flood-protection structures, many parts of the United States rely on land-use regulations to prevent flood damages. This view is gaining popularity also in Hungary. Prime Minister Viktor Orban said in a radio interview that he would try to block local governments from issuing building permits in flood plains.[1]

Response and Recovery

Different concepts such as flood forecast, flood warning, and evacuation programs are grouped under this label. Awareness programs are tailored to fit the specific village or community at risk. The community engagement is very important for preventing a natural disaster or reducing the effects of a natural disaster. In very short time the event can occur, why external help may not reach its location in time. The organisation and education of local volunteers is more and more recognised as an important flood risk management strategy [1].

Loss Sharing

In most countries the government compensated victims from natural disasters to some extent. While British people get almost no compensation at all in case of a flood, Hungarian people are used to receiving full compensation. For large disasters, where the region lacks funds for recovery, aid from other regions or from other countries are quite common. In countries with restrictive government compensation, the individual can buy additional protection in form of insurance. Insurance is a way to distribute the losses over time and between policy holders. There are many different types of insurance, some are strictly commercial while others are fully or partly run by the government. A well functioning loss sharing mechanism is

[1] He also said that he would see to it that a National Lands Foundation is set up to stop cultivation of farmlands that are frequently flooded [12].

important for the recovery of a region or a country. The risk is often reflected in the size of the insurance premia, or no insurance is offered at that location. In either case, the property owner has to pay for choosing to live in a high-risk area. This could be considered fair, or unfair. The design and implementation of loss-sharing strategies in a country is tightly connected with political and ideological views. By implementing good loss-sharing strategies, the losses can be reduced. If a property owner has to take private precautions, in terms of proofing the cellar for instance, to be able to buy insurance, then the losses are likely to be lowered.

3.1 Approaches to flood risk management

Different stakeholders have expressed their opinions on flood risk management policies in interviews [38, 39]. Based on these opinions, the following categorisation has been made by Linnerooth-Bayer. It is strongly stylized, and tries to illuminate the differences in the approaches:

1. Hierarchical approach
   This approach promotes governmental responsibility, with no private responsibility. Large-scale structural measures are built and maintained by the government. If a levee fails, or if an unprotected area is flooded, the government compensates the victims.

2. Individualistic approach
   The responsibility lies on the individual, private responsibility is extensive. People should be relocated if they live in a high-risk area, but they should receive compensation for this. A system of private insurance is an ingredient, with a margin for private incentives; in order to get a reduced premium of the ground has to be waterproofed, for instance.

3. Naturalistic approach
   This approach considers floods as natural, it would be better to take down the levees and let the hydrological balance take over. The government should actively support sustainable development. An alternative non-profit insurance system could be a part of this picture.

In countries like Australia, USA, and the Netherlands, there has for the last fifteen years been a change in focus away from large-scale structural measures to non-structural mitigation measures. There is a growing recognition that the problem of flooding cannot be successfully managed by structural mitigation solutions as these deal with the symptoms of the problem, and not the problem itself.

The increasing concentration of people and property in flood-prone areas raises questions of responsibility and vulnerability. By building flood-walls and dams the frequency of floods in an area is reduced, allowing for changes in land use. The flood risk is not eliminated, however. The structures only give protection up to a certain flood level, and there is also a risk of failure of the structures. Large expensive structural measures initiated and supported by the government, seems to be very much off the current policy agenda, this view was put forward at the Australian Disaster Conference [1]. A new holistic view recognises the importance of working in harmony with nature and of approaching the problem of flooding in terms of responsible management and restoration of the natural function of rivers. Instead of spending public funds on flood mitigation structures, concrete channels are removed and the original meandering streams are restored. This new ecological approach has different names in different places, such as Total Catchment Management in Australia and Watershed Management in the United States.

4 The Hungarian Insurance Policy Problem

The cost for protection and loss reduction is peaking and the Hungarian government is considering a flood management program where private insurance plays an important role. One reason for such a program is that it is a fairer way of sharing the losses from flooding: people who choose to live in flood-prone areas should carry a larger financial responsibility. Another vital reason is said to be that private insurance would modify the population distribution so that fewer people would live in flood-prone areas. This is supposed to be the effect of reflecting the risk-proneness of a geographical location in the size of the insurance premium. The people who prefer to live in a flood-prone area must either be willing to pay high premiums or to bear the loss themselves in case of a flood. In Upper Tisza, few people would afford private insurance without subsidies from the government or cross-subsidation among the insurance takers, which raises questions on equity and fairness. Should poor people be forced to move from areas where their families might have lived for generations?

4.1 Distribution of the Economical Responsibility

In most countries, the government helps the victims of a natural catastrophe. This can be viewed as a public insurance method, as all taxpayers contribute to the governmental budget through their taxes. To date, this form of collective loss sharing, financed by the tax-payers of today and of tomorrow, plays the most important role in absorbing the financial losses from the victims of natural disasters [4]. In some countries, these premium funds are treated separately in a national disaster fund or a catastrophe pool, while in others the premiums are not separated from the state budget. Instead of a private insurance company, the government institutes this insurance program. The National Flood Insurance Program in the US is an example on a governmental insurance, insurance is not mandatory, but it is a pre-requisite for being allowed a loan where the property is the security (a mortgage). The rationale for this system is that private insurers would stand too high a risk of bankruptcy.

At the other end of the scale of responsibility lies private insurance. The private insurance can be combined with a public guarantee to assure that the insurers can rely on financial backing to avoid insolvency in case of exceptional floods. Private insurance is often restricted by many exceptions. In the Upper Tisza flood basin, insurance is only available for households in protected areas, and the insurance only cover inundation resulting from catastrophic failure of major levees.

4.2 Responsibility for Compensation of Losses

The Hungarian Prime Minister Viktor Orban declared that the state would compensate for most road damage, and was likely to decide in favour of assisting local governments in repairing damage to roads they own, from the flooding in spring 2000. He also said that the government would not categorically reject any claim related to flood damage, see ReliefWeb [12]. In Hungary there is no explicit duty of the government to compensate flood victims, but it is the policy followed in practice. Around the world different countries have implemented different strategies on how to carry the economic responsibility. In most countries, it is common to compensate flood victims except for a few countries like the UK and Australia; more information can be found in a World Bank report [37]. In Italy, the government used to compensate most of the losses for the victims. As they have to live up to the Maastricht restrictions on government deficit relative to GDP, they are now however looking for ways of passing a large part of the compensation to the private sector; for more thorough information, consult Mitchell [29].

4.3 International Implications

The most recent flooding has also highlighted the international implications of the problem, as reported in the Swedish newspaper DN [6]. The Hungarian part of the Upper Tisza region borders to Slovakia, the Ukraine, and to Romania. Prime Minister Orban accuses the neighbouring countries Romania and Ukraine for causing the flood by massive deforestation along the Tisza River. The effect of the cutting of trees is that the melt water from the snow in the Carpathian Mountains is not absorbed by the soil, but instead fills the river channel.

4.4 Current Flood Management Strategies in Hungary

The use of structural measures is still very much on the political agenda. In the spring of 2000, Hungary received a World Bank study free of charge that proposed to build dams at a length of 740 km over 10 years at an estimated cost of HUF 60 billion. The Hungarian government has allocated an equally large amount to reinforce dams during the same time period, according to the Hungarian American List [15].

There are also discussions on the possibilities of implementing a National Insurance system. The advocators of such a system stress the usefulness of an economical fund, or pool. Having the entire population contribute via an insurance channel would finance this pool. By spreading the contribution to the pool equally, the premiums in areas where the risk is high can be kept on an acceptable level. The pool would serve at least two purposes. First, to acr as capital buffer needed for insurance companies dealing with catastrophic risks. As the events are interdependent, the companies stand a high risk of insolvency if a large flood occurs. In Hungary, there are only 17 non-life insurers at work, as compared to 200 in Ukraine. A pool could play the role of a risk reserve for the insurers, making the difference between insolvency or survival and also a means to keep the premiums on an affordable level. The second purpose would be to minimize costs for the government in terms of economic compensation to the victims. At present only 60 per cent of the 3.8 million households are insured in Hungary and in the Upper Tisza region as few as 30 per cent carry property insurance. Possible explanations of this can be economic situation, as poor households cannot afford to pay the premiums, regardless of the size. The households with higher income feel they cannot afford insurance, as the premiums reflect the risk in the region. In some areas, insurance companies are not offering insurance due to high hazard potential possibly in combination with a history of high claims. Some of the buildings are considered uninsurable, as they do not meet the minimum construction standards stated by the insurers. When a catastrophe occurs, the joint efforts of the local inhabitants have proved to be the most efficient defence. For instance, in November 1998, the dikes failed in the Ukrainian section of the Tisza River and destroyed several communities. As a result of heroic flood-fighting efforts, the river did not overtop the dikes in the Hungarian section, but damages caused to levees, roads, and agricultural production in the flood plain were significant. The adoption of a stakeholder approach is one way of addressing the need for commitment among volunteers. In Hungary the participation of citizens is not yet developed. The local and regional defence and evacuation plans are not public, leaving the people at risk with insufficient knowledge for taking proper action in case of flooding [40]. The cyanide spill in the spring of 2000 brought with it raised voices for a new ecological approach to flood-plain management where the overall aim is restoration of the ecology in the region [14].

The effects of the withstanding regulations of the Tisza River are now being debated. The dams that were built during the regulation of the river cut off the flood plains and run-off areas from the riverbed, thus minimizing the flood-risk beyond the dams. At the same time, the dams caused severe losses to natural values and biodiversity. Environmental non-governmental organisations (NGOs) in Ukraine and in Hungary have suggested that all development is stopped in the flood prone area and that it be turned into a national park.

5 The Problem from a System-Analytic Perspective

5.1 Catastrophe Modeling

For complex problems, the use of a generalised representation, a model of the problem, is commonly used. The flood risk management problem in Upper Tisza is a complex policy problem due to the large degree of uncertainties, the many interdependencies, and the ambition to incorporate different stakeholders. As historical data on natural catastrophes normally is insufficient for predicting events at any particular locations, catastrophe modeling can to a certain extent compensate for this lack of historical data.

5.2 Flood Probabilities

The probability for a flood to occur during a certain year is normally expressed by its return period. Hydrologic frequency analysis is the evaluation of hydrologic records to estimate how often events of a given magnitude or greater will occur. A 100-year flood is a flood of such magnitude that over a long period the average time between floods of equal or greater size, is 100 years. The term return period is treacherous as it gives a false sense of security. It is often misinterpreted to be a statistical guarantee that hydrologic events of a given size will occur on a predictable, fixed time schedule. The probability concerns one single year and tells nothing about the accumulated risk during a longer period. The accumulated probability for a 100-year flood to occur during a time period of 50 years is 39 per cent. A 100-year event might happen once, twice, several times, or not at all during our lifetime. It is also important to remember that the calculated probabilities only are valid for a specific location in the river. As the conditions in regulated rivers often change, as new dams or reservoirs are built successively, it is very difficult to estimate the likelihood for flooding. For extreme floods, with a very long return-period, for instance a return-period of 10 000 years, the probabilities are very hard to calculate as there are few historical records to look at. In most cases there are not even 100 observations to ground statistics upon.

Severe flooding in regulated rivers occur less frequently than in unregulated rivers. Still, floods do occur in regulated rivers from time to time. When these events occur, they are unexpected and people are not prepared. For the flood managers and the policy-makers, it is important to remember that not all flood risk can be eliminated by protections. Whatever mitigation measures are taken, there is always the issue of "residual risk" and the rare event. The 1993 floods of the Mississippi/Missouri River in the USA, when 48 people were killed, is an illustrative example on how systems designed to prevent the relatively frequent, moderately destructive flood, are overwhelmed and almost completely ineffective against the more rare devastating flood. Occasionally even structures built to stand against large floods break, either from old age or from an abundance of water. In 1228, for instance, a major flood smashed through the first primitive dikes in Friesland, the Netherlands, killing at least 100 000 people, see Rekenthaler [32]. Even when levees do not break, floods can still occur. The rivers and their tributaries may for instance swell due to large spring rains. Eventually they overflow their banks and inundate the surrounding flood plains. The Yellow River in China is known for its tendency to overflow its banks. Soil carried by the Yellow River has been deposited in large amounts at the bottom of the river. Because of the soil deposits, the riverbed has been raised, increasing the risk of flooding. In the 1887 flood, nearly a million people died in China after the river overflowed its banks largely due to crop failures and famine that followed from the catastrophe, as reported by the LA Emergency Operations Bureau [7]. Seen from an economical perspective, it is impossible to build ever-larger structures to cope with events of extremely low probability. The cost for protection against very rare events grows exponentially. By building a new protection at a specific location along the river, the risk is modified. The variance and frequency of risk is transformed, but the risk is not eliminated. By building a dam upstream, the probabilities for a flood downstream will increase. If a levee is made higher, floods will be less frequent but the consequences more severe.

5.3 Rationale of the Tisza Model

The conditions in rivers are affected by many different systems, and the river system affects them. The probabilities for a flood to occur in a river and the consequences of a flood are related to systems of economy, ecology, meteorology, and hydrology. These systems are in turn influenced by the conditions in the river system. In all these systems, uncertainty is inherent. The dynamic interaction between humans, nature and technology makes the flooding problem even more multifaceted. Because of the inherent uncertainty and complexity, flooding different from anything experienced in the past might occur. Nature catastrophes do not repeat themselves. The uncertainty is further aggravated by the technological revolution: new flood protection policies make old knowledge about flood management unreliable.

The uncertainty and complexity of the flood management problem of Upper Tisza makes it very hard to use analytical methods to estimate the consequences of potential policy strategies. Due to the relative infrequency of catastrophes there is also a lack of historical data concerning major floods, and data on minor and moderate floods is of little help when assessing new policy decisions as the physical and economical landscape is constantly changing. New houses are built and assets are clustered in new locations. The methodology of "learning by doing" is not applicable when coping with rare events like natural disasters. The interval between two occurrences could be very long, and it is not morally defensible to experiment with the security of humans in order to find good protection strategies. By combining mathematical representations of the natural occurrence patterns and characteristics of a flood with information on property values, construction types, and compensation policies, a simulation model can generate loss estimates that aid the policy makers and the stakeholders in assessing different policy strategies.

5.4 Relations in the Tisza Model

A number of relations should be represented in the model. These are listed on a very abstract level here, and will be specified further.

- The cost function C determines the cost of mitigation for each agent.
- The flood function F determines the characteristics of the simulated flood.
- The inundation function I tells how the flood water overflows land.
- The vulnerability function V determines how vulnerable a building is.
- The damage function D determines how much damage the flood causes a certain asset.
- The loss function L determines how large the economical losses for an agent is, measured by the size of the replacement value.
- The wealth transformation function W determines how the wealth of each agent changes over time.

For the Tisza model to be useful it must illustrate the spatial and temporal dependencies, specific to the studied area, and specific to each stakeholder, or agent, represented in the model. As stated in the project description, the Tisza model is intended to play two roles:

1. To be used as a tool in integrated assessment.
2. To assist policy makers in identifying optimal, or at least robust, policy strategies.

The different roles pose different design requirements on the model, these are discussed and identified in the following two chapters.

6 Integrated Assessment

Integrated assessment (IA) can be defined as a structured process of dealing with complex issues, using knowledge from various scientific disciplines and/or stakeholders, in such a way that integrated insights are made available to decision makers [33]. There is a growing recognition that the participation of the public and other stakeholders is an important part of IA. This view is also recognised in the Tisza project, where it is stated explicitly as a goal to adopt an integrated participatory approach. The method for fulfilling this goal was:

1. Extraction of mental models of organisations, institutions, and the public, as input for the catastrophe simulation model.
   - An investigation of the flood risk conditions and existing mitigation and loss-sharing alternatives was made [24, 30, 13]
   - A public survey was conducted to investigate public opinion on flood risk policy management issues, see [38, 39]
2. Communication and development of the model, together with the stakeholders
   - Interviews with stakeholders in Upper Tisza
   - Presentation of the model simulations, with different policy scenarios
3. Validate the model structure and simulation results with the stakeholders
   - During the final stakeholder workshop

It is, however, not self-evident how to design a model to be useful in IA. The setting where a group of stakeholders and public participators use the model collaboratively is very different from more traditional use where an expert policy-maker consults the model to gain insight into specific issues. There is not much information on what methodological requirements to make on the design of the model for participatory IA to be found. One exception is [5], the Working Paper from the ULYSSES project. The ULYSSES project is a European research project on public participation in Integrated Assessment. The project has aimed at advancing IA methodologies by pursuing the following specific research goals:

1. Advancing IA methodology by integrating computer models with a monitored process of social learning.
2. Testing this methodology on problems of urban lifestyles and sustainability.
3. Tailoring this methodology to fit the cultural heterogeneity of the EU.

To fulfil the first objective, 52 so-called focus groups around the world were studied. In these groups, a number of citizens together with a session leader met approximately five times and debated climate change and different climate policies. The focus groups used one of six state-of-the-art computer models as help within the discussions, see Appendix B of the Working Paper [5] for a description of the different models. The six models used are different, ranging from complex and dynamic global models to simple accounting tools.

The results of this study are of high relevance to the design of the Tisza model, as one of the purposes of the Tisza model is that it should be used in a participatory setting where different policies are discussed and assessed by the stakeholders involved.

6.1 Spatial and Temporal Scales

The different spatial scales in the models used by the focus groups caused problems. While most participants considered global information as necessary for the discussion, they were more interested in regional and local aspects. Climate change as a global and long-term risk proved to lie beyond this horizon of “here and now” and to think about it was unusual and challenging for the participants.

Issues that need to be tested and evaluated before the Tisza model is used in a collaborative setting are what scales the model will use. The spatial data for a pilot basin is currently available in three different scales: aggregated for the entire basin, aggregated per municipality, and per individual cell (10×10 metres). Should only one of these scales be used or is it possible to combine two or more in the same model? The time scales are also difficult, and a short time interval is required when the catastrophes are simulated, e.g., one simulation round per month. As insurance is on the political agenda, it must be possible to evaluate different insurance schemes, for which a time steps of one year seems natural for testing premium sizes. As the floods are rare, the time period covered by the model must be quite long, say, 50 years per simulation.

6.2 Complexity

In the focus groups that used computer models with a large number of interacting variables and constants, the complexity was difficult to manage both for the participants and for the session leader. They felt that the level of complexity was too high for the little time available and the given scientific understanding. If the Tisza model is to be used in a stakeholder session, the complexity will have to be reduced as much as possible. Tests must be performed in advance to find the right balance between reduced complexity and remained usefulness. There is a risk that a simple model will convey simple insights, i.e. results that can be achieved without the use of a model. When the model is to be used in a participatory manner, the balance between complexity of the model and time available must be good.

6.3 Exploration of Policy Options

How useful the focus groups found the model to be for exploring different policy options depended on whether it was a global or a regional model, where the regional models proved to be more useful. This result is easily understood, as the consequences for local decisions are less uncertain than the consequences of global decisions. However, the regional models were criticised for not addressing the exploration of policy options in a convincing way. One of the groups complained that the model said nothing about feasibility; to what extent the measures suggested and tried were realistic, given economic, social and political constraints. It was left to the users of the model to critically evaluate their own selection of variables, which made the participants in the focus group feel abandoned.

In the Tisza model, the stakeholders must be given the opportunity to explore different policy options. An ideal situation would be if the policy variables could be changed interactively during the session without making the model too hard to understand.

6.4 User-Friendliness

The language used in the model proved to be a problem for many persons in the focus groups. Several of the terms used were unknown to the participants and the leader of the focus group had to translate into a less academic language. Regarding the graphical user interface (GUI) of the model, most groups found that the participants expected far more excitement in the form of fancy graphics and moving pictures, and that the participants wanted to see colourful maps and more vivid imagery. They felt that the graphical potential of modern PCs had not been fully utilised and would have appreciated sounds, video-clips, etc. This would have helped the understanding of the issues most difficult to grasp. The participants who were more familiar with computers typically asked for more interactivity, they said that the possibility to interactively change the values on a variable and to see the effect it caused would give the model higher believability. When designing the Tisza model, much effort should be put on the GUI. The users are likely to expect colours, sounds, and possibilities to interact with the model, and there is a risk that the users will feel disappointed if these features are left out.

7 The Tisza Model as a Tool for Policy Makers

On a very general level, the Tisza model will simulate a time period in the pilot basin, with regard to the occurrence of floods and the consequences of them. During the simulations there will be a flood when one of the following occurs:

- The water level (WL) exceeds the height of the levee (LH).
- The flow rate (FR) exceeds the resistance of the levee (LR).

The Tisza model is not only designed to be useful in a participatory setting, but for aiding policy makers in identifying good policy strategies. In a participatory setting the use of pre-compiled scenarios can be motivated, as the goal might be to reach consensus or to make clear where the different stakeholders disagree. A decision-maker needs help to identify the best policy strategy given a number of assumptions and constraints.

7.1 The Influence of Policy Strategies

The set X contains all relevant policy strategies. A specific policy strategy, x_i, is a combination of one or more policy alternatives with specified attribute values for each attribute.

A policy alternative can for instance be the strengthening of an existing levee, the implementation of a new flood tax, or a reduction in compensation from the government. The task of the policy maker is to design on a policy strategy x_i, this means to set the attribute values of all alternatives in X. To indicate that an alternative is not included in the strategy the attribute values of that alternative are simply assigned “nil”. The consequences of a flood depend to a large degree on the current policy strategy. The height (LH) and resistance (LR) of a levee affect the frequency and size of floods. By adjusting the policy strategies, the overall outcome of the simulations will be affected, why many functions depend on the value of x:

- The cost function $C(x)$ determines the costs of mitigation for each agent. The cost is directly linked to the current policy strategy: the strengthening of a levee will affect the costs the government agent, for instance. The cost for a policy strategy might be shared by all agents, through taxes, or carried by a group of agents, the property owners for instance.

- The flood function $F(t, x, WL, FR)$ is dynamic and determines the water level and discharges in a number of initially specified cross sections the time $t + 1$, given the conditions at time $t0$. If the physical conditions in the river are altered, if the height of a levee is increased for example, the conditions will be affected. There is a flood whenever $WL > LH$ (height of levee) or $FR > LR$ (resistance of levee), if x comprises one or more levees. With or without a levee, a flood occurs whenever $WL > borderheight$.

- The inundation function $I(x, t, F(t, x, WL, FR))$ specifies the water levels at all geographical cells when there has been a flood. This function is also dynamic, the duration of an inundation can be obtained.

- The vulnerability function $V(x, SD)$ determines how vulnerable an asset is. The policy strategy can affect the vulnerability, if the policy includes proofing of all houses, then they will be less vulnerable to a flood. The specific soil type, and land-use at the location also affect the vulnerability. This information is gathered in the variable SD, for spatial data.

- The damage function $D(I(x, t, F(t, x, WL, FR)), V(x, SD))$ determines how much damage the flood causes a certain asset. The damage is a function of the inundation pattern, and of the vulnerability of the flooded asset.

- The loss function $L(x, D(I(x, t, F(t, x, WL, FR), V(x, SD))))$ determines the magnitude of the economical losses for an asset. The size of the losses depends on the damages and on the current policy strategy. If x incorporates a certain level of compensation from the government for instance, then the losses are reduced.
- The wealth transformation function $W(x, t)$ determines how the wealth of each agent is modified over time. The wealth of an agent is influenced by policy decisions, viz. the tax level.

7.2 The Objective Function

The objective function $f(x)$ measures the performance of a certain policy strategy at time t. Whether the objective function should be minimized or maximised is merely a design choice. A simple example of an objective function could be to minimize the costs and the economic losses is shown in equation 1:

$$z = f(x) = C(x) + L(x) \quad \text{should be minimized} \tag{1}$$

7.3 Constraints

Policy makers have to take different kinds of constraints into consideration when looking for the best policy strategies. These constraints might be logical, economical, or environmental. These constraints, $G(x)$, are expressed either as equations, or as linear inequalities. A linear inequality might for instance be that the compensation paid by the local government must not exceed its current wealth. The problem for the policy maker is to find the best policy strategy x with regard to the objective function without violating the constraints, see equation 2.

$$\begin{array}{rcl} \text{find} & x \in X & \\ \text{such that} & h_i(x) = 0, i = 1, \ldots, n & \text{and no constraints are violated} \\ \text{and} & z = f(x) & \text{is minimized} \end{array} \tag{2}$$

The different policy strategies are compared against the objective function, and the strategy that returns the smallest value of z without violating any constraints, is the best policy strategy.

7.4 The Influence of Uncertainty

Assessing the economical consequences of a certain policy strategy is difficult, especially when dealing with potential future policy strategies. Instead of assessing the experienced consequences of a policy, by looking back at the outcome, the consequences must first be estimated.

For the Upper Tisza flood management problem, several uncontrollable, or exogenous, parameters affect the consequences of a policy strategy. The consequences depend on the strength of a flood, the time when it happens, and the vulnerability of the inundated property, among other things. Because the occurrence of a flood, as well as the consequences of it, is probabilistic, the Upper Tisza model uses stochastic modelling techniques to generate simulated floods. A large number of conditions, or states of the river, are simulated in an iterative process. The stochastic variables are assigned random values from their probability distributions for each new simulation round. The set Ω contains all states the river system can be in. Each state ω_i consists of a vector of random variables. Each random variable is assigned a value from its corresponding probability distribution.

In flood simulation models, the random variables would typically include the discharge and river water level, as well as key meteorological parameters like precipitation, wind-speed, and temperature. Also other variables like inflation rate and unemployment rate could be included in Ω. It is important that the probability distributions are carefully selected, as they constitute a key assumption about the simulation model.

By randomly selecting a value for each variable from its distribution flood model simulates a time period, normally a month or a year, of flood activity. A large number of such simulations are performed to ensure that the estimated consequences of a policy strategy are representative. Many parts of the system are directly or indirectly affected by what state the river system is in. In the mathematical representation this is made explicit by letting the functions depend on ω, the randomly decided state.

- The cost function $C(x, \omega)$ is dependent on ω. The inflation rate and the weather conditions are likely to influence the cost for mitigation.
- The flood function $F(t, x, WL, FR)$ is affected by ω through the WL function and the flood rate (discharge) function.
- The inundation function $I(t, x, \omega, F)$ is influenced by the values of ω. The wind-speed and wind direction has impact on the inundation pattern.
- The vulnerability function $V(x, SD)$ is not a function of ω.
- The damage function $D(\omega, I, V)$ comprises uncertainty. The weather conditions have impact on the damages for instance.
- The loss function $L(x, D, V)$ is not directly affected by ω.
- The wealth transformation function $W(x, \omega, t)$ depends on the random outcome. The inflation rate affects the income and the expenditures.

By addressing uncertainty explicitly, the policy problem gets more complicated. If the constraints and the objective function are affected by ω, then E, the estimated values of the objective function and the constraints must be considered. The equation 3 describes the task of finding a policy strategy that minimizes the objective functions without violating any constraints, when uncertainty is taken into consideration.

$$
\begin{array}{lll}
\text{find} & x \in X & \\
\text{such that} & Eh_i(x) = 0,\ i = 1, \ldots, n & \\
& Eg_i(x, \omega) \leq 0, i = 1, \ldots, n & \text{no constraints are violated} \\
\text{and} & z = Ef(x, \omega) & \text{is minimized}
\end{array} \tag{3}
$$

Policy makers dealing with catastrophic events must specify what risk means in their specific policy setting, and to what extent risk should be avoided. For a flood management problem at an abstract level, the risk function could be the probability of a flood. When reducing risk is the single goal of a policy maker, then the objective function consists only of a risk function. In most real situations the decision-maker has to take other things into consideration as well. A flood management policy strategy that suits a local government would have the risk of insolvency as a part of the objective function, together with the objective to maximise the wealth, or budget. An objective function can consist of one objective function combined with one or more risk functions.

7.5 Adaptive Stochastic Simulations

When X and Ω contain more than a few items, the number of possible policy strategies to evaluate becomes unmanageable. The objective function in a catastrophe model can be non-smooth or even discontinuous. A local government would normally include the wish to maximise wealth, or maybe rather to minimize the deficits in the objective function. A stylized trajectory of the wealth transformation would look like an irregular stair. Simplifications of the problem, by substituting the ran-

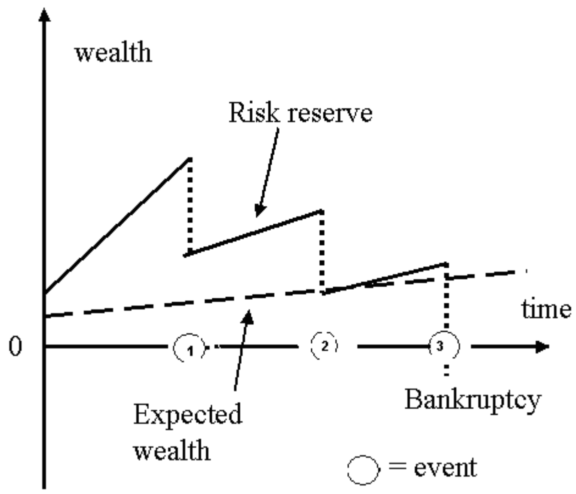

Figure 5: A stylized trajectory of the wealth of an insurance company, three events occur.

dom vector Ω by the expected values of the variables according to their distributions may lead to sub-optimal decisions. The Expected Wealth would grow linearly and insolvency would not occur at event number three, see Figure 5. The mean value hides the extreme values, and these need to be investigated when looking at catastrophic risks, characterised by having low probabilities and severe consequences. By running Monte Carlo simulations, it is possible to estimate the consequences of a policy strategy in domains including uncertainty.

A problem with traditional simulations is that it might lead the decision-maker into an endless number of time-consuming 'if—then' scenarios. Such runs start with an initial design of the policy strategy x, with which a large number of simulations are run. If the outcome of the simulation proves unsatisfactory, then the policy strategy is modified. For decisions with a large amount of alternative policy strategies, this method is highly inefficient.

To aid policy makers in identifying robust policy strategies within reasonable time limits, the Tisza model instead uses adaptive stochastic optimisation techniques. This means that several simulations are run in a series. After the first simulation the values of X are slightly changed, according to the optimisation algorithm. By running a series of simulations with an automated adaption of the policy strategy after each round, the search space is reduced, only the paths that showed promise in earlier rounds will be further explored, see Ermolieva [8] for more detailed information.

8 Executable Modules

The Tisza model will consist of a number of executable modules. The ones identified so far are the Stochastic module, the Catastrophe module, the Spatial module, the Agent module, the Consequence module, and finally the Policy and Optimisation module.

8.1 Stochastic Module

The purpose of this module is to address the uncertainty inherent in the policy problem. As the model will be used to assess different potential policy strategies, the model has to deal with the uncertainty of the future. The variables, for which we can not predict the value, are referred to as random variables in this model. The most important variables to include in Ω are:

1. The water level (WL) at all specified cross sections
2. The flow rate (WF) at all specified cross sections
3. Amount of precipitation (APR)
4. Intensity of precipitation (IPR)
5. Outdoor temperature ($TEMP$)
6. Wind speed (WS)
7. Inflation rate (IR)
8. Unemployment rate (UR)

For each variable the probability distributions must be provided. During each simulation round new values for the variables in Ω are randomly picked according to their specified distributions.

- Input (initialisation):

  - The set Ω containing the random variables, and their corresponding distributions

- Output (each round):
  - A random outcome, ω_i

8.2 Catastrophe Module

In the Tisza model, the catastrophes simulated are floods, but in other applications they might be earthquakes or cyclones. The Tisza model builds upon a catastrophe model made by Ermolieva [10] for simulating cyclones in Italy. Hydrological experts designed and built the catastrophe module. The Hungarian project partners possess expert knowledge in this field and they contributed two computer models, a hydrological model and an inundation model. The two models together constitute the catastrophe module. They are quite complex, for a more thorough description refer to documentation [34]. However, a brief explanation of the two models will be given here, in order to make the understanding of the data flow in the Tisza model easier.

In the hydrological model, the river channel of the pilot basin is represented as a network of connected hydrological units. The units are of the type cross-sections, nodes, branches, or levees. Each type has specific characteristics in terms of water resistance, etc. The hydrological model calculates the river water level (WL), and the flow rate (FR) at a number of cross sections in the network. This is done each time step, given the conditions last time step as input data. The hydrological model corresponds to the flood function $F(x, \omega)$.

Model number two, the inundation model, specifies how the water overflows the land neighbouring the river. Data collected from geographical information systems (GIS) has been used to produce inundation maps. The inundation model is represented by the inundation function $I(x, \omega)$.

- Input to the Hydrological Model (initialisation):
  - Descriptive data on the hydrological units (cross-sections, nodes, and branches)
- Input to the Hydrological Model (each round):
  - Current policy strategy, x
  - The random outcome, ω, specifically WL and FR
- Output from the Hydrological Model:
  - Water characteristics, new WL and FR, at selected cross sections
- Input to the Inundation Model (initialisation)
  - Digital Elevation Map (DEM) of the pilot basin
- Input to the Inundation Model (each round)

- Current policy strategy, x
- The random outcome, ω
- Water characteristics, new WL and FR, at selected cross sections

• Output from the Inundation Model

- Vector of inundated cells
- Information for each inundated cell:
  * Duration of the inundation (number of days)
  * Depth of water level

8.3 Spatial Module

The spatial features of the pilot basin are represented in three different scales. As an aggregate of the entire pilot basin, on a municipality level where the eleven municipalities in the basin form the units, and on a very fine-grained level where 1551×1551 equally large cells (10×10 metres) form a grid. The use of GIS data

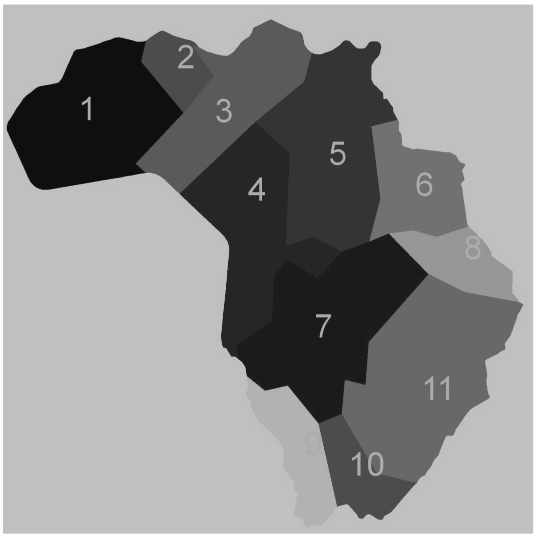

Figure 6: A map of the pilot basin with the eleven municipalities (listed in numerical order): Tiszakorod, Tiszacsecse, Milota, Sonkad, Tiszabecs, Uszka, Botpalad, Magosliget, Tiszaberek, Kishodos, and Kispalad.
Figure courtesy of VITUKI.

makes it possible to use distributed asset data rather than data aggregated on a municipality level or aggregated for the entire flood basin. Due to this distribution, the model can be used to estimate the consequences of a policy strategy on the cell-level as well as on an aggregated level, for the entire municipality.

• Input to the Spatial Module (initialisation):

- The Grid, a grid with n cells

  - Spatial data (SD) for each cell:
  - Municipality code 1-11, (see Figure 6) or 0 which indicates that the cell is outside the pilot basin
  - Asset value
  - Owner ID of each asset
  - Current land-use (code)
  - Digital elevation (metres above Baltic see level)
  - Input to the Spatial Module (each round)
  - Vector of inundated cells
  - For each inundated cell:
    * Duration of the inundation (number of days)
    * Depth of water level

- Output
  - For each inundated cell:
    * SD, spatial data

8.4 Agent Module

To be useful in participatory settings it is crucial that the model can estimate the effects of a policy strategy for different stakeholders or interest groups. The term agent here means stakeholder or interest group as an aggregate, it does not imply that the agent has the ability to communicate or act autonomously. It is stated in the project description that the different stakeholders should be represented and involved in the policy process. Many different kinds of agents can be identified as relevant to the flood management problem, e.g, the central government, the local government, the water bureau, the insurance companies, environmentalists groups, farmers, and property owners.

The interests of the agents in the model are characterised by their objective functions. Note that the objectives of the different agents could be conflicting. A specific policy strategy might be advantageous to one agent, while devastating to another; it is not sure that a strategy that maximizes the insurer's profit is popular with the individual property owner. The variable z is assigned a value from the objective function each round of the simulation. Assessing a policy strategy includes analysing how z changes over time for the different agents. In many cases the economic wealth is part of the objective function for the agents, and in these cases a wealth transformation function is required.

- Input to the Agent Module (initialisation)
  - For each type of agent (aggregate)
    * Objective function, $f(x, \omega)$
    * Wealth transformation function, $W(t, x, \omega)$
    * Initial wealth at time = t_0.

8.5 Consequence Module

For each round in the simulation when there has been a flood, the consequences must be calculated for all affected agents. The consequences from a flood vary with the location why spatial data is used in this module. Inundation information is received from the Catastrophe Module and additional data on each inundated cell is received from the Spatial Module. The damage function estimates the degree of destruction for an asset, by looking at how vulnerable the asset is among other things. A typical damage function for property would take into account the depth of the inundation, the duration of it, how vulnerable the building is, and the current weather conditions. A flood will have economic consequences for different agents in the model, the owner of a flooded asset will have its wealth updated. The wealth of other agents than the owner of an asset can also be affected; i.e., if the asset was insured the insurer will have to pay compensation.

- Input to the Consequence Module (initialisation)
  - For each type of asset
    - Vulnerability function $V(x, SD)$
    - Damage function $D(\omega, I, V)$
- Input to the Consequence Module (each round)
  - Vector of inundated cells
  - Information for each inundated cell:
    - Duration of the inundation (number of days)
    - Depth of water level
    - Spatial Data, SD, from the Spatial Module
- Output from the Consequence Module
  - Updated value of damaged assets
  - Updated wealth for affected agents

8.6 Policy and Optimisation Module

If the model is used for running scenarios, this module will not be turned on. If the simulation involves optimisation of policy options, then this module is consulted each round as the policy strategy x is shaped here. The initial strategy x is adaptively altered to fit the overall objective function, which might be the objective function of one of the agents or a compound function for different agents.

- Input to the Policy and Optimisation Module (initialisation):
  - The set X
  - Initial policy strategy, x
  - Optimisation algorithm

  - Overall objective function $f(x, \omega)$
  - Constraints $G(x, \omega)$

- Output from the Policy and Optimisation Module (each round):

  - New policy strategy $x\prime$

9 Experiments

An executable prototype catastrophe model was implemented at an early stage and refined when more relations and data were identified. All described modules were present in the prototype, but they were simplified to allow quick implementation and testing. The experiments consisted of simulating a number of different financial strategies including the optimisation of a policy variable. Two different agents were incorporated, the property agent, and the insurer agent. The property agent was modelled as a conceptual fusion of the physical property (the house) and the owner of that property. The property value represented the wealth of the owner besides how much the building was worth. The time-period simulated was 50 years, and every simulation-year consisted of 12 simulation-months.

In the Stochastic Module it was randomly decided whether the levee in the prototype model would be overtopped, break, or hold back the water. The variable $flood$ was assigned a random value between 0 and 1 from a uniform distribution with equal probability for all values in the range, every simulation-month. If the value was higher than a specified limit (representing the height of the levee border/the resistance capacity), the flood broke through, or over-topped, the levee and flooded a number of cells. As we did not have real hydrological or geographical data at that time, the following variables were assigned values randomly:

- Location of the initial levee burst/overtopping,
  one of the cells bordering the levee (equal probability).

- Initial strength of flood $= \gamma^{stepNo} \times r$,
  γ and r were random variables with values between 0 and 1, stepNo denoted the order in the inundation walk, see Figure 7 where number 1 to 4 denotes the order in which the cells are flooded. The earlier they are inundated, the larger amount of water will cover the land.

In the experiments, the inundation walk, i.e., how the water flooded the land, was represented by a random walk of five steps. For each step of the random walk, a new cell was flooded, and the flood moved randomly to one of the neighbouring cells. The strength of the variable $flood$ was reduced for each step. The wealth transformation functions for the property agents and the insurer agents were described in the Agent Module. Each agent was assigned an initial wealth: for the property agents this equalled the property value and for the insurer agents it was the risk reserve. The wealth of all agents was updated every simulation-year.

$$WT_{t+1} = PropVal_t - D_t + \sum_{j=1}^{noIns} H_t^j(x, D_t) +$$

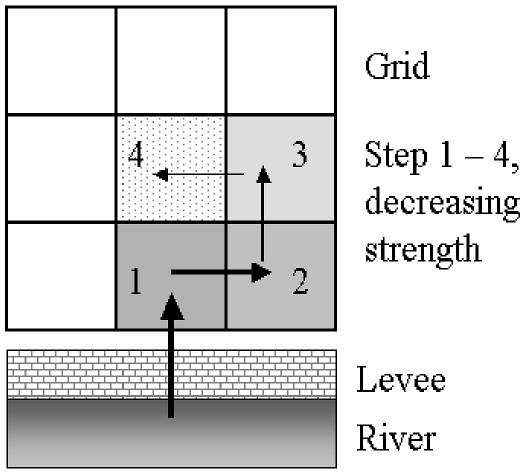

Figure 7: The flood inundates a number of cells in the grid.
Figure courtesy of VITUKI.

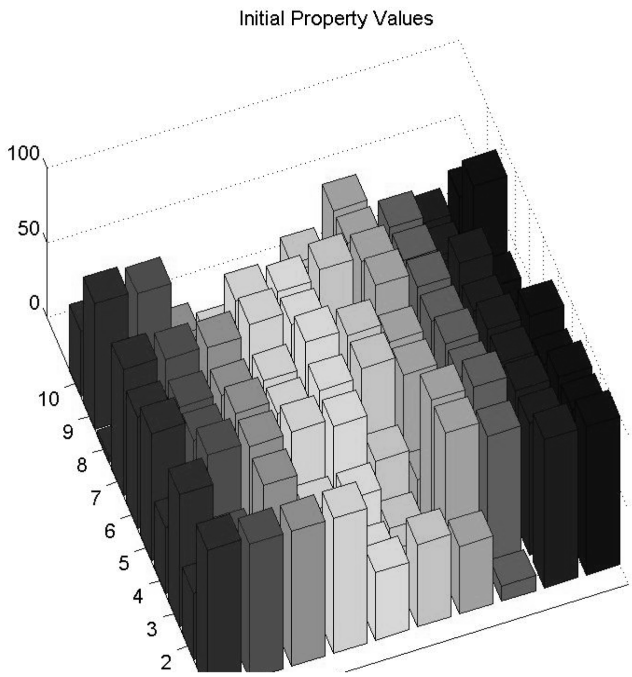

Figure 8: A landscape of initial property values.

$$GovComp_t(x, D_t) - \sum_{j=1}^{noIns} Prem_t(x, PropVal_t) \qquad (4)$$

The wealth transformation function, see equation 4, of property agents describes how the wealth (property value) is decreased with possible damages D, and increased with possible compensations H from all insurance companies the property agent has contracts with. The size of the compensation depended on the coverage, a variable in the policy vector x, and on the extent of the damage that has occurred during the year. The premiums paid to the insurance companies were deducted from the wealth (property value).

$$WT_{t+1} = RR_t - \sum_{j=1}^{noProp} H_t(x, D_t) + \sum_{j=1}^{noProp} Prem_t(x, PropVal_t) \qquad (5)$$

Equation 5 describes the wealth transformation function for insurer agents. The risk reserve, RR, of the insurance company was reduced with the sum of H, all compensations paid during the simulation-year. The size of the compensation was a function of the coverage offered (in x) and the size of the damage, D. The premiums from all clients, $Prem$, were added to the risk reserve, the size of the premiums was a function of x and the property value, $PropVal$.

Every simulation-month, when a flood occurred, the economical damages were estimated by the Consequence Module.

$$Damage_t = PropVal_t - (\gamma^{StepNo} \times r) \qquad (6)$$

How much the value of a property was reduced after a flood, was decided by the damage function, see equation 6. $PropVal$ denoted the economical value of the building, γ was a random variable in the range 01 which decided the strength of the flood, represented by the variable $flood$. The value of $flood$ was reduced stepwise, for each new cell that was inundated. $StepNo$ stated the position of the step in the inundation walk. The random variable r, also in the range 01, was added to tune the size of the damages.

Different policy strategies regarding insurance were investigated in the experiments. The variables looked at were the premium size, and the pattern of coverage. Each insurer agent was assigned a number of contracts, or cells, initially. The insurance companies offered contracts where only a part of the property value was covered, or the entire property value. For instance, when coverage was set to 0.5 of the property in a cell, it meant that that insurance company insured 50 per cent of the total property value. If the building was worth 100 000 HUF and a flood destroyed 20 per cent of the property value, the insurance company would pay 10 000 HUF (50 per cent of the damaged value) to the property agent. A coverage set to 0, constituted that the building was uninsured and a coverage set to 1 meant that the building was fully insured. The coverage patterns for each insurer agent were defined in the policy vector x.

An insurer agent could have contracts with different coverage in different cells and different insurer agents could provide insurance to the same cell, see table 2.

In a cell, the summed coverage from the different insurer agents was not allowed to exceed 1, the building could not be insured to more than 100 per cent of its value.

The pattern of coverage was optimised in the Policy and Optimisation Module in the end of each simulation-year.

The three insurer agents were given identical goal functions.

$$Goal = \prod_{i=1}^{noClients} (Prem_i(x) \times Cov_i(x)) + Risk \times min[0, RR_t] \tag{7}$$

should be maximized

In equation 7 the goal function for the Insurer agents is described. The goal function was invoked for each cell and for each insurer. If the risk reserve was negative that year, then the deficit was multiplied by the variable *Risk*. The size of *Risk* stated the risk profile of the insurance company. A high value indicated a risk-avoiding insurer. For each insurer the pattern of coverage was optimised each year. A quadratic programming algorithm was used, looking at the derivatives, the risk reserve, and the value of z (returned from the goal function), see Ermolieva [10] for details.

9.1 Results

In the first experiment the pattern of coverage was optimised, with only one insurer agent operating in the region. The experiments showed that a single insurer in the area would go insolvent rather fast, unless the premiums were very high and/or the coverage reflected the risk of the cell. The optimised coverage offered by the insurer approached zero for high-risk cells and one for low-risk cells, see Figure 9 and figure 10. In a real situation this would mean that no insurance would be offered to

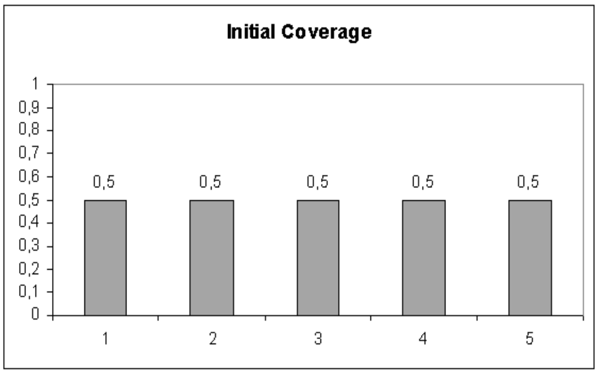

Figure 9: Initial coverage offered to five locations.

Insurer Agent	Cell 1	Cell 2	Cell 3	Cell 100
1	0.0	0.5	0.3	0.0
2	0.1	0.2	0.3	0.0
3	0.2	0.3	0.2	0.0

Table 2: Example patterns of coverage for three insurers.

households located close to a river. The economic losses for the property agents were severe as the ones who needed insurance the most could not buy it.

We introduced an additional insurance company for the next series of experiments. The insurance contracts were evenly shared between the two insurers. One cell could be insured by both insurance companies, as long as the total coverage of the cell did not exceed one (100 per cent).

By spreading the risks this way, the insurer agents managed to avoid insolvency as well as offer coverage also to high-risk locations. More information on the results from the experiments can be found in [17].

10 Conclusions and Future Work

The use of models to simulate catastrophic events is very much in demand, and the insurance industry are more and more using computer models to quantify risk, instead of relying on traditional actuarial techniques for deciding levels of premium and coverage. For such models to be useful it is necessary that they are geographically explicit.

The experiments performed on the prototype model shows that an integrated approach to modelling of policy decisions is successful. During the iterative design process relevant and realistic data has been identified, and will be included in the real model. The implementation of the prototype model and the experiments performed gave clear indications that geographically explicit catastrophe models are useful to investigate policy strategies.

For optimisation of a single policy variable, the current optimisation algorithm worked fine. Other optimisation algorithms must be implemented in order to deal with multiple policy variables.

Much work remains until the model can be used as a tool in integrated assessment. The major challenge is to find the balance where the model is easy to learn and use, without becoming simplistic and naive. A number of scenarios are under construction, describing different insurance strategies. These scenarios will be tested on the model, in a stakeholder workshop, which will take place in the autumn of 2002. Real GIS data has recently become available, and is now incorporated in the

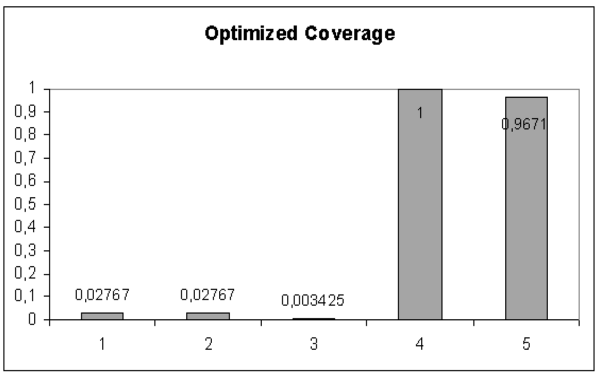

Figure 10: Optimised coverage offered to five locations.

model. Different experiments are being performed, where miscellaneous insurance schemes are investigated. To make it possible to explore the consequences for individuals as well as for aggregates, the agents are being extended with the ability of making decisions.

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Article B

Simulation of Three Competing Flood Management Strategies—A Case Study

SIMULATION OF THREE COMPETING FLOOD MANAGEMENT STRATEGIES - A CASE STUDY

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ABSTRACT

We argue that integrated catastrophe models are useful for policy decisions, for which a large degree of uncertainty is a natural ingredient. Recently, much attention has been given to the financial management of natural disasters. This article describes the results of a case study performed in northeastern Hungary where different flood management strategies have been explored and compared using an integrated catastrophe model. The area used for the pilot study is the Palad-Csecsei basin (the Pilot basin) where 4 621 persons live. The Pilot basin is located in the Upper Tisza region. An executable and geographically explicit model has been developed, linking hydrological, geographical, financial, and social data. The outcomes of the policy simulations are represented at different granularity-levels; the individual, the aggregated (entire basin), and the governmental.

KEYWORDS

flood-management, catastrophe, simulation, insurance, integrated models, risk.

1. INTRODUCTION

Natural disasters and especially floods are increasing in frequency and magnitude. Hence, costs for mitigation and compensation are rising [1].

Hungary is a country where as much as 20 per cent of its 93 000 square meters of territory are at risk for flooding. During the past decades, the central government has spent huge sums on building and maintaining extensive levee systems along the main rivers to protect the endangered land and communities. The government has not only taken the pre-flood responsibility, but also the post-flood responsibility. If a flood occurs in a protected area, this is considered to be the responsibility of the government, and the government has by tradition compensated the victims. After the recent devastating floods of the river Tisza, in 2001 and 2002, the government paid full compensation for all damaged private properties.

In Hungary, as in other countries, the government is looking for alternative flood management strategies, where part of the economic responsibility is transferred from the public to the private. In the design of different flood management strategies, a key interest for the Hungarian government has been to find the balance between social solidarity and private responsibility.

In this document, the consequences of imposing three different policy strategies are investigated. The studied flood management strategies are not necessarily optimal in any respect, but are constructed for the purpose of illuminating significant effects of adopting different insurance policies. Therefore, a main focus in this investigation has been placed on insurance schemes in combination with level of governmental compensation. In particular, the degree of solidarity, i.e., the subsidiary level has been studied, that is, how much money is transferred from low-risk areas to high-risk areas, and from richer property owners to poorer. A case study has been performed in the Palad-Csecsei basin (the Pilot basin), situated in the Szabolcs-Szatmár-Bereg County in northeastern Hungary. The second largest river in Hungary, the Tisza River flows trough the County. This is one of the poorest agricultural regions of Europe, and floods repeatedly strike large areas. The Pilot basin consists of 11 municipalities, of which primarily two experience flood damages.

The work presented in this article is part of an ongoing research project between IIASA (International Institute of Applied Systems Analysis), the Hungarian Academy of Sciences, and the Department of Computer and Systems Sciences in Sweden [2]. Interviews with stakeholders in the Upper Tisza region were also performed [3]. The purpose of these was to identify flood management strategies that are realistic and considered 'fair' by the public. Based on the interviews, three alternative flood management strategies were produced.

2. SIMULATING FLOOD FAILURE

It is impossible to predict the time, the location and the magnitude of a flood, due to the inherent infrequency of natural disasters. The shortcoming of statistical methods emphasises the role of models for evaluating new policies in presence of dependencies and lack of data c.f. [4]. Simulation models are also increasingly used for flood inundation and damage assessment, see for instance [5, 6].

The uncertainty can be treated in different ways, we have chosen to make the uncertainty explicit by considering the flood-related variables as stochastic variables. The catastrophes that are simulated in the geographical model are of the type 'flood failures'. A flood failure occurs when the flood overtops a structural flood mitigation measure, for instance a levee, or if the levee breaks. The reason for restricting the simulations to only flood failures is that insurance companies only compensate damages caused by failures, not damages caused by ground water related floods.

Nine different flood failure scenarios are implemented in the model; the flood can be of three different magnitudes, and the failure can occur at three different locations. The financial damages are estimated for all flooded properties for the nine failure scenarios. The size of the damages is directly affected by the imposed flood management strategy. The effects of these are investigated in a time-horizon of ten years. The simulation is iterated 10 000 times in order to get a statistically reliable result.

The individual property owner can choose to buy insurance or not, this choice affects the outcome both for the individual and for the insurance company. Computer based simulations are increasingly used to understand how micro order actions affect the macro order outcome, see for instance [7, 8, 9]. Simulations are a most convenient approach in this case, since it would be very hard to determine an analytical solution to this problem. In the present version of the model, we use ten different possible scenarios (nine with flood failures and one without), simulated over a period of ten years, i.e., we have $\frac{19!}{10!*9!}$ different possible outcomes for each of the three different flood management strategies.

3. THE FLOOD MODEL

The flood model consists of five modules, see figure 1. For each simulated year, the financial consequences for the different stakeholders are compiled and saved in the Consequence Module. A brief description of the functionality of the different modules is given in the following sections.

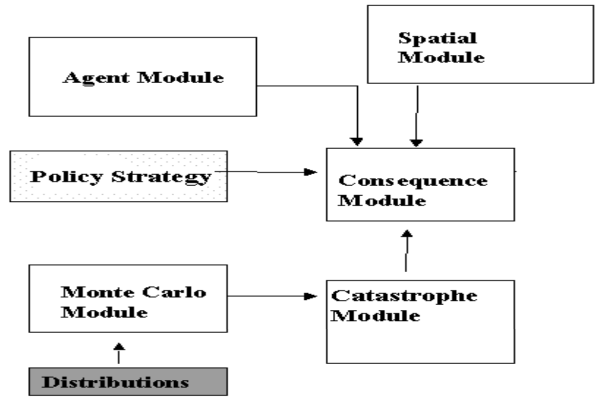

Figure 1. Modules in the flood model

3.1 THE MONTE CARLO MODULE

Two stochastic variables are used to represent the uncertainty of floods. The first variable *Magnitude* tells if there will be a 100-year flood, a 150-year flood, a 1000-year flood, or no flood at all this simulation-year. The probabilities are: 1/100, 1/150, 1/ 1000, and 1 - (1/100 + 1/150 + 1/1000). The second variable *Failure* tells if the flood will cause a levee failure at one of the three locations. The following probability distribution is used, provided by Vituki Consult Rt. [10]:

100-year flood	Location 1:	0,12
100-year flood	Location 2:	0,20
100-year flood	Location 3:	0,28
150-year flood	Location 1:	0,18
150-year flood	Location 2:	0,22
150-year flood	Location 3:	0,40
1000-year flood	Location 1:	0,19
1000-year flood	Location 2:	0,33
1000-year flood	Location 3:	0,45
no flood	Location 1-3:	0,0

For each new simulation-year, the stochastic variables are assigned random values. The random outcome is passed to the Catastrophe module.

3.2 THE CATASTROPHE MODULE

The value of the stochastic variable *Failure* is checked. For each of the nine failure scenarios, the Catastrophe module calculates what land areas are inundated, and by how deep water.

3.3 THE SPATIAL MODULE

The Pilot basin is geographically represented in form of a grid, in which every cell represents an area of 10 square meters. There are 1551*1551 cells in the grid. For each cell there is a rich amount of data, e.g., soil type, land-use pattern, digital elevation, and property value. In the simulations, only structural flood losses are considered, why agricultural data is omitted.

3.4 THE CONSEQUENCE MODULE

Only the simulation-years when a flood failure has occurred, this module is consulted. The financial consequences are calculated for each inundated cell. Data on property values and vulnerability for all inundated cells are collected from the Spatial Module. The structural losses are estimated by a loss-function, which considers initial property value, vulnerability, and depth and duration of inundating water.

3.5 THE AGENT MODULE

The various stakeholders represented in the flood model are; the individual property owner, the insurance companies, and the central government. In the end of each simulated year, the economical situation for all agents is updated. See [11]. If there has been a failure during the year, the property-value is reduced for the affected cells. Premiums are paid annually. The financial consequences also depend highly on the current flood management strategy, i.e., how much the government and the insurance companies compensates. For more detailed information on the flood model and the settings see [12, 13].

4. SIMULATIONS

This section describes the settings for the simulations, and a description of the financial indicators that are being examined.

The indicators that are outputted from the simulations and analysed, are:

- **Governmental load**: Compensation from government (plus subsidies and contribution to re-insurance fund in Scenario 3).
- **Balance for the insurance companies**: Income in form of premiums to flood insurance, minus compensation paid to property owners.
- **Balance for individual property owners**: Compensation from government plus compensation from insurance companies minus property damages and premiums.
- **Balance per municipality**: Compensation from government plus compensation from insurance companies minus property damages and premiums, the individual balances are aggregated per municipality.
- **Balance for entire Pilot basin**: Compensation from government plus compensation from insurance companies minus property damages and premiums, the individual balances are aggregated for the entire Pilot basin (all municipalities).

In this article, only the results concerning the individuals, the insurance companies and the central government are presented. For those interested, full simulation results can be collected at: http://www.dsv.su.se/~karinh/simResults0202.zip

The results of the simulations of the different flood management strategies are described in terms of financial consequences; the indicators are examined using statistical methods. When the results are presented in form of histograms, the different intervals, or bins, should be understood the following way: *–100* under a bin means that it represents the results with values less than or equal to –100. That is, the bin label always states the upper limit of the range. The lower limit should be clear from the context.

4.1 POLICY SCENARIO 1: "BUSINESS AS USUAL"

This scenario is a continuation of the current policy strategy in Hungary, where the government is the main bearer of the economical responsibility. The assumptions for this scenario are the following:

- The government compensates 100 per cent of property damages.
- 30 per cent of the households have private property insurance, a bundled insurance in which 2 per cent of the total premium accounts for flood insurance.
- Holders of private (bundled) insurance are compensated by 80 per cent by the insurance company.
- The insurance premium is not risk-based. It is based on the property-value (2 per cent of the property-value per year).

Governmental Load

The costs for the government equal zero in most 10-year periods (in 88 per cent of the periods), see figure 2.

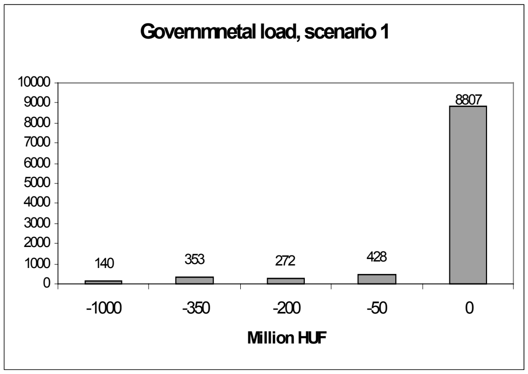

Figure 2. Histogram showing the governmental load, scenario 3.

In these decades no flood failures occurred. However, out of 10 000 simulations, 428 times the costs were greater than zero, but less than (or equal to) 50 million HUF. In 272 times the costs were 200 millions. In the most extreme decade it amounted to 2.6 milliards HUF.

Balance for Insurance Companies

When the balance for the insurance companies was investigated, only premium incomes from the Pilot basin was considered. Note that only 30 per cent of the property owners in this region has property insurance as compared to 60 per cent in Hungary in total.

The simulations show that the insurance companies make a small profit in most decades, since they receive flood premiums (2 per cent of the bundled property insurance premium) while no compensations are paid. In decades with minor flood failures the balance is slightly negative, premiums are not sufficient to cover for compensations. In extreme decades the shortage is even larger, in 272 time-periods the deficit was greater than 25 million HUF. In the decade with most failures, the deficit amounted to 560 million HUF. One explanation to why the insurance companies have a negative result in many decades is the low fraction of households with insurance.

Balance for Individual Property Owner

The results for the individuals vary considerably, mostly depending on the location of the property. To exemplify the consequences for an individual, the outcomes for an insured property owner living in a high-risk area , are presented.

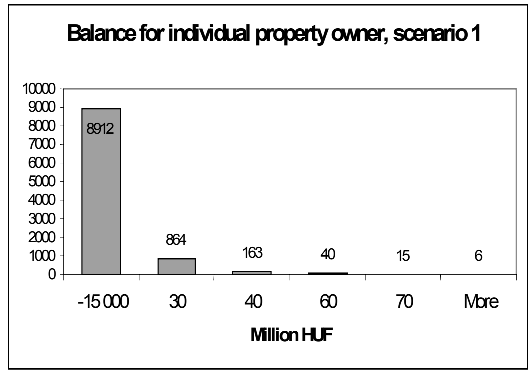

Figure 3. Histogram showing the balance for an individual property owner, scenario 1.

In most decades the property owner pays premiums without retrieving any compensation, since no flood failure occurs. When a failure occurs, the property owner is compensated by the government by 100 per cent of damages, and is also compensated by the insurance company by 80 per cent of the damages. Because of this double-compensation, the property owner gains economically if there is a flood failure. Since the premiums are based on the property value only, the risk of the location is not considered. Property owners with insurance in low-risk location subsidy the premiums for those living in high-risk locations. In 1088 decades the property owner profited largely, more than 25 million HUF.

Summary Scenario 1

1. The governmental load is extensive in this scenario, compensations to individual property owners are high, in extreme occasions more than 350 millions HUF.
2. Insurance companies in the pilot basin become insolvent when there is a flood failure. As only 30 per cent of the property owners are insured, the risk reserve is insufficient.
3. Property owners with insurance perform very well. They are double compensated; i.e. they are (highly) compensated by the government as well as by the insurance companies. The premiums are not risk based, why a person in a high-risk area pays a subsidised premium. Individuals in high-risk areas can gain economically from floods.
4. The pilot basin balance is negative in most decades, since costs for premiums are paid. Largest positive outcome was more than 500 million HUF; many households in the basin were double compensated from flood failures.

4.2 POLICY SCENARIO 2 "MORE PRIVATE INSURANCE"

In this scenario part of the responsibility is shifted from the government to the individual property owner. This is done by lowering the compensation from the government as well as the level of compensation from the subsidised property insurance, insurance 1. A new additional insurance, insurance 2, is introduced. This insurance has a risk-based premium. The assumptions are the following:

- The government compensates 30 per cent of property damages.
- 30 per cent of the households have a bundled insurance, in which 2 per cent of the total premium accounts for flood insurance. This is referred to as insurance 1.
- Holders of insurance 1 are compensated by 40 per cent by the insurance companies.
- The premium of insurance 1 is based on the property-value (1 per cent of the property-value per year).
- Holders of risk-based insurance 2 are compensated by 100 per cent.
- The premium of insurance 2 is risk-based. It is calculated from the expected damage per municipality divided by the number of properties in the municipality.

Governmental Load

As in the previous scenario, the majority of decades result in no flood failures, and no compensation is paid to the property owners. This occurs in 88 per cent of the decades. In 394 periods the losses were 2 million HUF or more. In 118 decades there compensations were large. The largest load for a 10-year period was 546 millions HUF, which is a considerably smaller load than in scenario 1.

Balance for Insurance Companies

The insurance companies receive premiums from two different insurances; one with subsidised premiums (30 per cent uptake rate in the pilot basin) and one with risk-based premiums (5 per cent uptake rate).

The balance for the insurance companies is calculated accordingly: income in form of premiums, both subsidised and risk-based, minus expenditures in form of compensation. The resulting balance is positive in most ten-year periods. In more than 8 900 simulations the balance is 15 millions HUF. The insurance companies manage to stay solvent even for minor flood failures; this can be contributed to the risk-based insurance. When flood failures occur, the insurance companies pay less compensation less than in scenario 1. The reason for this is the low compensation level for the subsidised insurance 1, in combination with the low uptake rate for the risk-based insurance 2. The most severe losses summed up to 303 million HUF.

Balance for Individual Property Owner

A property owner, who has both subsidised insurance 1 and risk-based insurance 2, pays large premiums if the property is located in a high-risk area. Premiums amount to almost 94 thousands HUF per decade for this example-individual, that is approximately 780 HUF per month. When floods occur the individual is compensated generously, from two insurance companies as well as from the government.

Summary Scenario 2

1. The governmental load is substantially smaller than in scenario 1. The largest loss was 546 millions HUF. The reason for this is that the compensation level was considerably lower.
2. The pilot basin balance shows a more negative result, since risk-based premiums are expensive for the property owner.
3. Insurance companies are showing a more balanced result than in scenario 1. The incomes are a bit lower and the expenditures are smaller. The major shortage is 303 million HUF.
4. Most property owners are worse off than in scenario 1, since only five per cent are assumed to have risk based insurance. Risk-based premiums are very expensive in municipalities 1 and 2. The example individual pays more than 9 thousands HUF per year in premiums for insurance 1 and 2. However, when floods strike highly insured households, they receive high compensation. This is because risk-based insurance compensates to 100 per cent and this is combined with compensation from government and insurance 1.

4.3 POLICY SCENARIO 3: "MANDATORY INSURANCE"

In this scenario, the government does not compensate the flood failure victims at all. Instead it is mandatory for the property owners to purchase insurance. The compensation for losses is 60 per cent. Premiums for the mandatory insurance are cross-subsidised in two ways; (1) as the premiums are not risk-based, property owners in high-risk locations are subsidised by property owners in low-risk locations, and (2) low-income households are subsidised by the government who pays the premium. The relatively low compensation is intended to stimulate property owners to take own mitigation precautions. A part of the premium income is transferred from the insurance companies to a governmental re-insurance fund. The government contributes to this fund with a small amount of the income taxes. If the insurance companies cannot cover the claims after a severe flood failure event with very high losses, the property owners will be compensated from the re-insurance fund. If the re-insurance fund would run out of money, the government would reimburse the re-insurance fund. The assumptions are the following:

- The insurance companies are re-insured by a governmentally run re-insurance fund.
- A mandatory subsidised insurance is introduced; a bundled property insurance in which 2 per cent of the total premium accounts for flood insurance.
- The premium for the mandatory insurance is 1.5 per cent of property value/year.
- Holders of mandatory (bundled) insurance are compensated by 60 per cent by the insurance company.
- The insurance companies pay 5 per cent of their premium incomes to the re-insurance fund.
- The government subsidises insurance premiums for low-income households, 60 per cent of the property owners in the pilot basin are considered to be low-income households.
- The government contributes with 0.5 per cent of the income taxes (in the Pilot basin) to the re-insurance fund.

Balance for Re-Insurance Fund

If the insurance company can not cover the claims, the re-insurance fund contributes with the deficit.

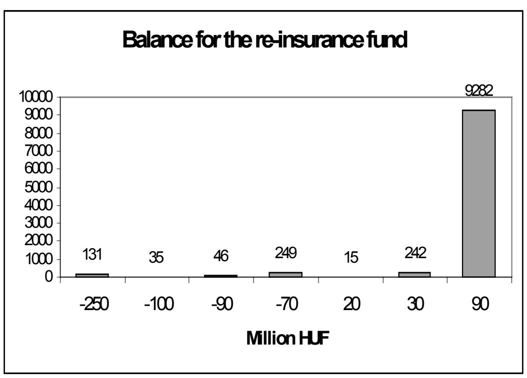

Figure 4. A histogram showing the balance for the re-insurance fund, scenario 3.

The balance for the re-insurance fund is positive in most of the 10-year periods, see figure 4. In fact, the surplus reaches 90 millions HUF in more than 92 per cent of the decades. In these time-periods, the insurance companies do not need support from the re-insurance fund (since no or only small failure occurs). However, in 461 ten-year periods, the fund has a negative balance. In 131 of the decades, the deficit is approximately 250 millions HUF. These losses occur when the re-insurance fund must support the insurance companies. The worst case scenario is a deficit of 1.4 billions HUF.

Governmental Load

The governmental load in scenario 3 consists of the money that is transferred from the government to the re-insurance fund when the balance of the fund is negative, plus the premium subsidies for the low-income households. Furthermore, tax contribution (0.05 per cent of income for individuals) to the re-insurance fund is added as a load for the government.

The load of the government is in most cases 120 millions HUF; this value consists of the subsidisation of the premiums for low-income households (60 per cent of the property owners) in the pilot basin, in addition the government contributes to the re-insurance fund yearly by 0.5 per cent of the income taxes. When the re-insurance fund is unable to cover the claims, the government reimburses these deficits. It occurs in 461 of the 10 000 simulations. However, when it does occur, the magnitude of the loss is at 249 occasions more than 190 millions HUF. In the most extreme decade, the load amounted to 1.5 billions HUF.

No description of the balance for the insurance companies is included, since insures are re-insured by the fund, and the balance for the insurance company is consequently always positive.

Balance for Property Owner

The balance for the individual property owners consists of compensation from the insurance company minus property damages and premiums.

The balance never becomes positive. This is due to the low compensation level (60 per cent). The premium costs are 20 000 HUF for each time-period. For a low-income household, the government would however subsidise the premiums.

Summary Scenario 3

1. The balance for the re-insurance fund is rather positive. In rare occasions the fund suffers high losses.
2. The costs for the government are higher than in the other scenarios, due to the cost for contribution to re-insurance fund, and aid to low-income households.
3. The insurance companies suffer no losses whatsoever, since the re-insurance fund compensates in case of insolvency.
4. The individual property owner shows a negative balance. The flood compensation is low. In the

scenario there are no possibilities for the individuals to buy extra insurance.

5. CONCLUSIONS AND FUTURE WORK

The analysis of different policy strategies would have been very hard to conduct without a geographically explicit model where the flood failures are simulated. The use of an integrated model, i.e., a model in which geographical, hydrological, social, and institutional data is represented, has been very successful in this study. By calculating the financial consequences for the most important stakeholders in the model, it is fairly easy to produce interesting results for all involved parties. It is not straightforward to conclude which of the three policy scenarios is the best, the preferences concerning level of solidarity/private responsibility have affect on this choice.

The results from these simulations will be used for exploring how suitable the three described policy strategies are for nation-wide implementation. In a first step, early March 2002, interviews will be performed with the different stakeholders in the region. They will be presented the results from the simulations and their views on the outcomes will be elicited. In the next step a stakeholder workshop will be conducted where the stakeholders can debate and promote the different policy strategies. The stakeholder workshop will take place in the late spring of 2002.

Other activities within the research project are to scale up the results of the Pilot basin to the entire County. More policy strategies are also being identified and implemented, for instance re-naturalisation; by taking down sections of the levee upstream the villages. This step is quite controversial, as much arable land would be sacrificed to save the villages. It can also be seen as a more holistic flood management strategy; floods are a natural part of the riverine system, the problem occurs when people build houses in flood basins.

It is worth mentioning that the frequency of floods and levee failures used in the described simulations are based on historical data. That is, they do not reflect recent years flood increase at all. For a number of years, the flood peaks have constantly increased. This may be accounted for by the change in the land use, for instance forest cutting, urbanization, asphalting and other changes of land use, or it could be contributed to climate changes, c.f. [14]. Further experiments with increased probabilities would in all circumstances be most interesting.

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Article C

MicroWorlds as a Tool for Policy Making

MicroWorlds as a Tool for Policy Making

Lisa Brouwers and Karin Hansson

Abstract

The Hungarian government is experiencing escalating costs for flood mitigation measures and for economical compensation to victims. In a joint research project between the International Institute of Applied System Analysis (IIASA) in Austria, Computer and System Science Department (DSV) in Sweden, and the Hungarian Academy of Science, the flooding problem of Upper Tisza in Hungary is investigated. A catastrophe simulation model has been implemented, where different policy options are tested and evaluated. We investigate how the willingness to buy insurance affects the results on the macro-level and on the micro-level.

Introduction

The economic losses from floods are escalating. One reason is that the severity and frequency of floods are increasing. Climate change may be one of the explanations of this phenomenon; a warmer atmosphere absorbs more moisture, which leads to increased precipitation as a part of the heating will go into evaporating larger quantities of water from the surface of the earth. The atmosphere is also capable of supporting greater amounts of water vapour. In general, an increase in the proportion of extreme and heavy precipitation events would occur where there is enough atmospheric instability to trigger precipitation events. This intensification of the hydrological cycle means more flooding with an increase in extreme precipitation events according to [4]. Another reason has to do with land-use changes; there has been a concentration of people and vulnerable assets in flood-prone areas during the last years.

In Hungary, the costs for protection of flood and compensation to victims are by tradition considered the responsibility of the government [6]. The Hungarian government is looking for new loss-sharing mechanisms. The government is investigating the possibilities to transfer part of the economic responsibility from the government to the individuals. A reason for this intension is that the government is under press to lower its expenditures in order to pass the economical requirements in order to be accepted as a new member of the European Union. Another motive is that the government has a desire to implement a system that is fairer, a system where the flood risk of the geographical locations affects the degree of responsibility. A person living in a flood prone area should contribute more than a person living in a safe area should. The current situation is that all taxpayers contribute equally and share the majority of the cost trough their income tax. A financial mechanism, like private insurance is one possible method for better reflecting the risk level of a certain area. The size of the premiums may reflect the flood risk of a location. Differentiated premiums can besides giving a fairer distribution of the economical responsibility also be seen as an incitement for a sounder land-use.

The implementation of a National Insurance system is a complicated policy problem. It is vital that the different stakeholders support the policy before it is implemented. One of the important stakeholders is the insurance industry. Insurers normally regard flooding as uninsurable. With escalating losses, many insurers are reducing their catastrophic cover. In Hungary, only a few companies offer insurance against floods. Moreover, the insurance contracts that are offered are connected with a number of limiting conditions; ground water related floods are for instance excluded. Many times it is difficult to tell if the flood is caused by intense precipitation, by a failure of some flood protection, by ground water elevation, or if it is caused by a combination of these factors.

The relative infrequency of catastrophe events and the resulting scarcity of historical loss data make it nearly impossible to reliably estimate catastrophe losses using standard actuarial techniques. However, recent advances in computer modelling of catastrophic events have increased the interest to offer flood insurance. By combining mathematical representations of the flood occurrence, with information on property values, construction types etc., simulation models that generate loss estimates can guide insurers and other policy makers. For such a catastrophe simulation model to be useful, it must demonstrate the spatial and temporal dependencies specific to the studied area, and specific to each stakeholder in the region. In order to investigate the effects of different flood management strategies for Upper Tisza in Hungary, an executable simulation model of the river basin has been built. In Figure 1 the basin investigated is presented. Before real data from the basin was available, a prototype model was used to perform initial experiments, see [1, 3]. These experiments indicated what features to improve or leave out in the real simulation model, which is described in next chapter.

Simulation Model

A river is affected by many systems, and the river affects these systems. The probabilities for a flood to occur in a river, and the economic consequences from a flood are strongly connected with systems of economy, ecology, meteorology, and hydrology. In all these systems, uncertainty is inherent. For complex problems, the use of a generalised representation, a model of the problem, is commonly used. The problem of investigating different policy strategies for flood mitigation is indeed complex as it is impossible to predict what state the system will be in at a certain time. By simulating the change of states, different policy strategies can be tested and evaluated on the model. A policy strategy is here a combination of one or more policy alternatives. An example strategy is *"Levee height at location 1: 5 metres, levee height at location 2: 3 metres, levee height at location 3: 2 metres, Compensation level from the government: 30 per cent, Premium levels: 3 per cent of property value"*. The catastrophe simulation model consists of several modules; see Figure 2. The stochastic variables (i.e., water-level, precipitation, discharge) are assigned new random values from the specified distributions in the Monte Carlo module each round of the simulation. The random outcome, the values of the stochastic variables telling what state the system is in, is passed to the Catastrophe module. This module contains a hydrological model and an inundation model, both developed in Hungary by Vituki Consulting [7]. The Catastrophe module calculates how the water overflows the levees in case of a flood, what land areas are inundated, and by how deep water. The Consequence module consults the Spatial Module for information on property values for the inundated cells. For each cell where

Figure 1: Basin 2.55, the study area for the Tisza Project.

there is flooded property, the economic consequences for all concerned agents are calculated and their wealth is updated accordingly. The different agents represented in the model are the property agent, the insurer agent, and the governmental agent. For a more exhaustive description of the agents, see [2]. The economic consequences depend on the current policy strategy. For each year (here represented as one simulation round) the Policy and Optimisation module evaluates the success of the current policy strategy with regard to the stated goal function. If the optimisation feature is turned on during the simulations, the policy strategy is slightly altered, in the direction that seems most promising trough an automated dynamic adaption. The search space can be further delimited by different constraints; and violations against these are checked before a new policy strategy is generated. This process of adaptive Monte Carlo simulation is described in detail by [4].

Mathematical Representation

Let X be the set of all possible policy strategies, then x_i is one specific policy strategy. The strategy described earlier is an example of such a strategy. The set Ω contains all states the system can be in, each state is described by the values of the stochastic variables. A certain state is for instance, ω_7 a vector with the following values of the stochastic variables, *"Amount of precipitation: 37 mm, Water level: 7 m, Discharge: 12"*. During our

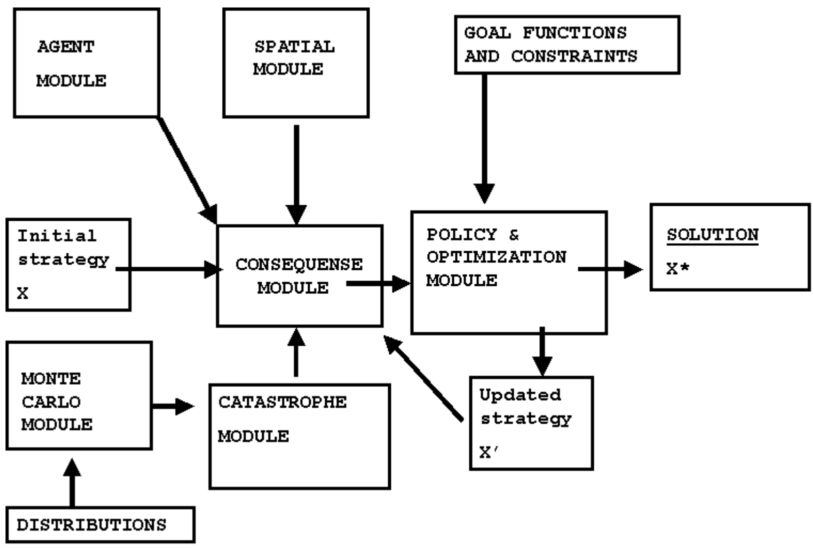

Figure 2: Modules in the system.

simulations, the vector (contains only one variable, *flood*. The hydrological relationship between water-speed, temperature, wind-speed and the flood conditions is not yet fully determined. Instead, we use nine scenarios of levee failures. Each scenario describes the structural damages for each cell.

When the economic consequences are calculated in the Consequence module, the wealth transformation function of each agent is consulted. These functions are described in the following sections.

Wealth transformation function for each Property agent

$$W_{t+1}^{prA}(x,\omega) = W_t + \sum_1^n H_t(x, g_i^t, \omega) + G_t(x, c^t, \omega) -$$
$$D_t(x,\omega) - \sum_1^n (\pi_t(x, g_i^t, \omega)) + I_t(x,\omega) - T_t(x,\omega) - E_t(x,\omega) \quad (1)$$

Let W_1 be the initial amount of wealth of the property agent, given initially as a constant. The wealth is transformed over time as a function on the size of compensation H received from one or more insurer agents i, at time t. The amount of compensation also depends on the coverage g for each insurer agent, where n represents number of insurer agents. Coverage might be a percentage of the property value or a more complicated function with thresholds. Compensation from the local government G is added to the wealth, where c is the compensation level. Cost for damages D on property is deducted. Premiums π are deducted from the wealth according to each insurer agent policy and coverage. The wealth is increased with the income I and decreased with the Catastrophe taxes to the Local Government T and the expenditures E, which contains all other expenses.

Wealth transformation function for Local government agent

$$W_{t+1}^{Gov}(x,\omega) = W_t + \sum_1^n T_t(x,\omega) - \sum_1^n G_t(x, c_t, \omega) - M(x,\omega) \quad (2)$$

The wealth of the local government is increased by the tax T, received from n property agents. The wealth W is reduced by flood compensation G paid to the property agents, and c is the compensation level. M represents the costs for flood mitigation; cost for maintenance of the three levees.

0.1 Wealth transformation function for each Insurer agent

$$W_{i=1}^{Ins}(x,\omega) = W_t + \sum_{1}^{n} \pi_t(x, g_t, \omega) - \sum_{1}^{n} H_t(x, g_t, \omega) \tag{3}$$

The initial wealth of the insurer agents, wealth at $t = 1$, is transformed by their income in form of premiums π minus compensation H according to size of coverage g.

Policy Simulations

In the simulations, we use nine pre-compiled scenarios of levee failures. For each scenario Vituki Consulting [5], has estimated the pattern of inundation and the amount of economic damages for each cell. We have the following probability distribution for the nine scenarios, also provided by Vituki:

Location.:	1	2	3
100-year flood	0,0012	0,0020	0,0028
150-year flood	0,0012	0,0015	0,0027
1000-year flood	0,00019	0,00033	0,00045

Table 1: Probabilities for flood failures at three locations, from floods of three magnitudes.

The value of the random variable $flood$ is determined in the Monte Carlo module and checked in the Catastrophe module. If it is less than 0.01238 an event has occurred. The variable $flood$ is assigned either the value of the scenario that has occurred according to the scenario distribution, or zero. The geographical information data at hand were at a very fine-grained resolution, the size of each cell measuring 10 m^2, forming a grid of 1551 $\times$ 1551 cells. As the focus of our simulations is to investigate the economical consequences of different financial policy measures, we filtered out all cells that did not contain property and use only the remaining 2508 cells.

Depending on the desired scale of granularity in a model, an agent can represent either an individual or an aggregate. For a realistic modelling of the flood management problem of Upper Tisza, the ideal would be to model each individual property owner as an agent with capabilities to reason and act autonomously and with the ability to communicate with other agents. Our agents lack the ability of communication, however they can reason about the choice to buy insurance or not.

Results of the Simulations

We present the results of four policy simulations, where insurance was used as the policy strategy of which the parameters were altered. In the first rounds of simulations, we used the settings described in Table 2. We found

Compensation level from local government	100 per cent of damages
Catastrophe tax level	2 per cent
Number of insurer agents	0
Number of simulations	50 × 12
Income of property agents	Randomly generated Normal distribution, mean = 33690 Standard deviation 10000)

Table 2: Settings for the first rounds of simulations.

that the local government went insolvent at the first flood event, see Figure 3. This indicates that such a policy strategy is very costly for the local government. For the second simulation, we increased the tax level to 10 per

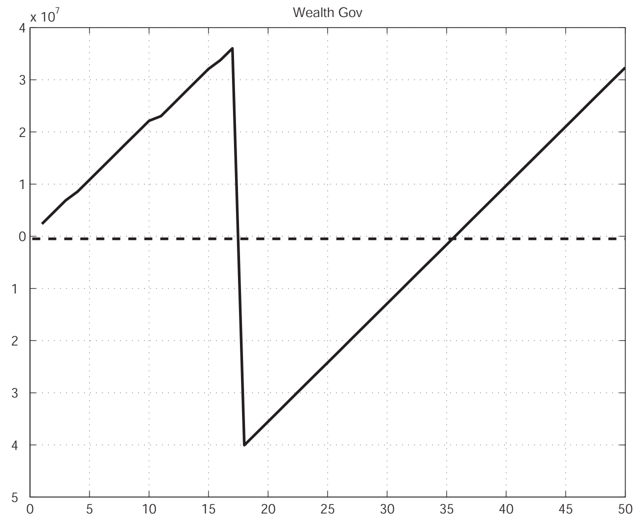

Figure 3: Dynamic wealth of government (tax 2 per cent).

cent, all other parameters stayed the same. We found that even though the government avoided insolvency, some of the property agents became very poor, see Figure 4. We investigated a different approach by introducing two insurer agents the next simulation. Tax level was lowered to 2 per cent, and compensation level from the local government was reduced to 40 per cent. The coverage level of the insurers was set to 70 per cent of the property value. The assumption that all property agents would buy insurance was made. Premium size was set to 3 per cent of covered property value.

The overall results from this policy simulation looked good. However, the assumption made is not realistic. In Hungary only 40 per cent of the house owners buy insurance. Therefore, we performed a last round of simulations where property agents were given the choice of buying insurance or not.

The decision function $DF = N + AW + H + RW$ consisted of the following four parts:

1. N (neighbours): A function of the number of neighbours (the four closest), who have insurance
   0 returns - 5, 1 returns - 3, 2 returns 0, 3 returns 3, and 4 returns 5.
   Range: [-5 , -3 , 0 , 3 , 5]

2. AW (available wealth): Returns 1 if current wealth minus premium ≥ 0
   otherwise -10 is returned
   Range: [-10 , 1]

3. H (history): Returns -5 if the sum of $flood$ for $cell_i$ from the first round to current round = 0
   (in that case no flood failure has occurred)

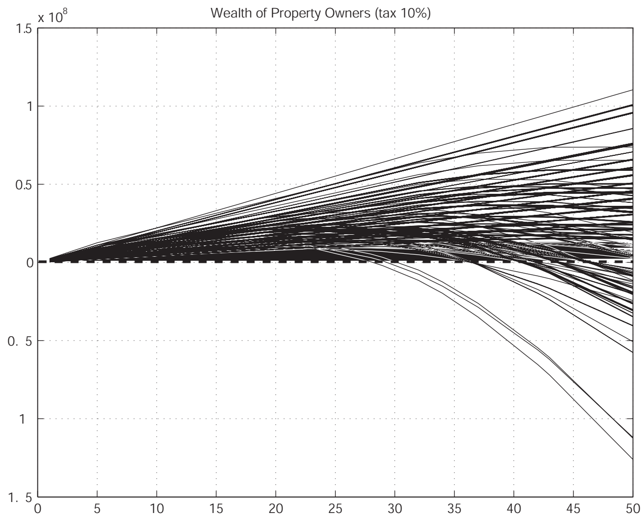

Figure 4: Property agents go bankrupt.

otherwise the sum is returned
Range: [-5 , 1 ... $9^{CurrRoundNo}$].

4. *RW* (risk willingness): Returns a random value
Range: [-5 ... 5]

In the initialisation of this simulation, 40 per cent of the property agents were randomly picked to have insurance. The proportion was chosen as it corresponds to the real situation, as much as 60 per cent of the people in flood risk areas in Hungary has no flood insurance for their homes [6]. All other parameters where unchanged. The decision function was consulted for each property agent for each round (each year) and if the value was 0 or below the agent did not buy insurance.

The results showed that the insurer agents went insolvent after a few events, since the wealth was reduced with the number of property agents who declined the offer. The government stayed solvent, as their wealth was not affected since a large proportion of the responsibility had been transferred to the property agents. On the surface the property agents appeared to be solvent, but when investigating the micro level we found that insolvency did occur, see Figure 5.

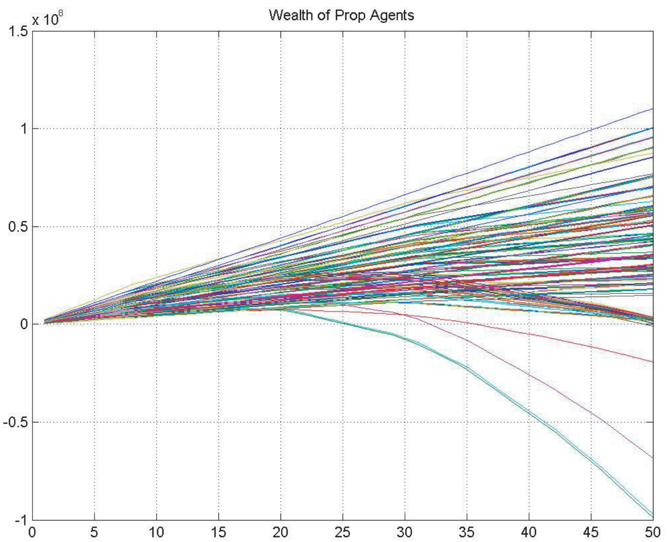

Figure 5: Wealth of property agents, when risk-willingness is introduced.

Most vulnerable were the poor property agents in risk-prone location who could not afford insurance. Risk-willing property agents in safe areas, decided not to buy insurance, as history indicated that it was unnecessary. When a rare disaster (scenario 7 or higher) occurred, these property agents were severely affected.

Conclusions

When modelling policy problems it is important to take the linkage between the micro and the macro level into consideration. Traditional catastrophe models neglect this aspect, by using aggregates and average values instead of distributions. Our simulations of the flood management problem of the Upper Tisza basin show the need for catastrophe models with the ability to represent agents at different levels of granularity and with the possibility to include social patterns. We have made a first step in this direction by letting the overall outcome be affected by the decisions of the individuals. The individual decision-maker is in turn affected by other agents, forming a social network of decision-makers.

The model is currently being extended and provided with a graphical user interface, in order to use it interactively at a stakeholder workshop.

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Article D

Applying the Consumat Model to Flood Management Policies

APPLYING THE CONSUMAT MODEL TO FLOOD MANAGEMENT POLICIES

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ABSTRACT

The number and severity of weather related catastrophes is increasing, possibly due to climate changes and changes in land use. Economic losses from these catastrophes are escalating, mainly as a result of concentration of assets and population in high-risk areas. How to deal with these economic liabilities in a fair way at the level of the individual property owners is the focus of our research.

As a case study we choose the second largest river in Hungary, the Tisza, which flows through one of the poorest agricultural regions of Europe, and where large areas are repeatedly struck by floods. The Hungarian government is experiencing huge costs for flood mitigation measures and for economical compensation to the victims. The use of a simulation model for evaluating alternative flood management policies is a natural choice, since it is impossible to predict the time, the location and the magnitude of a flood; historical data is of limited use when looking at the outcome of future policies. The simulation model (Brouwers 2002) shows the economic outcome for the various stakeholders (the individual property owner, the insurance companies, and the central government). The behavior of the river and the financial consequences are simulated on a year-by-year basis.

In the research reported upon, we have extended the simulation model by using the Consumat approach to model the individual property owners. We compare the results with respect to wealth distribution in the case of Consumat agents and simple (non-Consumat) agents.

It is shown that in the Consumat case, the system is more dynamic and seems more realistic. We plan to further investigate these effects and hope to obtain real world data on insurance distributions to verify the outcomes.

INTRODUCTION

There are strong indications that humans are gradually but definitely changing the climate of the earth. Emissions from fossil fuels and greenhouse gasses are altering the atmosphere, leading to an uncertain future of global warming (Jepma and Munasinghe 1998). A possible correlation between the climate change and the frequency and severity of natural disasters can be seen. When the number of catastrophes is increasing the financial losses escalates as well. During the period 1988 - 1997 major natural catastrophes cost the worlds economies US$ 700 billion (Munich Reinsurance Company 1998). The raise cannot be explained by the higher frequency of catastrophes alone. An increased concentration of populations and vulnerable assets in high-risk zones is said to be the main reason to the rise of economic damages (Loster 1999). A key

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problem for policy makers is to identify ways to improve resilience and to protect society effectively against the increasing risk. Questions of accountability and liability for preventing and absorbing the financial losses are on the political agenda in most countries.

For the current article we want to focus upon the distribution of wealth to see if the floods, that only effect part of the basin, has disproportional effects upon the income and wealth of just a few agents. For this we use the Gini coefficient (Gini 1912). As part of the continuous development of the model, we implemented an agent-based model based upon the Consumat approach (Jansen and Jager 1999, Jager 2000). Below we will in more detail describe the case and the Consumat approach. Following this we describe the simulation model. After this we present the simulation results and finally the conclusions and future research are discussed.

THE UPPER TISZA CASE

Hungary is a country where as much as 20 per cent of its 93,000 square meters of territory are at risk for flooding. The Upper Tisza region is one of the largest, natural riverside systems in Central Europe. Both international and Hungarian studies indicate that floods are becoming higher and more frequent, probably as a result of global warming and land-use changes.

The Tisza is the second largest river in Hungary. The part of the Tisza called Upper Tisza stretches to the county of Szabolcs-Szatmár-Bereg. There is no extensive lake system in the Carpathian Mountains, resulting in a large contrast between the maximum and minimum level of water. The lack of lakes is also the explanation to the three annual floods in the Tisza. The first flood occurs in early spring, the second in early summer, and the third in the autumn. Apart from the minor or moderate annual floods, extreme floods occur every 10 – 12 year. During the last years the large floods appear to have become more frequent, large floods occurred in: 1970 (levee breaches), 1993, 1995, 1998, 1999, 2000, and 2001 (dike burst).

Within an international research project (from Austria: IIASA, from Sweden: Department of Computer and Systems Sciences - Stockholm University/KTH, and the Hungarian Academy of Sciences) a case study was performed to identify flood management strategies that were acceptable to the involved stakeholders. The stakeholders involved in the project were the water management bureaus, the insurance companies, the municipalities (represented trough the mayors), catastrophe management organizations, and environmentalist NGO's. To be able to test different flood management policies, a small basin was modeled. During the final stakeholder workshop, which took place in September 2002, the stakeholders used the computer model as a tool for discussing and evaluating different policy alternatives.

The basin of study is located in a poor area where the population is dependent on agriculture. Still, the income from agriculture is not sufficient to support the local population. The intention to shift part of the economical responsibility from the government to the individual property owners is a challenging task to accomplish, as most people are too poor to be able to buy insurance. A flood can be very rewarding for those with insurance however; due to current practice of double-compensating the victims, some property owners receive compensation from both government and insurer.

In the flood model, which was used in the Tisza-project, the property owner agents were not modeled as decision-making agents. It was assumed that all property owners who could afford insurance would buy it. The extended model presented here is a first step in the direction of making the model more realistic.

THE CONSUMAT APPROACH

Wander Jager (Jager 2000) and Marco Jansen developed the Consumat approach. It is a model of human behavior with a focus on consumer behavior. It combines in an elegant way many of the leading psychological theories, such as theories about human needs, motivational processes, social comparison theory, social learning theory, theory of reasoned action, etc. The theories mentioned all explain parts of human behavior but lack the generality to take all circumstances into account, thus rendering them less useful for an overall view. To rectify this, Jansen and Jager set out to develop a meta-theory, which in its turn became the Consumat model.

The driving forces at the macro and the micro level determine the environmental setting for the Consumat behavior. The micro level is formed by the individual Consumats, have needs which may more or less satisfied, have opportunities to consume, and have various abilities to consume the opportunities. Furthermore, Consumats have a certain degree of uncertainty. Depending on the combinations satisfied/not satisfied and certain/uncertain, the Consumats are engaged in four different cognitive processes: repetition, deliberation, imitation and social comparison. When a Consumat is both certain and satisfied, it has of course no reason to change its behavior, thus repetition is the strategy chosen. An uncertain but satisfied Consumat has a reason to change its behavior. In this case the cognitive process chosen is imitation of its neighbors. An unsatisfied but certain Consumat on the other hand will deliberate. The final strategy is to consult the social network, the strategy chosen by uncertain and unsatisfied Consumats.

SIMULATION STUDIES

The simulation experiments are performed on the flood simulation model introduced above, used for investigating the effects of various different flood risk management strategies. The flood model has been used in a study about flood mitigation and loss sharing in northeastern Hungary, in the Upper Tisza region (see Brouwers 2002 for a detailed description). Most of the data used in these agent-based social simulations are real data from the Palad–Csecsei basin; in some cases real data were not available (e.g., a geographically explicit income distribution) in which case we used fictive but realistic data.

The flood model simulates flood failures in the Palad–Csecsei basin. A flood failure occurs when a levee breaks, the flood overtops the levee, or when the water finds its way under the levee. The reason for restricting the simulations to flood failures is that insurance companies compensate damages caused by failures, but not damages caused by ground water related floods.

Nine different flood failure scenarios are implemented in the model. This is based on the assumption that the flood can be of three different magnitudes, and that a failure can occur at three different locations. The financial damages are estimated for all flooded private properties for the nine failure scenarios. Even with a hydrological model, it is impossible to model when and where a levee failure will occur. This uncertainty is made explicit in the stochastic variables Magnitude and Failure. For each simulation year the stochastic variables are assigned new random values. Magnitude tells if there will be a 100-year flood, a 150-year flood, a 1000-year flood, or no flood at all. The probabilities for these events are: 1/100, 1/150, 1/ 1000, and 1-(1/100 + 1/150 + 1/1000). The second variable Failure tells if the flood will cause a levee failure at one of the three locations.

For each simulated year, the financial consequences for the property owner agents are computed. If there was a flood failure the simulated year, the Catastrophe module calculates what land areas (cells in the grid) are inundated, and by how deep water. The Palad-Csecsei basin is geographically represented in form of a grid, in which every cell represents an area of 10 square meters. There are 1551*1551 cells in the grid. Only private properties are considered in these experiments, so all other cells are filtered out. If a flood failure occurred the simulated year, the Catastrophe module is consulted. The financial damages are calculated for each inundated cell. The losses for an individual property owner depend on the prevailing loss-sharing policies. In some countries the government compensates the victims to 100 per cent, while other countries are more restrictive. In addition, the property owner can buy flood insurance. The wealth of all property owner agents is updated in the agent module every year, after consulting the policy module to find the current loss-sharing strategies.

Description of Agent Decision Making Model

As described above, we have two different types of agents that we compare. The first type of agents have a simple decision making model. This means that if an agent has enough financial means to buy insurance, it does. The other model is based upon the Consumat approach described above. Thus agents have the following alternatives:

1. Agent is satisfied and certain: Repetition

2. Agent is satisfied but uncertain: Imitate neighbors (if more than 2 neighbors are insured, the agent will also buy insurance)

3. Agent is not satisfied but is certain on flood risk: Deliberate (change strategy if the agent can afford to buy insurance)

4. Agent is not satisfied and is uncertain on flood risk: Imitates Social Network (goes with the majority in its network)

Agent satisfaction is coupled to the financial means an agent has. An agent is satisfied if its wealth is larger than the agent's satisfaction threshold and if its wealth is larger than last year. The uncertainty of an agent is coupled to its risk profile and the number of years that has passed since the last flood failure occurred. In the section on simulation setup all functions are specified.

Simulation Setups

General assumptions:

- Income = random distribution with mean 36 900 * 12
  12 * average monthly income (which is 36 900 Hungarian Forints, statistics from 1998) using a normal distribution
- Flood frequency = 4
  As statistical records do not reflect last decades' increased flooding, the return period for floods has been decreased. Flood frequency 4 means that the probability for a 100-year flood to occur is: 1/100 * 4
- Premium size for insurance = 0.02 per cent of the property value
  The size of the insurance premium does not reflect the underlying flood-risk; it is based on the property value alone. This corresponds with existing premium prizing in Hungary
- Penetration rate = 0.6
  The fraction of property owners who carry flood insurance (bundled with property insurance). The average penetration rate for property insurance in Hungary is 60 per cent
- Expenses = 0.9
  The figure 0.9 is just estimation, however, the area that is simulated is a very poor area. Thus 90 percent of an agents year income is spend on direct expenses.
- Content Threshold = 10.000 HUF
  This figure corresponds roughly to 1/3 of a monthly income, an agent who has less money to spend (for an entire year) is not content

- Flood Compensation from Government = 0.5
  This figure shows the trend to reduce compensation from government; it used to be much higher (90 – 100 per cent of damages).
- Flood Compensation from Insurer = 0.8
  For the property owners with insurance contract, the insurance companies compensate a fraction of the damages. The size of the fraction can be decided by using different coverage, or deductibles. For simplicity, we are assuming that the companies deduct 20 per cent of the damages and only compensate to 80 per cent

Social assumptions:

- Minimum number of contacts in social network = 2
- Maximum number of contacts in social network = 50
- Number of Social Nodes = 10
- Probability for a property owner to know a social node = 0.9
- Number of neighbors = 5

Simulation assumptions:

- Time period that is simulated = 30 years
- Number of property owner agents = 2580
- Series of simulations = 2
- One series of 9 * 30 years with Consumat model for decision making on insurance
- One series of 5 * 30 years with simple model for decision making on insurance
- Wealth transformation function for property agents (an agent can not have a negative wealth in these experiments)
- No flood failure occurred this year:
  - Wealth year n = max (0, Wealth year n –1 + Income * (1-expenses) – Insurance premiums)
- A Flood failure did occur this year:
  - Wealth year n = max (0, Wealth year n –1 + Income * (1-expenses) – Insurance premiums – Flood Damages + Gov Compensation + Insurance Compensation)
- Risk function
  - Risk for flooding = RiskValue - log2 (Number of years since last flood)

  If the risk is higher than zero, a flood is expected. The risk values are randomly distributed between zero and five. A risk value of zero means that the agent will never expect a flood since the risk function is always below zero. A risk value of 5 means the agent will always expect a flood even if it has not occurred within the last 30 years (which is the maximum number of years in the simulation).

The Gini coefficient

The Gini coefficient is the most used measure for inequality. We used the Gini coefficient to analyze the results of the different simulation settings with respect to the distribution of wealth within the agent population. Since we do not have the corresponding data for the real population, we are only interested in trends.

SIMULATION RESULTS

The simulations were run only a couple of times to obtain a feeling for the possible results. The base model, where agents buy insurance when they can afford it proved to produce a rather static society. Less and less agents bought insurance since most of the uncertain agents were those who suffered from floods while their neighbors did not and most of time did not buy any insurance. The results for the five runs of this model are depicted in figure 1.

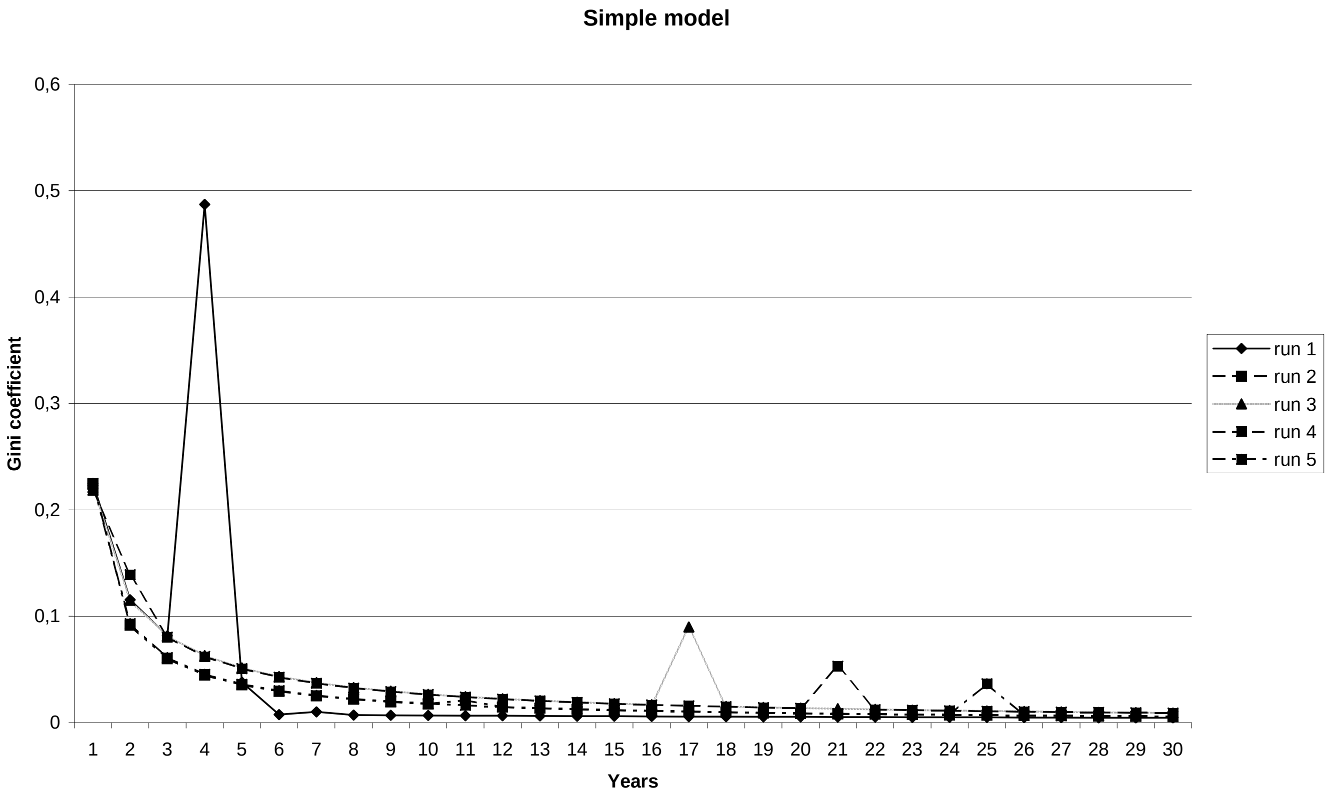

Figure 1: Gini coefficient for the base case simulations

The Consumat based simulations on the other hand show a more dynamic, one might even say chaotic society. Most floods resulted in changes in insurance buying behavior and in a skewer wealth distribution. The results are depicted in figure 2.

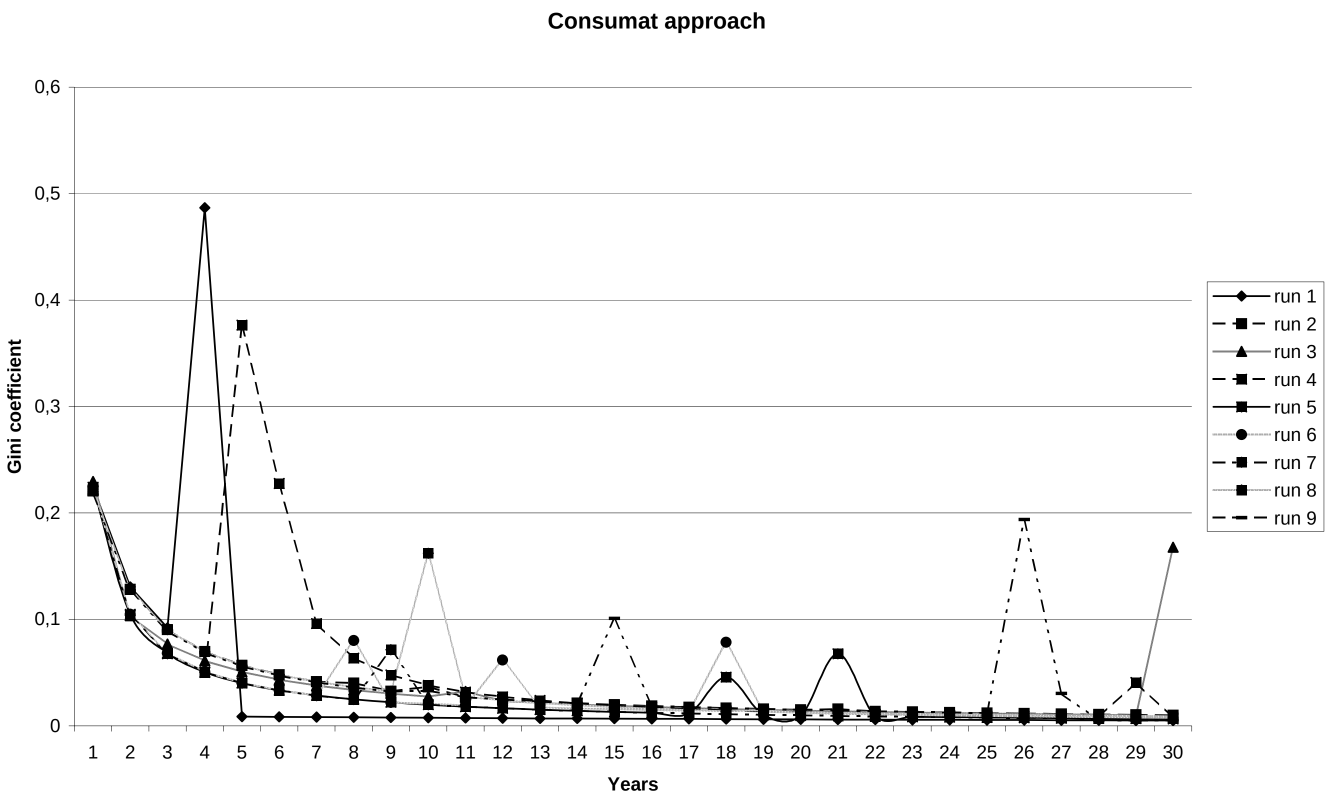

Figure 2: Gini coefficient for the Consumat-based simulations.

DISCUSSION AND FUTURE RESEARCH

The extension of the model has proven successful, since the results are more in line to the real world. Even if the Gini coefficient values are not in the range usually found in a whole society, in our case most inhabitants are very poor and have about the same amount of money to spend. We plan to further investigate these by on the one hand approach insurance companies to try and get access to their statistics, and on the other hand by interviewing a representative selection of the inhabitants in the studied basin to investigate their social network and decision making procedures.

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Article E

Multi-Criteria Decision-Making of Policy Strategies with Public-Private Re-Insurance Systems

Article F

Consensus by Simulation: A Flood Model for Participatory Policy Making

Consensus by Simulation:
A Flood Model for Participatory Policy Making

Lisa Brouwers & Mona Påhlman

Abstract

In this article, we describe the design, implementation, and use of a flood simulation model, one of the activities n the Upper Tisza flood management project. The overarching goal of the project was to design a flood management policy that shifted part of economic disaster liability from the central government to individuals. The developed model was dynamic and spatially explicit, and it incorporated elements like micro-level representation and Monte Carlo techniques. It was also provided with an interactive graphical user interface; this addition changed the simulation model from a decision tool for a single expert user into a tool more suitable for decision-making in a participatory setting with multiple users. The model supported comparisons between predefined policy options as well as the design of new policy options. During a workshop that concluded the research project, the model was used interactively by the stakeholders in support of their decision making process; consensus was reached on a policy option that was designed during the workshop.

1 Background

It is hard to estimate the consequences of imposing new flood management policies; the outcome is a result of interacting natural, economic, political, and social systems. Recent interest in sustainable development and integrated assessment has demonstrated the need for holistic models in which natural systems are represented together with social and economic systems, and the interconnectedness between these systems is made explicit. A holistic approach often means that the problem under study becomes complex. When the merits and drawbacks of potential policy options are analyzed, it is hard to estimate the consequences on the real system. Instead, it is common to use a model to which the competing policy options are applied. Since the policies are intended to be applied in the future, it is not possible to decide the state on the system beforehand. One way of tackling this uncertainty is to evaluate the policy options under different possible future scenarios. The policy options must be evaluated many times to allow for a large variety of possible future scenarios. Modern computer techniques allow us to test systematically the uncertain variables such as water level or amount of precipitation, are assigned new random values for each simulation round. The simulation is repeated many times to ensure statistical reliability.

During the past two decades, spatially explicit catastrophe models have been used to quantify the risk of damage exposure, primarily by insurance and reinsurance companies [7, 11]. These models normally cover large geographic areas and use large amounts of property data and land data to calculate the effects of occurrences at different locations. Because of data intensity, the models are often aggregated by region or zip code. Micro models, on the other hand, represent each individual or household explicitly, that is, the objects in the real world correspond to the objects in the model in a 1:1 relationship. Models of this type are increasingly used in policymaking [13]. A micro model used for policy experiments outputs the effect of the new policy on each individual included in the model, allowing investigation of the distributional effects of new policies. A drawback of models that aggregate individuals is that the average outcome may hide inequalities; a policy that seems acceptable on average can be economically devastating to certain individuals. Fairness and equity between individuals, different societal groups, and different geographical regions are factors relevant for the acceptance of a new policy.

Several researchers have pointed out the need for a participatory approach to infrastructure planning, stressing the need for stakeholder involvement [16, 14]. When multiple stakeholders generate and exchange information, there is a need for common ground where different viewpoints may be discussed [19, 15]. According to Ramirez, it is important to support activities like reformulation and reexamination, and to promote ongoing adaptation during policy negotiations. The use of computer simulation models to support participatory decision-making on complex environmental issues was investigated in the ULYSSES and FIRMA projects [4, 5]. The results from these projects support the view that the use of computer models provides direct access to expertise, and that the interactive process supports understanding, learning, and decision-making.

In the Upper Tisza flood management project, the overarching goal was to design a robust, socially and economically acceptable policy for flood management that shifted part of the economic disaster liability from the central government to individuals. The real challenge was to fulfill both requirements: identify a policy that moves part of the economic burden to individuals, while still being socially and economically acceptable to all, or most, stakeholders. A flood simulation model was designed, implemented, and tested within the project. The purpose was to support the stakeholders when deciding on such a policy.

The flood simulation model combines the features of micro models and catastrophe models; it is a spatially explicit flood simulation model with disaggregated data at the level of households. Conceptually, it can be divided into four modules: the disaster module, the policy module, the consequence module, and the interface module. Section 2 presents the theoretical background of the simulation model, followed by a conceptual description of how the different modules interact. Section 3 provides a description of how the catastrophe events are generated in the model, and Section 4 shows how policy options are constituted and how they are tested on the simulation model. Section 5 provides a description of the economic update rules for the government, the insurance company, and the property owners. Section 6 describes the graphical user interface and the principles that governed the design of it. In Section 7, we describe how the simulation model was used during the final stakeholder workshop. Our conclusions are presented in Section 8. For further descriptions of the simulation model, see Brouwers *et al.* [2, 3], Brouwers [1], and Ekenberg *et al.* [6].

2 Model Description

Simulation models with a predictive characteristic are tailored to answer questions of the "what-if" type, that is, what state will the modeled system be in if certain events occur.

An explicitly stated goal for the Tisza project was to adopt an integrated participatory approach. To do this, the issues to be represented in the what-part of the model were identified through interviews and surveys with the involved stakeholders. Current research demonstrates the importance of eliciting stakeholder values and incorporating them into the design of new technology [8]. In the Tisza case, following the initial interviews [18, 12], four significant economic indicators were identified, representing values important to the main stakeholders. To ensure that comparisons could be made easily, it was important that all stakeholders have a common frame of reference, in this case monetary outcome. Other, subjective factors, such as the emotional attachment to a house, would be more difficult to quantify, and to incorporate into the simulation model. Therefore, such factors were not considered in this pilot project. The only factor of interest in this case was the economic consequences of imposing a new flood management policy. The consequences should ideally be presented from the perspectives of the various stakeholders; those of the government, the insurer, the pilot basin, and the individual property owner. The indicators and the wealth transformation functions are described in Section 5.

The if-part was composed of two events: flood state and choice of policy option. These two if-parts were conceptually very different in the model. The flood state was truly stochastic, represented as an uncontrollable natural process, while the choice of policy was a controllable parameter. Before the start of a new simulation, the users had to choose between applying a predefined policy option and designing a new policy. Only policies comprising non-structural financial measures were implemented in the model. The main reason for this limitation was that estimates of costs and consequences of imposing other types of mitigation measures, like heightening the levees or building an emergency reservoir, were very uncertain and considered beyond the scope of this pilot project.

Since micro-level data was available for each household in the pilot basin, the data was kept disaggregated to facilitate analysis at the household level. A simulation approach was chosen over finding analytical solutions, since the system under study is complex and stochastic. The stochastic processes operate both at the macro level (levee failures) and at the micro level (distribution of insurance contracts and of poverty). The stochasticity at the macro and micro level in combination with the dynamic property of the model make the space of possible simulation outcomes very large. The basic time-step in the simulation model is one year, and one simulation round consists of one, five, or ten successive years. A complete simulation consists of 500, 1 000, or 10 000 iterated simulation rounds.

During a simulated year, the system can be in one of ten possible flood states (for details, see Section 3). If a 10-year period is simulated, the number of possible outcomes is 92 378 (19!/9!10!) for each policy option. It makes a difference when a levee failure occurs; the two time series of flood states [0,0,0,0,0,0,0,0,0,5] and [0,5,0,0,0,0,0,0,0,0] are different. In the first series, the insurance company has accumulated a financial risk reserve over nine years (collected premiums) when the levee failure occurs, while the risk reserve would be much smaller in the second series, which implies a greater risk of insolvency.

The number of possible outcomes only takes flood states into consideration; it would be considerably larger if insurance and poverty distributions were included.

The studied river basin occupies an area of 107 km^2. The basin lies in the Szabolcs-Szatmár-Bereg County (area approx. 5 900 km^2), located in the north eastern corner of Hungary. This county borders on Romania, Slovakia, and Ukraine.

In the model, the basin is geographically represented in form of a grid, consisting of 1551×1551 cells, each side measuring 10 m. There are 2 580 properties in the basin, located in 11 municipalities.

The simulation model consists of the following modules: the disaster module, the policy module, the consequence module and the interface module. The disaster module determines what flood state the system will be in each simulation year. The governing flood management policy is specified in the policy module, that is, the values are set for policy variables such as price of premiums and level of post-disaster compensation from the government. The economic outcome for the different stakeholders represented in the model is updated annually in the consequence model. The interface module provides the users with a graphical interface to communicate with the policy module and display results generated by the consequence module.

3 Disaster Module

In an unprotected river, all floods would overtop the embankments; floods would be more frequent and smaller. However, since the part of the Tisza River that was modeled is protected by levees, only levee failures were considered. A levee failure occurs when a levee fails to hold back the water, that is, it breaks or the water overtops the levee. The uncertain nature of the river is represented in the model by dynamically changing the flood state of the system.

Hungarian hydrologists at Vituki Consult Rt. [17] calculated the probabilities for nine plausible levee failure scenarios. The nine scenarios are based on the assumption that a levee failure can occur at one of three geographic locations, and that the flood has one of three magnitudes (100-year flood, 150-year flood, and 1000-year flood). The combination of location and magnitude gives nine failure scenarios, the flood states the system can be in. The tenth and complementing state is the zero-event when no levee failure occurs.

The probabilities that floods of different magnitude will occur any single year are defined as 0.01 for a 100-year flood, 0.0667 for a 150-year flood, 0.001 for a 1 000-year flood and 0.9823 $(1 - (1/100 + 1/150 + 1/1\,000))$ for no flood. If there is a flood, then one of two possible things can happen: the levee holds back the water (no levee failure) or the levee fails since it is overtopped or it bursts. The probabilities of levee failure at three locations are presented in Table 1.

Location:	1	2	3
Levee failure from 100-year flood	0.12	0.20	0.28
Levee failure from 150-year flood	0.18	0.22	0.40
Levee failure from 1000-year flood	0.19	0.33	0.45

Table 1: Failure probabilities, numbers from Vituki

Since it is impossible to tell when a flood or a levee failure will occur, Monte Carlo techniques were used to determine the state of the system. Each simulated year, the stochastic variable *flood* is assigned a random number in the range $0 - 1$ from a uniform distribution. The value is checked against nine threshold-values. If the value is <= 0.0012 scenario 1 occurs, (failure at location 1 from a 100-year flood), if it is <= 0.0032 scenario 2 occurs (failure at location 1 from a 150-year flood), and the check against thresholds continues until 0.0123 for the ninth scenario. If the value is greater than this, scenario 10 (no failure) occurs. The probability of a failure is obtained by the compound probability of the flood and the failure. For instance the probability of a levee failure at location 3 from a 1000-year flood' is 0.00045 (0.001×0.45).

4 Policy module

Designing new policies for the future and modifying predefined policies is an exploratory task. Since it would be impossible to consider all possible flood management policies that could be applied, the number of policies had to be reduced. A common way to do this is to lift out a subset of important policy parameters from the futures, and design plausible future *scenarios* where the values of these parameters differ. This approach was, for instance, used by the Intergovernmental Panel on Climate Change (IPCC) when they developed a set of long-term emission scenarios describing how greenhouse gas emissions might evolve between 2000 and 2100 [9].

The scenarios formulated in the Tisza case are referred to as policy options, and are based on the answers that were collected during the initial stakeholder interviews and surveys. The policy options described below reflect the widespread stakeholder support for continuing large-scale government involvement in a national insurance program with post-disaster relief for flood victims, as well as for the simultaneous introduction of individual responsibility and insurance. The three predefined policy scenarios that were simulated with the model at the stakeholder workshop are described in Linnerooth-Bayer *et al.* [12], but are summarized below.

- Policy Option A1: a mixed public private system
  - insurance premiums are flat-rated (cross subsidised)
  - holders of insurance receives 50 per cent post disaster compensation
  - government offers 50 per cent post disaster compensation and subsidises (part of) premiums for poor households
- Policy Option B1: private responsibility and insurance

- risk-based premiums
- coverage varies between 30 and 100 per cent
- government offers no post disaster compensation, but subsidises (part of) premiums for poor households
- government re-insures insurer

- Policy Option C1: mandatory public insurance
  - public insurance scheme - no private insurers
  - flat rated 'premiums' (new mandatory property tax)
  - government offers 100 per cent post disaster compensation and subsidises (part of) property tax for poor households
  - government underwrites all risks (acts as re-insurer)

During the workshop a desire to modify the pre-defined policies and design new policies emerged. This activity was supported by the simulation tool, since it allowed for interactive design of new policies by setting a number of parameters such as *premiumsize* and *level of compensation.*

5 Consequence Module

The economic outcome was presented from three perspectives:

- Government
- Insurance company
- Property-owners (one single property owner and one aggregated outcome for all property-owners in the entire pilot basin)

For each of these stakeholders, the policy-relevant parts of their economy were updated annually. The outcomes were saved after each simulated 10-year period. The total outcomes were analyzed after an entire simulation, which consisted of 1 000 10-year periods.

The outcome from a 10-year period was not merely the result of the flood states and the governing policy; before each simulation round it was randomly decided whether or not each property had an insurance policy. The overall proportion of insured households was either already decided in the three policy options (see Section 4), or it was decided interactively through the graphical user interface. There were 2 580 properties, which yields $2^{2\,580}$

possible outcomes of a binary insurance choice (insured/not insured). The insurance distribution stayed fixed over a 10-year period.

Approximately 60 per cent of the households in the region were considered poor [10]. In the simulation model, this affects to what extent the government subsidizes the insurance premiums for the property owner. Since we did not have access to micro data on income, we reduced the income variability to two states: poor or non-poor. The poverty distribution stayed fixed during a simulation round, and it did not affect the likelihood of buying insurance coverage.

5.1 Damages

$$\mathrm{ScenDam_i} = \sum_{\mathrm{j=1}}^{2\,580} \mathrm{ScenDamProp_{i,j}} \tag{1}$$

For each of the ten levee failure scenarios i (nine with failures and one without) there is a corresponding damage distribution for each property j. In equation 1, *ScenDamProp* is the economical damage distribution for each failure scenario and each property.

$$\mathrm{ScenDamMun_{i,j}} = \sum_{\mathrm{k=1}}^{2\,580} \mathrm{IsInMun_j(k)ScenDamProp_{i,k}} \tag{2}$$

The total damages from a levee failure scneario i in the municipality j are described in equation 2. The function $IsInMun$ returns 1 if property owner k lives in municipality j, otherwise 0.

$$\mathrm{ExpIndDam_i} = \frac{\sum_{\mathrm{j=1}}^{10} \mathrm{ScenDamMun_{i,j}ProbDam_j}}{\mathrm{NoPropOwners_i}} \tag{3}$$

Equation 3 calculates the average expected damages for an individual property owner located in municipality i. The premium of the risk-based insurance is based on the local risk, that is, the expected damage per municipality. $ProbDam$ is the probabilty that failure scenario j occurs. See equation 8 for determination of risk-based premiums.

5.2 Government

$$\mathrm{TotGovSubs} = \sum_{\mathrm{i=1}}^{2\,580} \mathrm{IsPoor(i)InsPrem_iSubsLevel} \tag{4}$$

The government subsidises part of the flood insurance premium for poor households. The function *IsPoor* returns true (1) or false (0). *InsPrem* is the size of the flood insurance premium, which the property owner pays to the insurance company. *SubsLevel* is the level to which the government will subsidise the insurance premium for a poor household.

$$\text{TotGovComp} = \text{GovCompLevel}(\sum_{\text{i=1}}^{11} \text{AllDamMun}_{\text{i}}) \tag{5}$$

After a levee failure, the government compensates the owners of the flooded properties to a certain percentage of the damages. Equation 5 calculates the amount of governmental compensation, *GovCompLevel* is the fraction of the damages that the government will compensate for. *AllDamMun* is the total damages (from all failure scenarios) for the municipality i.

$$\text{GovBalance(t+1)} = \text{GovBalance(t)} - \text{TotGovSubs} - \text{TotGovComp} \tag{6}$$

Equation 6 is the dynamic update-rule for the economic balance of the government, t represents the current year in the simulation. At t=0 $GovBalance = 0$.

5.3 Insurance agent

$$\text{TotInsPremFR} = \sum_{\text{i=1}}^{2\,580} \text{PropVal}_{\text{i}}\text{(1-Deductible}_{\text{i}}\text{)PremSize} \tag{7}$$

In equation 7, the insurance company receives incomes from insurance premiums, see equation 11 how the size of the flat-rated premium is decided. *PropVal* denotes the value of property i. *Deductible* is the fraction of property i that is uninsured. *Premsize* is the size of the flat-rated premium. Consider for instance the following policy: the premium size for a flood policy is 0.1 per cent of the property value, and the deductible is 20 per cent, then the annual premium for a policy insuring a property worth 200 000 USD would be 160 USD.

$$\text{TotInsPremRB} = \sum_{\text{i=1}}^{2\,580} \sum_{\text{j=1}}^{11} \text{IsInMun(i)ExpIndDam}_{\text{j}} \tag{8}$$
$$\text{(1+SafetyLoading)(1-Deductible}_{\text{i}}\text{)}$$

Equation 8 describes how the risk-based premium is calculated. For each property owner, the expected damages (based on current municipality, see equation 3) are multiplied with the $SafetyLoading$ (the insurer's add-on) and the coverage for that property $(1 - Deductible)$.

$$\text{TotInsComp} = \sum_{\text{i}=1}^{2\,580} \text{PropDam}_{\text{i}}(\text{1-Deductible}_{\text{i}}) \tag{9}$$

The insurer compensates the policy holders who suffer damages from a peril they are insured against. In equation, 9 the total amount of compensation the insurer has to pay is described. For each policy holder who has experienced damages, the compensation depends on the size of the damages and the level of the deductible. Assume that the damages for a property summed to 10 000 USD. If this policy had a 30 per cent deductible, then the property owner would receive 7 000 USD in compensation: size of damage×(1-deductible).

$$\begin{aligned}\text{InsBalance(t+1)} = \text{InsBalance(t)} + \text{TotInsPremFR+} \\ \text{TotInsPremRB} - \text{TotInsComp}\end{aligned} \tag{10}$$

A year when a flood has occurred, the insurers will compensate the policy holders according to the size of the damages and the level of deductibles. Equation 10 displays the wealth transformation over time for the insurance company.

5.4 Property Owners

$$\begin{aligned}\text{PremFR}_{\text{i}} = \text{PropVal}_{\text{i}}(\text{1-Deductible}_{\text{i}})\text{PremSize} \\ \text{[1-(IsPoor(i)(SubsLevel))]}\end{aligned} \tag{11}$$

Equation 11 describes how the size of the flat-rated insurance premium for property owner i is decided. A poor property owner only pays part of the insurance premium, the other part is subsidised by the government.

$$\begin{aligned}\text{PremRB}_{\text{i,j}} = \text{ExpIndDam}_{\text{j}}\text{(1+SafetyLoading)}(\text{1-Deductible}_{\text{i}}) \\ \text{[1-(IsPoor(i)(SubsLevel))]}\end{aligned} \tag{12}$$

The size of the risk-based insurance premium for property owner i is described in equation 12, based on the expected average damage for the municipality j.

$$\text{GovSubs}_{\text{i}} = (\text{PremFR}_{\text{i}} + \text{PremRB}_{\text{i}})\text{(IsPoor(i)SubsLevel)} \tag{13}$$

The level of governmental subsidation for insurance premiums (flat rated and/or risk based premiums) is described in equation 13.

$$\text{PropComp}_{\text{i}} = \text{PropDam}_{\text{i,j}}(\text{1-Deductible}_{\text{i}}) + \text{PropDam}_{\text{i}}\text{GovCompLevel} \tag{14}$$

In equation 14 the insurance compensation plus the governmental compensation to the property owner i is described. One of the ten possible levee failure scenarios j occurs each year.

$$\begin{aligned}\mathrm{PropBalance_i(t{+}1)} = \mathrm{PropBalance_i(t)} - \mathrm{PremFR_i} - \mathrm{PremRB_i} \\ +\mathrm{GovSubs_i} + \mathrm{PropComp_i}\end{aligned} \tag{15}$$

The dynamic balance of the property owner agent i is described in equation 15.

$$\mathrm{PilotBalance(t{+}1)} = \mathrm{PilotBalance(t)} + \sum_{\mathrm{i}=1}^{2\,580} \mathrm{PropBalance_i(t)} \tag{16}$$

The Pilot balance in equation 16 is calculated by aggregating the balance of all property owners.

6 Interface Module

Usability was an essential aspect. All users with the relevant background knowledge regarding floods in the investigated area should be able to interact with the model, regardless of computer skills. It was important to stimulate and engage all participants in spite of the limited time setting, that is, we made an interface that was easy to learn in a short time a priority. Ideally, the economic consequences for the different policy options would be presented in an unbiased fashion, taking into account as many of the potential stakeholder objectives as possible. Two things were accomplished by allowing stakeholders to easily view outcomes resulting from specific parameter settings: We refuted misconceptions regarding the importance of individual parameters and confirmed that the value range of specific parameters was acceptable to the users involved .

The main considerations at the beginning of the design of the GUI were to decide which variables from the model to make available to users. We had to weigh the pros and cons of exposing each model variable, and decide whether to hide a variable at the cost of compromising transparency, or make it accessible at the risk of jeopardizing the easy-to-use interface. Since we were trying to support the exploration of possible consequences of applying different policy options, the policy variables were made more explicit (for example, *insurance rate*, *premium size*, and *level of government compensation*). To simplify the input procedure and make it more suitable for collaborative work, interaction with the model was accomplished by mouse input, choosing values from pop-up menus, dragging sliders, or choosing radio buttons.

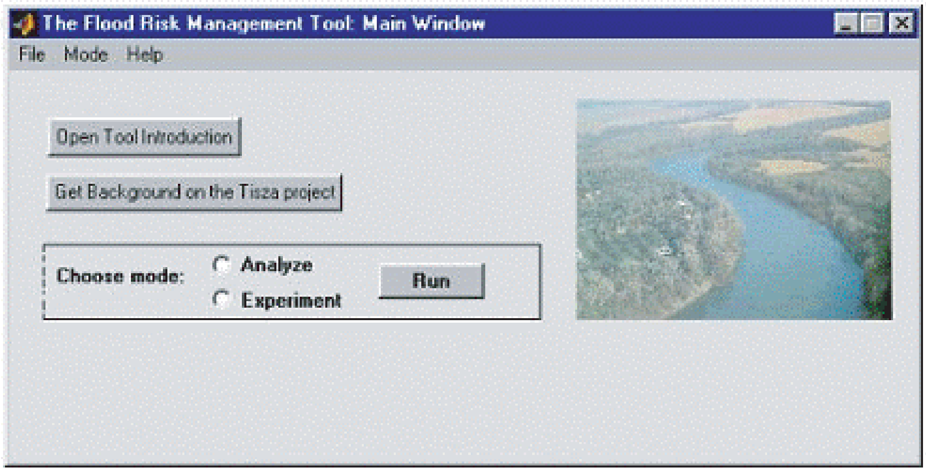

Figure 1: The Main Window.

Results from similar projects, for example, the ULYSSES project [4], show that participants prefer such input procedures. Also, this increases process awareness for the whole group (and not just for the person in control of the keyboard) as everyone can follow the course of events and view possible options.

A windowing system approach was used for the simulation model. The different steps of in the simulation procedure resulted in a natural division of interaction with the model into three stages: choose a mode; set variables; and view results.

6.1 The Main Window: Choose a Mode

The flood simulation model can be used in two separate modes: the Analyze Mode (analysis of the three predefined policy options) or the Experiment Mode (design of new policy options). Figure 1 shows the main window of the model (the user interface), where the user can choose to open the "settings" window for either of the two modes.

6.2 Settings Windows: Set Variables

When simulating policy options, the user has the option of choosing the number of simulated years, the number of times to repeat the simulation (number of simulation rounds), and whether to let the flood frequency have the current rate or to increase/decrease it.

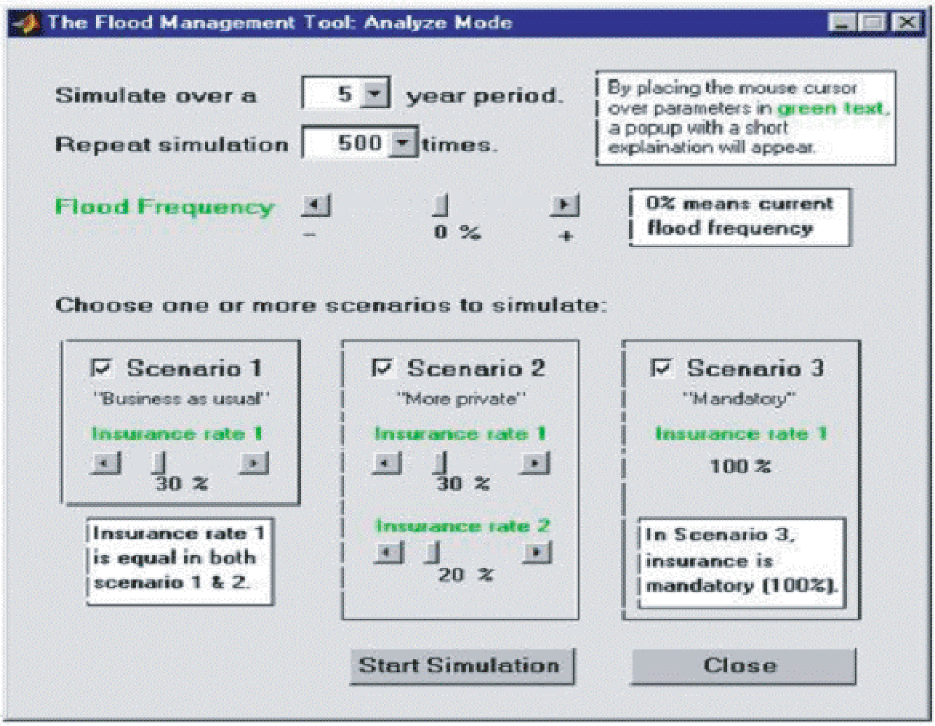

Figure 2: The settings window for the Analyze Mode.

Each mode has its specific purpose. The Analyze Mode is a direct implementation of the three proposed flood management policies, options A1, B1, and C1 [12], here referred to as scenarios 1, 2, and 3. In the settings window of the Analyze Mode, the user can choose which scenario(s) to include in the simulation. The user can set the values of the parameters for insurance rates, that is, the fraction of all households that have *insurance 1* and *insurance 2*.

The Experiment Mode was designed to support exploratory processes where users can modify existing policies and design new ones (up to three at a time). In the settings window of the Experiment Mode, the users design their own policy options by setting a group of parameters, namely *Yearly Income*, *Insurance Rate 1*, *Insurance Premium 1*, *Compensation from Insurance 1*, *Insurance Rate 2*, *Compensation from Government*, *Government Acts as Reinsurer*, and *Flood Tax*.

6.3 Results Window: View Results

After each simulation, the results are displayed in a common view. The user can view the results from one of the four stakeholder perspectives at a time,

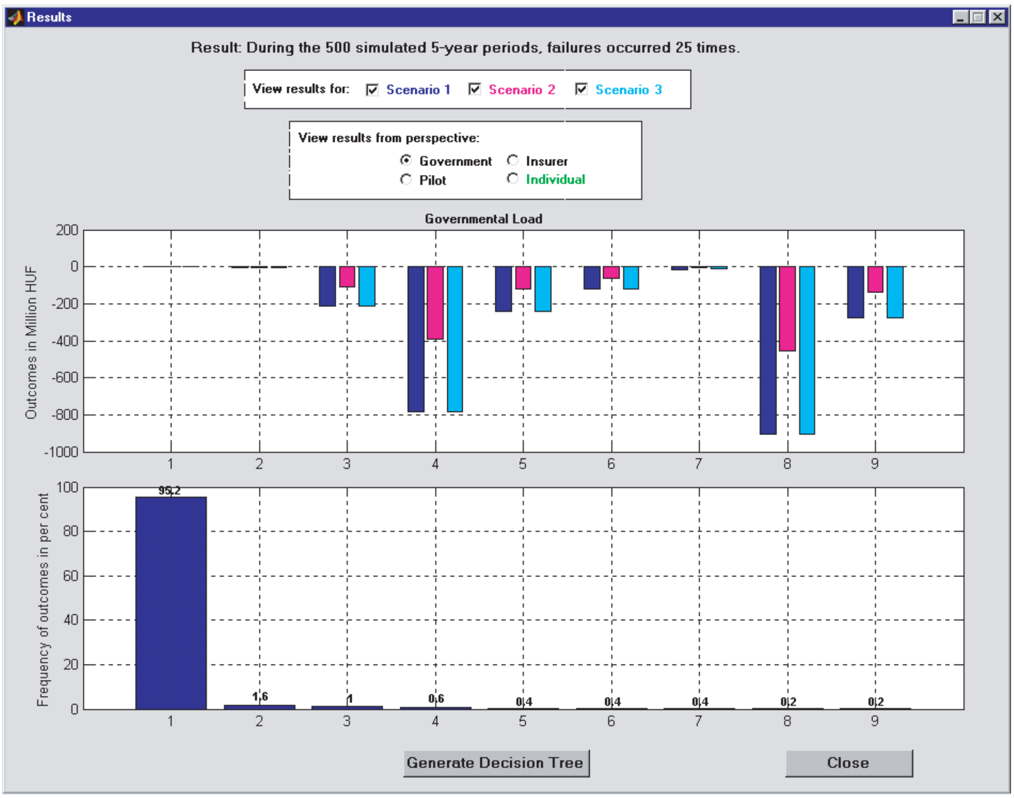

Figure 3: The Results Window. The top graph shows the different types of outcomes resulting from the simulation. The bottom graph shows the corresponding frequency of each type of outcome.

and also switch between displaying one, two or three simulated scenarios simultaneously. Results corresponding to each perspective are displayed in two graphs (see Figure 3). The top graph shows the different economic outcomes resulting from the simulation, whereas the lower graph shows the corresponding percentage of each outcome, that is, the number of times that each outcome occurred out of all repetitions of the simulation. This view enables the user to compare relatively easily the different policy options; for example, in the majority of the outcomes (95.2 per cent) the government has 0 florins (HUF) in expenses in scenarios 1, 2 and 3, but in the most extreme case (0.2 per cent of the outcomes) the government has a loss of over 400 million HUF for scenario 2, and in the case of scenarios 1 and 3, a loss of 900 million HUF.

7 Stakeholder Workshop

In line with results from similar projects such as ULYSSES [4], the final stakeholder workshop was moderated by two experts, one group moderator and one model moderator. The group moderator (whose mother tongue was Hungarian but who was fluent in English) guided the discussions during the workshop, and the model moderator guided the specific discussions during the computer interaction phase. Initially, the model moderator presented the simulation model briefly to clarify the meaning of simulations, some of the terms used, and how to interpret generated results.

The stakeholders (representatives from different interest groups) were divided into three groups depending on which of the three predefined policy options they preferred. After discussions [12], the whole group reached consensus on a new acceptable scenario (Policy Option D), and the final design of it was made on screen interactively using the Experiment Mode:

- Policy Option D: Consensus Option
  - flat rated (cross subsidised) insurance premium
  - holders of insurance contract receives 50 per cent post disaster compensation
  - government offers 50 per cent post disaster compensation - but only to insured households
  - government subsidises (part of) insurance premium to poor households
  - government does not re-insure insurer

After viewing the results, there was an open discussion of the results and of the use of the simulation model. The participants had a positive attitude toward using such a tool in future discussions on policies.

8 Conclusions

The Tisza pilot study showed that a participatory decision-making process can be enhanced in several ways by enabling the main stakeholders to interact with a flood simulation model. The complexity of the simulation model could have inhibited user understanding and involvement in the informed decision-making process; instead, the design of the tool provided them with a useful and logical basis for comparison and discussion. Users were able to argue for their opinions and easily express them as policy options during discussions.

The group as a whole could interactively explore different insurance policies and compare settings and their corresponding results. The interactive process during the workshop added to overall awareness within the group, which is important when making an informed decision and attempting to reach consensus.The views and suggestions of others as well as possible effects of implementation were more transparent because all participants used the same means of evaluation and presentation. In spite of initially conflicting opinions, active stakeholder involvement eventually led to agreement on an acceptable policy option.

Our expectation is that a tool like this could be used by more people and that the use of simulation models could empower them during a decision process. Allowing decision-makers to access and explore decision data in a more transparent manner, may lead to a greater acceptance of the final decision. In addition, it may be considered a more democratic way of making decisions that affect a large number of people, given that the users represent the population that is immediately affected by the decisions in question. However, there is a need for more thorough studies on its usefulness under these circumstances

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Article G

MicroPox: A Large-Scale and Spatially Explicit Micro-Simulation Model for Smallpox Planning

MicroPox: a Large-scale and Spatially Explicit Microsimulation Model for Smallpox Transmission

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Abstract

The motivation for this microsimulation model is the need to analyze and compare effects of implementing potential intervention policies against smallpox. By including contact patterns and spatial information extracted from governmental registers, we strive to make the simulation model more realistic than traditional transmission models, and thus better suited as a policy tool. MicroPox, the probabilistic large-scale microsimulation model described in this article uses real but anonymized data for the entire Swedish population. Since the unique data set contains family relations and workplace data for all Swedes, we have been able to incorporate many of their close social contacts, the type of contacts that are important for the transmission of smallpox. The level of detail of the data makes it possible to capture a large amount of the heterogeneity of the contact structure; most people have a small number of contacts, while a few have a large number. As the data set also contains geographic coordinates for all workplaces and dwellings, we were able to make the model spatially explicit. Besides a description of the model, the article also describes a preliminary experiment in which 50 initially infected persons spread the disease among 2,500,000 people, mainly located in Stockholm, Sweden.

1 INTRODUCTION

Fear of bioterror attacks has forced policymakers worldwide to examine their countries' emergency plans. A common scenario is that an infectious disease agent is deliberately released, threatening an entire region with a lethal epidemic. Smallpox is often cited as an example in such a scenario, because it is perceived to be easily transmitted, it has a high mortality rate, and the level of immunity in the population is low. The task at hand for policymakers is to evaluate potential control and prevention strategies with regard to effectiveness, cost, and risk.

Epidemiological models are often used to estimate the course of an epidemic with and without counter measures, such as, for example, vaccination or isolation of infectious persons. Most epidemiological models are elaborations of the fundamental SIR model, in which the closed and homogenous population is divided into groups (typically Susceptible, Infective, and Removed). A number of differential equations dictate the deterministic flow between these groups over time. In models of this type, all contacts between two individuals from different groups are equally probable, an abstraction that removes the explicit contact structure from the population. Such models have been successfully used as transmission models for highly contagious diseases such as measles, for which the contact pattern of possible contagious contacts very much resembles random mixing. They have shortcomings, however, when it comes to modeling less contagious diseases [Liljeros et al., 2003].

A number of smallpox transmission models have been built to support decision-makers in the task of comparing potential control strategies. An article by Edward Kaplan and colleagues has received much attention [Kaplan et al., 2002]. The article describes their model, based on a set of coupled differential equations, and a number of experiments in which different control strategies are applied to a scenario in which smallpox is spread in the population by terrorists. From the results of the experiments, the authors recommend mass vaccination as the best policy intervention in case of a terrorist attack. Note that vaccination is always associated with risk: according to historical data, post-vaccinial encephalitis has occurred at a rate of 1 per 300,000 vaccinations, of which 25 percent were fatal [Henderson et al., 1999, Henderson 1999]. A fraction of the population would experience an adverse event if a mass vaccination program were carried out, and as many as 10 million individuals in the U.S. may be immunocompromised and at risk for severe complications. To minimize the danger, these high-risk individuals and their close contacts would have to be excluded from the vaccination program, at the cost of lowering the level of immunity in the population [Kemper and Matthew 2003]. The same year as Kaplan's model was presented, Samuel Bozzette [Bozzette et al., 2003] presented a stochastic transmission model from which they demonstrated that mass vaccination is recommendable only if the probability of a severe bioterror attack is high. Both models assume random interaction, implying that transmission between two individuals living 1000 kilometers apart is just as likely as transmission between family members. In contrast with this assumption, several scientists have pointed out that the attack rates between close contacts and casual contacts differ; the probability for transmission is much higher if the contact is prolonged and close [Fenner et al. 1988; Fenner 1988]. Elizabeth Halloran has proposed another policy: post-outbreak ring vaccination. Their simulation model [Halloran et al., 2002] involves a 2000-person community that is structured into families with 1 to 7 members. Transmission occurs in the household and at places where people meet, such as in neighborhoods and at schools.

The model only includes eight instances of places of this type; all high-school children attend the same school and the entire community is divided into four neighborhoods with 500 people each.

Data from historical outbreaks supports the view that smallpox is primarily spread between close contacts, as reported by Eichner and Dietz, who have analyzed data from an outbreak in Nigeria [Eichner and Dietz 2003]. In 79.9 percent of the cases, the disease was transmitted between members of the same household, and in as many as 93.3 percent of the cases, the transmission occurred between persons belonging to either the same household or to the group of "other close contacts." These findings point to the importance of including reasonable estimations of the contact patterns.

An increasing number of models include a more ambitious and more realistic representation of the population. One early example of a microsimulation model (a model that represents each individual explicitly) is the GERMS model [Adams et al., 1999]. More recent examples are a model based on parameter estimations from the Nigeria outbreak [Eichner 2003] and a model in which the transmission probabilities vary with the type of contact, close or casual [Kretzschmar et al., 2004].

In an individual-based and spatially explicit model of Portland, in the United States, a social network was constructed over a synthetic population [Eubank et al., 2004]. The network is based on land-use data and census data on transportation in the city. The simulation approach is bottom-up; no value for the basic reproduction rate R_0[1], is given prior to the simulation, but instead is derived afterwards.

2 THE MICROPOX MODEL

The data set we use for this transmission model is unique. It belongs to the Spatial Modelling Centre (SMC) and is delivered to them by Statistics Sweden (SCB). SMC has been granted permission to use the data set for model research. Since we collaborate with Einar Holm and Kalle Mäkilä at SMC in this project, we may use a subset of this data set for this specific transmission model. This cooperation gives us access to real but anonymized data from 1998 for the entire Swedish population, consisting of close to nine million individuals. The database contains references to the workplaces of each person. All dwellings and workplaces have geographic coordinates, and each coordinate maps to one cell (100 x 100 meters) in a grid that represents Sweden.

The simulation model is dynamic; the simulation proceeds hourly. Each day is divided into three 8-hour periods. In the simulation, morning people make probabilistic choices about where to go. First they check their health; if they are well and have a job they go to their workplace. If they are ill, unemployed, or retired they stay at home. After eight hours at work all persons return home and remain there until the next morning.

Persons and places are the basic entities of the MicroPox model. Since transmission only occurs where they are co-located, the transmission process executes at particular places, and we have distinguished the most important types of places for smallpox transmission. These include dwellings, kindergartens, schools, hospitals, and offices. Furthermore the model includes two abstract places, "travel" and "neighborhood." More information about the different places is found in the section "Representation of Places."

A simulation is run for a number of days, normally 100 to 300. Three groups of parameters are set before the start of a simulation:

- Simulation parameters
  - Number of days
  - Number of replications
  - Names of files to be read (population, etc.)
- Model parameters
  - Number of initially infected persons
  - Use hubs (here, a hub is an individual with a very large number of contacts)
  - Transmission probability (per *place*)
  - Stage Weight (prodromal, symptomatic I, symptomatic II)
  - Probability that a person in the prodromal stage feels well
- Underlying assumptions
  - Maximum number of contacts (per place)
  - Daily probability that a person is ill (from other cause than smallpox)
  - Daily probability that a person who is ill visits an emergency ward
  - Daily probability that a person travels

The attributes are described in the following five subsections and their use is exemplified in the last section, "Experiment." During the simulation, all transmission events are logged and written to a file, called the event file. It contains the time (day from start of simulation) of the transmission, at what type of place the transmission occurred, person-id of the infected and the infector, and the age and the sex of the infected. This explicit logging makes

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[1] R_0 defines the average number of persons who become infected by one infector in a totally susceptible population if no policy interventions are implemented.

it possible to follow the chain of transmission all the way back to the initial infector. It also makes it possible to plot the locations where at least one infected individual lives (see Figure 1). Since the coordinates are plotted daily, the spatial spread of the epidemic is captured.

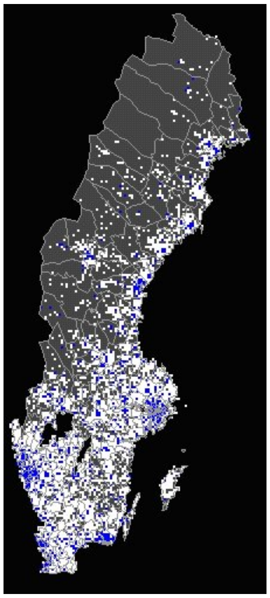

Figure 1. Visualization of spatial distribution of all infected individuals (snapshot). The visualization tool was developed by Kalle Mäkilä and Julien Gaffuri at SMC.

2.1 Representation of Individuals

Each individual has the following attributes: *person-id, sex, age, family-id, workplace, immune, state,* and *clinic*. Persons who are unemployed or retired do not have a workplace. Children spend their days at school or at kindergarten, which may be seen as their "workplace." The data set contains schools and kindergartens in the form of workplaces for adults, but it contains no information about which school a child is enrolled in. Therefore, we must generate a proxy for this connection in the MicroPox model. The choice of kindergarten/school/college/university depends on age and on the geographic distance between school and dwelling. If the closest appropriate type of school/kindergarten is not yet filled, the child is added to its enrollment list and the workplace attribute is updated accordingly. All children from 1 to 15 are connected with a school or kindergarten. For young people 16 to 20, we first check whether they have a workplace, and if not the majority of the unemployed youths are placed in schools.

The attribute *immune* tells whether an individual is immune to smallpox or not. Immunity comes either from vaccination or from having survived a smallpox infection. The *state* attribute describes what stage of smallpox the person currently is in. An uninfected but susceptible person has state 0 for instance (see subsection "Representation of the Disease" for more information about stages and transition rules). *Clinic* holds information about which emergency ward the individual should visit if needed. The choice of clinic is based on vicinity.

2.2 Representation of Places

All places have the following attributes: *type*, *transmission probability*, *current infection risk*, *coordinates*, and *members* (a list). *Dwellings* are places where families live. They have the additional attribute *family-id*, which makes it is possible to connect families and dwellings. Several dwellings can have the same coordinates, since the cells are 100 square meters in size. If the *member* list of the dwelling contains one or more infectious people, a neighborhood list is created. *Emergency wards* are specializations of the *hospital* place. Some hospitals have an emergency ward. Emergencies have a *patient list*, representing patients in the waiting room. At the time of transmission, the *patient list* is concatenated with the *member list* (staff) to enable transmission from one group to the other. *Office* is the default place type for workplaces.

The last two places can be seen as proxies for relations that are important to include in the social network, but for which we have no real data. The purpose of the *travel* place is to represent the contacts between persons away from their ordinary location. The proxy represents one-day trips within Sweden. Each region in Sweden is provided with a *travel* place. At this place people who travel to this region (or within the region) will meet other travelers. A fraction of the population travels each morning; the destination of their travels is probabilistically determined by using a gravitation model. The number of people in the region and the vicinity from the dwelling of the traveler decide the probability that the trip will have that region as its destination. Short trips are more likely than long ones, and trips to a densely populated region are more likely than to one that is sparsely populated. *Neighborhood* is a proxy for random encounters. These encounters could take place at grocery stores, cinemas, public transports or other places where many people meet. The underlying assumption for this is that it is more likely for a person to meet someone from his or her immediate area than from far away. When a transmission has occurred in a dwelling, a *neighborhood* list is created and filled with a number of individuals. The probability that a person will be added to this list decreases with distance.

2. 3 Representation of the Disease

For an overview of the clinical features of smallpox, consult an overview, for instance by Fenner [Fenner 1988]. However, there is no general agreement upon the exact values of the disease parameters such as time and duration of infectiousness. We have divided the disease period into six stages:

- Incubating I: asymptomatic, vaccine sensitive, not infectious
- Incubating II: asymptomatic, vaccine insensitive, not infectious
- Prodromal: acutely ill, possibly infectious

- Symptomatic I: overtly symptomatic, highly infectious
- Symptomatic II: overtly symptomatic, infectious
- Dead or immune: all recovered persons become immune

The transition from one stage to the next is time-dependent: after a number of days in one stage the infected person enters the next stage. The duration is decided either deterministically or probabilistically.

2.4 Smallpox Transmission

The first step in the transmission process is to count the number of infectious members at each place. The *current infection risk* of each specific place depends on:

1. the predefined *transmission probability* for that type of place, *TrP*
2. a vector of *stage weights*, **SW,** for the three infectious stages
3. a vector containing the number of infectious people at each of the three specific stages of infectiousness **NoInf**
4. the number of members at that specific place, *NoC*

The risk that a susceptible individual will become infected by infectious individuals at a certain place can be written as

$$P(infected|place)_t = 1 - \prod_{stage=1}^{3} \left((1 - TrP_{place} \cdot SW_{stage})^{NoInf_{stage}}\right) \quad (1)$$

Equation 1. We calculate the probability of being infected at a certain place at a certain time by deducting it from the complement of the probability of *not* being infected in all three stages (1=prodromal, symptomatic I, and symptomatic II.

For places with a large number of members it seems unrealistic that all persons meet during a day. If the number of people at a place exceeds the value of the parameter *maximum number of contacts*, *NoC,* for that type of place, the *current infection risk* from each single infectious individual is reduced by the proportion δ of the total number of members, *NoM* at the place, as described in equation 2.

$$P(infected|place)_t = 1 - \prod_{stage=1}^{3} \left((1 - TrP_{place} \cdot SW_{stage} \cdot \delta)^{NoInf_{stage}}\right),$$

where

$$\delta = \begin{cases} 1 & : NoM \le NoC \\ \frac{NoC}{NoM} & : NoM > NoC \end{cases} \quad (2)$$

Equation 2. The probability that a susceptible member will be infected by infectious member(s) where the number of members at each place may exceed the maximum numbers of contacts each day.

2.5 Initially Infected

The number of *initially infected* persons can vary from 1 to the size of the entire population. In a bioterror scenario, a credible number would be somewhere between 1 and 100. There are two ways of choosing which individuals to infect: randomly or by identifying 'hubs'. A hub is a person who has extremely many contacts in the social network. He or she may have a large family and work at a large workplace. The program makes it possible to decide limits for minimum number of family members and for members of the workplace. If the value of the parameter *use hubs* is 1, a list of hub-persons is created from which the initially infected persons are picked.

3 EXPERIMENT

We have performed a small experiment to demonstrate how the model can be used. We used a population that consists of all persons in Stockholm plus 1/10 of the persons from other places in Sweden (2,500,000 persons in total). The simulation was executed on a PC with 2 Gb RAM memory. The following parameter values were used:

Table 1. Parameter values that were used in the simulation.

Parameter	Value
Number of days	250
Number of replications	1
Number of initially infected	50
Use hubs	0 (no)
Transmission probabilities (places):	
Dwelling	0.25
Kindergarten, School, Hospital	0.15
Office	0.05
Travel	0.15
Emergency ward	0.25
Neighborhood	0.10
Maximum number of contacts:	
Dwelling	20
Kindergarten, School	30
Hospital	50
Office	20
Travel	30
Emergency ward	50
Neighborhood	30
Daily probabilities of:	
Feeling well in prodromal	0.05
Feeling ill (not smallpox)	0.1
Visiting the emergency if ill	0.1
Traveling	0.1
Stage Weights (for transmission)	
Prodromal	0.2
Symptomatic I	1.0
Symptomatic II	0.5

We varied the level of infectiousness by the stage. Reducing infectiousness during the prodromal stage drastically reduced the potential for a person to infect others since infected persons stay home as soon they become symptomatic. We assumed the level of residual immunity in the population to be zero; no persons were immune at the start of the simulation.

Table 2. Duration of the smallpox stages.

Stage	Duration	Distribution
Incubating I	3	Deterministic
Incubating II	4-16	See Fig. 2
Prodromal	3-5	Uniform
Symptomatic I	4	Deterministic
Symptomatic II	16	Deterministic
Immune		2/3 survive
Dead		1/3 die; prodromal stage + 7--14 days; uniform distribution

The first stage, when a person is vaccine sensitive was set to 3 days. Total length of the period from infection to onset of fever varied between 7 and 19 days. Fig. 2 presents the probability density for the duration of this period (Incubating I plus Incubating II).

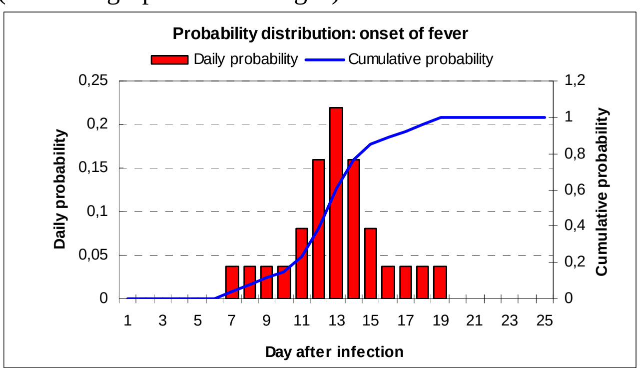

Figure 2. Daily probabilities for transition to state Prodromal. Time of infection is day 0.

The value 0.05 of the parameter *Feeling well in prodromal* guarantees that most persons fall ill and stay home when they enter the prodromal stage. The remaining 5 percent can infect persons away from home. On the last day of the prodromal stage all persons visit the emergency ward located closest to their dwelling, where they may infect other patients or hospital staff. When the rash appears on a person (Symptomatic I) he or she stays home and becomes highly infectious. This period of early rash lasts for 4 days. Symptomatic II stage consists of three periods: pustular rash, pustules and scabs, and resolving scabs. A person is infectious throughout this stage. The chance of survival is 2/3.The figure corresponds to the mortality rate used in other smallpox models; however, it is possible that it is to pessimistic if recent years' advances in health care are considered. If a person doesn't survive, he or she dies one to two weeks after entering the prodromal stage, the distribution within the time interval is uniform. Persons who survive the disease become immune after leaving stage Symptomatic II. No policy interventions were used in the experiment, that is, the infected person was neither isolated nor vaccinated, and no contact tracing was performed. As shown in Figure 3, it took quite long time before the epidemic took off.

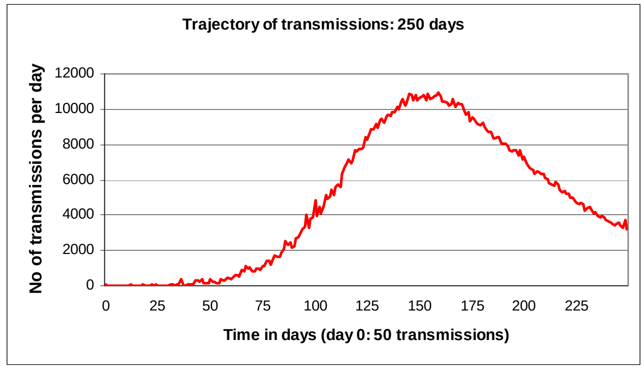

Figure 3. Daily number of newly infected cases over the entire simulation period (250 days).

Including the 50 initially infected persons 1,190,121 infections occurred (Figure 4).

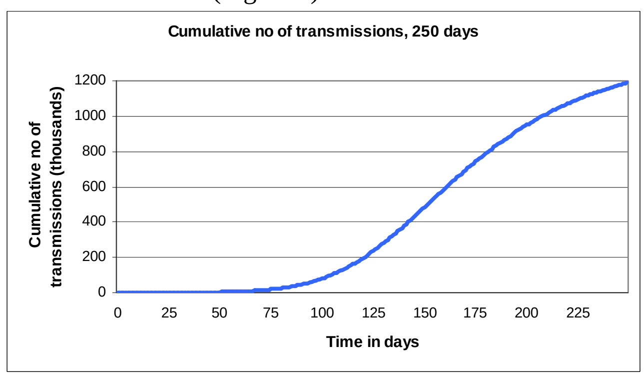

Figure 4. Cumulative number of infections.

By analyzing the *event file* it is possible to study transmission in greater detail. Figure 5 shows the number of persons in each stage per day.

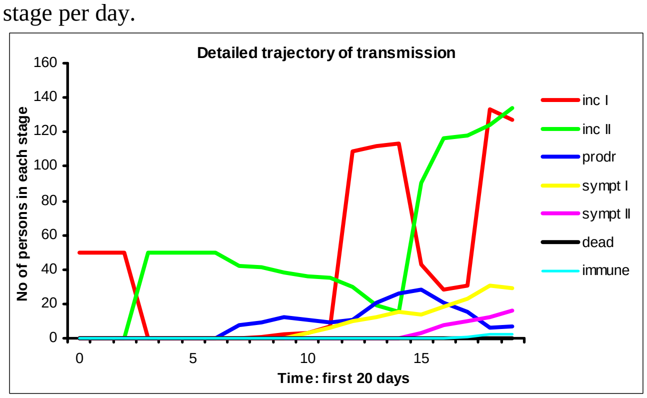

Figure 5. Number of persons in different stages, first 20 days.

Since we log where transmissions occur, it is possible to analyze the distribution of places for transmission events.

Figure 6 shows that in this experiment most transmissions took place in dwellings.

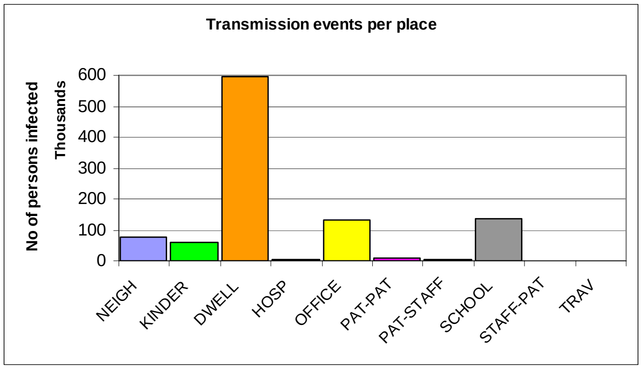

Figure 6. Total number of transmission events per place: *Neighborhood, kindergarten, dwelling, hospital, office: patient infects patient (emergency), patient infects staff (emergency), school, travel; staff infects patients (emergency), travel*

4 DISCUSSION

The experiment presented is merely included to illustrate the features of the model; since the model is still under development it has not yet been fully validated. The next step for this model is to include policy interventions, starting with isolation and contact tracing. We will also introduce a level of *national smallpox awareness*. Before the first case is verified, the level will be zero. After one or more verified cases, the routines at emergency wards will be changed; infected patients will be redirected to special infection clinics, etc. At some *awareness* level the daily habits of persons will change as well; people keep their children home from school and reduce their social contacts and travel less.

ACKNOWLEDGEMENTS

This model could not have been implemented without the solid experience in designing and programming large-scale micro simulation models that Kalle Mäkilä at Spatial Modelling Center (SMC) has. The simulation program is based on the EVSIM simulation engine and the SVERIGE model [Holm et al., 2002]. The project is partly financed by the Swedish Emergency Management Agency (SEMA), and partly by the Swedish Institute for Infectious Disease Control (SMI). The initiative for this research project was taken by Magnus Boman and Fredrik Liljeros. A number of other persons were involved from the start, including Anders Tegnell, Johan Giesecke, Åke Svensson and Kasia Grabowska.

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Article H

The Functional Form of an Epidemic in a Real-World Contact Network

The Functional Form of an Epidemic in a Real-World Contact Network

Lisa Brouwers & Fredrik Liljeros

Abstract

Epidemics initially grow exponentially in large populations with random homogeneous mixing. In a clustered network, where there is an increased probability that an individual's contacts will also have contact with each other, the initial speed of the outbreak will be slower than in a random network. If the level of clustering is high enough, the initial growth will be polynomial instead of exponential. In this paper we simulate the spread of an infectious disease in a highly clustered contact network, where the contacts are family and workplace contacts. The contact network is extracted from official governmental data on nine million Swedes. The experiment shows that, in spite of the high level of clustering, the simulated spread is almost exponential.

1 Introduction

The initial speed of an epidemic can be measured by the number of new infections per time unit. One policy consideration where information on the growth rate of an epidemic is of interest is whether an epidemic can be stopped by targeted vaccination or whether mass vaccination is required. Highly contagious diseases, such as measles, often grow exponentially in a susceptible population. This type of growth is characterized by a slow growth in the beginning, followed by an explosion of new infections, see Figure 1. For a disease that spreads exponentially, public health officials must be particularly alert to stop an epidemic from developing. Three main factors affect the course of an epidemic: (1) how infectious the disease is; (2) the time a person remains infectious; and (3) how many susceptible persons a carrier meets during the infectious period (Giesecke 2002). It has been demonstrated that extremely simplified assumptions about the contact structure in a population are often sufficient to create very precise transmission models (Andersson and May 1992, Diekmann and Heesterbeek 2000). A common simplification of the contact structure is to assume that all individuals are equally likely to meet during a certain time period, a principle referred to as random homogeneous mixing. In such models, all persons have more or less the same number of contacts, and each person's contacts are randomly chosen from the entire population. The probability that a contact is already infected is therefore very low during the early stages of an outbreak in a large population. Note that such models also can be represented as random networks, where the nodes are persons and the edges indicate that a contact has occurred.

The number of infected persons at time is determined by the rate at which an infectious individual transmits the disease per unit of time, referred to as the transmission rate k, and the number of infectious persons at time t, referred to as I. The speed of new infections during the early stages of an outbreak can then be expressed by a differential equation,

$$\frac{dI}{dt} = kI \tag{1}$$

This differential equation has the solution,

$$I(t) = e^{kt} \tag{2}$$

The deterministic model described by Equation 1 predicts that the number of infected persons will rise exponentially ad infinitum. Naturally, this prediction is unrealistic since populations are finite. Sooner or later the number of infected persons will be large enough to slow down the rate of new infections, a phenomenon called *global saturation.* We focus, however, only on the early stages of an epidemic, when global saturation has not yet been achieved.

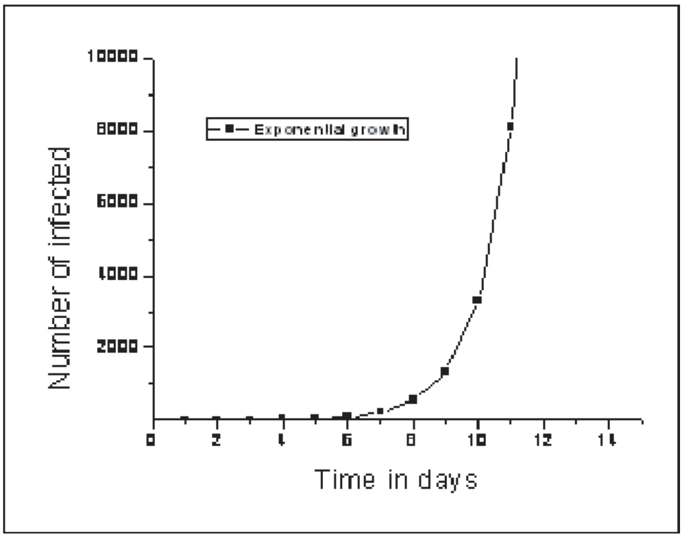

Figure 1: Illustration of an exponential growth process

2 Polynomial Growth Rate

A striking difference between human contact networks and random networks is that in human contact networks people tend to interact in different social arenas. They also tend to interact with almost all other persons in the same arena, for example at workplaces and in households. It is characteristic of contacts within such stable social settings that the different contacts one individual has are likely to have contacts with each other as well (Newman 2003). In network research, this phenomenon is called clustering or transitivity (Scott 2000, Wasserman and Faust 1994).

A high level of clustering in a contact network has recently been suggested to slow down the initial growth from an exponential to a polynomial functional form, where is a constant (cf. Szendroi and Csanyi (2004). The rationale for this is that a local degree of saturation will set in rapidly in a clustered network because it is highly probable that the contacts of infected individuals are already infected. A similar tendency, that is, slower initial growth, has also been detected in spatially structured contact networks (Gastner and Newman 2004). The differences between exponential and polynomial growth of a disease are shown in Figures 3 and 4. The purpose of this research is to investigate whether the high level of clustering in a realistic human contact network will decelerate the initial spread from an exponential functional form to a polynomial functional form.

Here, a relevant objection could be that a polynomial growth rate is not always "better", that is, slower, than exponential growth. A rapid polynomial function does not necessarily have to be slower initially than slow exponential function (even though exponential growth always outpaces polynomial growth in the long run. Polynomial growth in a highly clustered

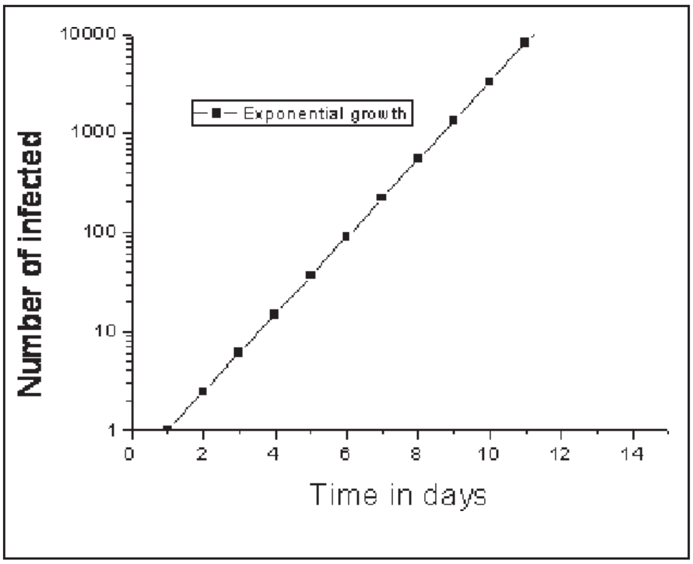

Figure 2: An exponential growth process in a graph with alogarithmic y-axis. An exponential trajectory takes the form of a straight line in such graphs.

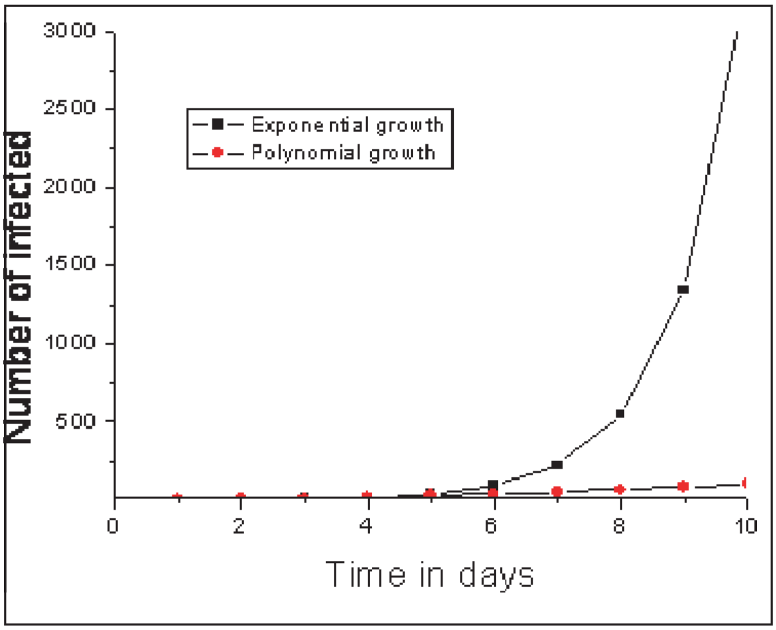

Figure 3: Exponential and polynomial growth in two outbreaks with similar growth rates the five first days, the first 10 days.

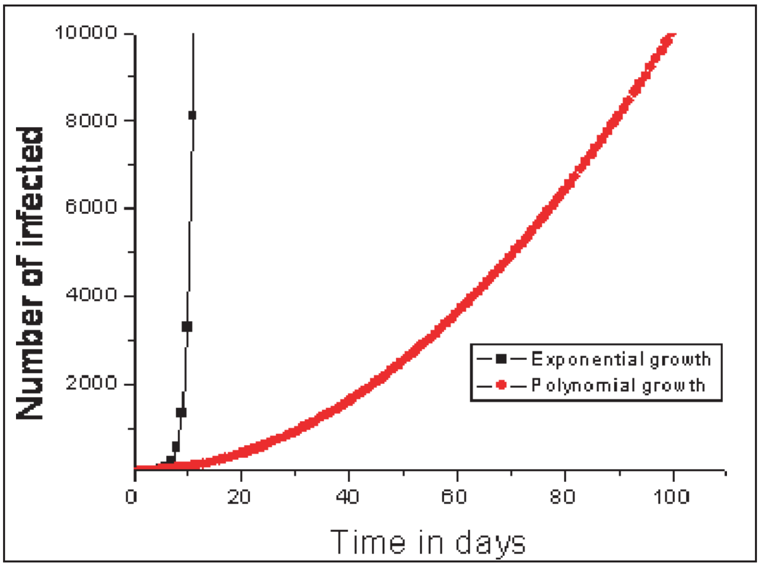

Figure 4: Exponential and polynomial growth in two outbreaks with similar growth rates the five first days, the first 100 days.

network will, however, be slower than exponential growth in a random network with a similar degree of distribution. We can therefore be certain that if the level of clustering is high enough to yield polynomial growth, it will be slower than an exponential growth in a similar network. Another possible objection is that, because it is nearly impossible to distinguish a polynomial growth process with large α (roughly $\alpha \geq 4$) from an exponential growth process during the short time interval under study, we cannot be sure that the growth is indeed reduced to a polynomial functional form in a clustered network. Such a high α value is, however, not realistic for most infectious diseases because it implies that the first infectious individual must infect 15 other persons during the first day of the infectious period. This can be compared with the spread of measles, for which it has been estimated that in a totally susceptible western population, an infectious individual on average infects a total of 15 other persons during the entire 6-8 days the person is infectious (cf. Giesecke (2002), Heymann (2004)). If measles followed a polynomial growth function, we would expect it to have an exponent $\alpha \approx 1.6$ to predict 16 cases day 6.

he remainder of this article is organized as follows. We describe the experiment by first briefly discussing the disease that is transmitted and its parameter values. We then present the MicroPox model and the experiment. After this we present the results of the simulation. The article concludes with a discussion of the results.

3 The Disease

We have chosen to model an outbreak of a disease that resembles smallpox (Heymann 2004). This decision is motivated by the fact that smallpox is known to be spread mainly through close contacts, and that it is therefore reasonable to assume that the contact network is of greater importance than it would be for a highly contagious disease like measles. Smallpox has also gained a great deal of publicity lately as a potential bioweapon used by terrorists (Henderson 1999). As a consequence, the disease has gained much attention among epidemiological modelers (Bozzette et al. 2003, Eubank et al. 2004, Kaplan et al. 2002). After September 11th, a number of simulation models evaluating potential smallpox policy interventions were published. Kaplan et al. elaborated one of the first models that investigated policy interventions against smallpox (Kaplan et al. 2002). From experimental simulation results that showed an apparently exponential progress of the outbreak, they concluded that mass vaccination would be a better alternative than targeted vaccination to hinder an epidemic. The success of targeted vaccination-in this case to vaccinate only persons who have been in contact with an infected person-depends on the speed with which the disease spreads in relation to the speed with which the contacts of the infected persons are traced, referred to by Kaplan et al. as the "race to trace." The faster the disease spreads, the harder it is to control it by tracking down the infected persons, and to isolate and vaccinate them. Even as the model gained acceptance for the level of detail and realism with which the post-outbreak vaccination and contact tracing was represented, a number of its assumptions were also criticized as being simplistic (Halloran et al. 2002). The main critique was the underlying assumption of homogeneous mixing; in the model by Kaplan *et al.*, it was assumed that all persons met all other persons during each time unit. In response to this, several modelers have developed models that in various respects claim to be less simplistic (c.f. Halloran et al. (2002)).

We have, as far as possible, chosen to represent the disease that is transmitted in the model using the same parameter values as Kaplan et al. use, since it makes it possible to compare the results. A drawback of this approach is that Kaplan et al. make some unrealistic assumptions about when a person becomes infective and about the behavioral response, for instance assuming that all persons go to work during the entire infective period. Our results will therefore be a poor prediction of a real smallpox outbreak, but should instead be seen as representing the first stages of an outbreak of any moderately infectious disease that is transmitted through close contact in a socially structured network.

4 The MicroPox Model and the Experiment

MicroPox is a microsimulation model designed to represent the Swedish contact structure realistically enough to provide good estimates of the path of an epidemic and of the effect of various interventions such as ring vaccination and mass vaccination. For the purpose of this work, we will not use all features of the model, but only what is required to simulate the spread of the disease in households and at workplaces. The model is a microsimulation model, meaning that all 8 861 393 Swedes (size of the Swedish population when the dataset was collected) are represented in the model. The level of clustering is calculated as the average of all fractions between the "actual number of contacts between the neighbors" and the "maximum possible number of contacts between the neighbors" for each node (Watts and Strogatz 1998). In the contact network, extracted from governmental data, the level of clustering is as high as 0.927.[1] A unique feature of the model is that it uses governmental registry data about where each person works, with whom the person works, and with whom the person lives, which makes it possible to extract a contact network that shows the work and family contacts. The contact network deterministically depicts the contacts between persons. A day in the simulation model is divided into day and night. During the first hour of the day, persons with a job go to work. If they are unemployed or retired, they stay at home. Schools and kindergartens are not are included in this experiment, since we do not have data on these "workplaces" for children. Children are therefore assumed to spend the days at home in this model. All persons return home after work and spend the night there with the family. Since transmission only occurs where persons are collocated, the transmission process proceeds at dwellings and workplaces. A simulation is run for a number of days. Two groups of parameters are set before the start of a simulation. We present the parameters together with the values that were used in the experiment.

- Simulation parameters
  - Number of days (100)
  - Number of replications (100)
- Model parameters
  - Population (8 861 393 persons)
  - Number of initially infected persons (30)
  - Transmission probability, TrP per place: (0.5 at dwellings, 0.1 at workplaces)
  - Maximum number of contacts NoC per place: (20 at dwellings, 25 at workplaces)
  - Incubation period (7 - 19 days from infection), see (Brouwers 2005) for distribution
  - Infectious period (3 days)

Transmission of the disease is done in the following way. The first step in the transmission process is to count the number of infectious members at each place. A place's current infection risk depends on:

1. the predefined transmission probability for that type of place, TrP

[1] The network used in these experiments has a slightly lower value since the number of contacts at workplaces has an upper limit, NoC.

2. the number of infectious people at that place

3. the maximum number of possible contacts at that specific place, NoC

The risk that infectious individual(s) at a certain place will infect a susceptible individual can be written as

$$P(infected|place)_t \quad = 1 - (1 - TrP_{place} \cdot SW_{stage} \cdot \delta)^{NoInf}$$

where

$$\delta = \{ {}^{1 \quad :NoM \leq NoC}_{\frac{NoC}{NoM}:NoM > NoC} \tag{3}$$

The term δ is used to decrease the number of contacts at large workplaces. If the number of people at a workplace exceeds the value of the parameter maximum number of contacts, NoC for that type of place, the current infection risk from each single infectious individual is reduced by the proportion of the total number of members, NoM at the place.

5 Results

In Figure 5, the dynamic evolution of the average number of new infections is plotted on a graph in which the y-axis is logarithmic; pure exponential growth would generate a straight line, as indicated by the red line. In Figure 6, the same plot is displayed on a graph where both axes are logarithmic. Pure polynomial growth would generate a straight line, as indicated by the red line for which the value is three. Graph 5 shows clearly that the functional form of the growth of the simulated epidemic is close to exponential. Graph 6 gives further support for this interpretation. The error bars in Figures 5 and 6 show the upper and lower interval for the 95% of the simulations that are closest to the mean value. The functional form of the growth becomes steeper and steeper each day; it does not follow the polynomial form indicated by the red line.

The small initial deviations in growth during the first 30 days are likely to be explained by the stochastic incubation time (7-14 days), resulting in waves that can be separated initially but that later are blurred. A small tendency toward a sub exponential growth may possibly be observed in Figure 5.

6 Discussion

The results show that, in spite of the high level of clustering, the functional form of a moderately infectious disease will be close to exponential during

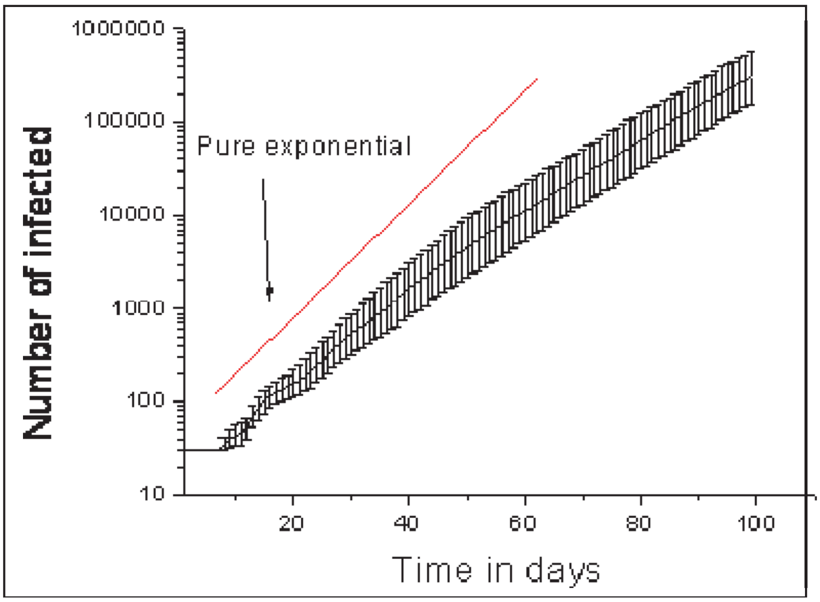

Figure 5: Evolution of average number of infected plotted on a graph with logarithmic y-axis.

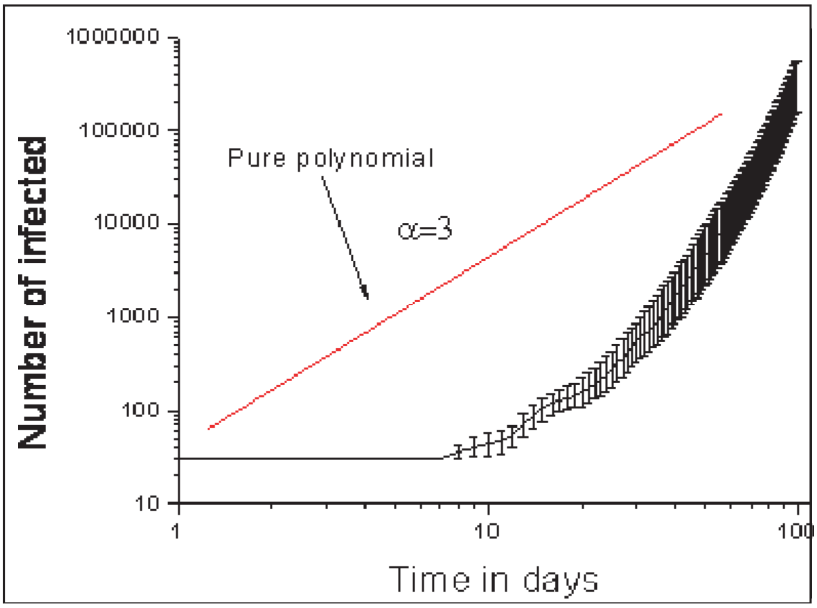

Figure 6: Evolution of average number of infected plotted on a graph with logarithmic x-axis and y-axis.

the early stages (before global saturation slows down spread). The results are to some extent surprising, considering how highly clustered the network is. A possible explanation is that the model assumes random homogeneous mixing at workplaces with more than 25 employees. If the number of members is larger than NoC (25 in this experiment), risk is reduced (see Equation 3). This was true for 62% of all working persons and for 32% of the total population. Another possible explanation is that the contact structure under study is a small-world network as suggested by Watts and Strogatz Watts and Strogatz (1998). They have shown that it is often enough to add a small fraction of contacts between a set of randomly selected pairs of nodes to give an ordered network an average shortest path length[2] similar to that of a random network with similar number of nodes and links. A disease would therefore be transmitted more or less as rapidly in a small-world network as in a random network. In this model, such "additional random" connections could be persons who live far from their workplaces, who therefore tie together different parts of the network. For policy purposes it is important to use transmission models that represent the contact structure realistically. This experiment shows that, in Sweden and for a disease that is spread in a similar way, the high level of clustering will not be able to slow down the speed of the outbreak enough to give it a polynomial form.

[2]To calculate the average shortest path of a network: for all possible node pairs, identify the shortest path between them, and then calculate the average of these paths for the entire network.

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Appendices

Appendix A

Project Members

1. The Flood Management Case
The Swedish project members were: Lisa Brouwers, Mats Danielson, Love Ekenberg (leader), Karin Hansson, and Ari Riabacke. The project members from Austria and Hungary were: István Galambos in the area of hydrology. Galambos produced a hydrological flow model of the Upper Tisza river and an inundation model of the Palad-Csecsei basin. Yuri Ermoliev and Tatiana Ermolieva, catastrophe theory. Ermoliev and Ermolieva contributed their expertise in the fields of mathematics and statistics for disaster management. A disaster model by Ermolieva was the basis for the flood simulation model. Anna Vári and Joanne Linnerooth-Bayer, in sociology and economics. They shared the results of initial surveys and interviews with stakeholders in the region and designed the policy option based on these surveys.
2. The Disease Transmission Case
The project was initiated by Fredrik Liljeros, the Swedish Institute for Infectious Disease Control (SMI), and Magnus Boman, SICS. The following persons have been involved: Kalle Mäkilä (Umeå University), Anders Tegnell (the National Board of Health and Welfare), Johan Giesecke (state epidemiologist, SMI), Åke Svensson (statistics, SMI), Fredrik Elgh (the Swedish Defence Research Agency), and Kasia Grabowska (statistics, SMI).

Appendix B

Stakeholder Interview

Questionnaire

Questions regarding your insurance (property) decisionprocess
Is your property insured (yes/no)
For those answering 'yes', please mark which of the following statements you agree with:

- Economical situation
  I compared the insurance companies with regard to the premium price
  I compared the insurance companies with regard to general insurance conditions
  I chose the company that offered the lowest premium
  I chose the company that offered the best general insurance conditions

- My property is insured to a value below the current market value
  If that is true:
  - How much below market value (percentage)?
  - What is the reason for this?

  - Premiums would be too expensive otherwise
  - I had no clear idea about the market value of my property at that time
  - I don't know

- Tradition
  I have always had may property insured
  I have never considered not to insure my property
  I have never considered to change insurance company

- Risk profile
  I generally avoid economcial risks
  Confidence in insurance companies
  My confidence in insurance companies is high
  My confidence in insurance companies is neutral
  My confidence in insurance companies is low

- History (risk history, floods, fires, etc.)
  My decision (to buy insurance or not) was affected by the local risk history (my property)
  My decision (to buy insurance or not) was affected by the regional risk history (my neighbourhood, county)

- Social influence
  I have discussed the insurance issue with my neighbours
  My decision was influenced by these discussions
  I have discussed the insurance issue with my friend and/or relatives
  My decision was influenced by these discussions

For those answering 'no' to question no. 1, please mark which of the following statements you agree with:

- Economical situation
  I can not afford to pay insurance premiums

I choose to spend my money on other things

- Tradition
  I have never insured my property
  I have never considered starting to insure my property

- Risk profile
  In general, I like to take economical risks
  I generally avoid economical risks
- Confidence in insurance companies
  My confidence in insurance companies is high
  My confidence in insurance companies is neutral
  My confidence in insurance companies is low

- History (risk history, floods, fires, etc.)
  My decision (to buy insurance or not) was affected by the local risk history (my property)
  My decision (to buy insurance or not) was affected by the regional risk history (my neighbourhood, county)

- Social influence
  I have discussed the insurance issue with my neighbours
  My decision was influenced by these discussions
  I have discussed the insurance issue with my friend and/or relatives
  My decision was influenced by these discussions

Replies

The questions were posed to four stakeholders. All of them (B, J, S and L) had their properties insured. On the question on *economical situation*, S agreed with the statement "I compared the insurance companies with regard to the premium price", noone had compared the insurance companies with regard to the general insurance conditions. J and B, somewhat contradictory, said that "I chose the company that offered the best general insurance conditions" while no-one chose the company that offered the lowest premium. One of the persons, B, agreed with the statement "My property is insured to a value below the current market value". The reason for this was inflation.

All four persons responded to the question regarding *confidence in insurance companies*: B, L and J agreed with the statement "My confidence in insurance companies is neutral", while S confidence in insurance companies was low. No-one had high confidence in insurance companies.

Two of the stakeholders, J and B, responded the question about *history*. Both agreed that their decision to buy insurance or not, was affected by the regional risk history (neighbourhood, county). Their decisions were not affected by the local risk history (property).

The last question, on the subject *social influence*, was only responded by L who had discussed the insurance issue with relatives, and was influenced by these discussions. An optional statement was formulated, which was chosen by J and L: "I selected insurance company based on former aquaintance with the agent".

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