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.

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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

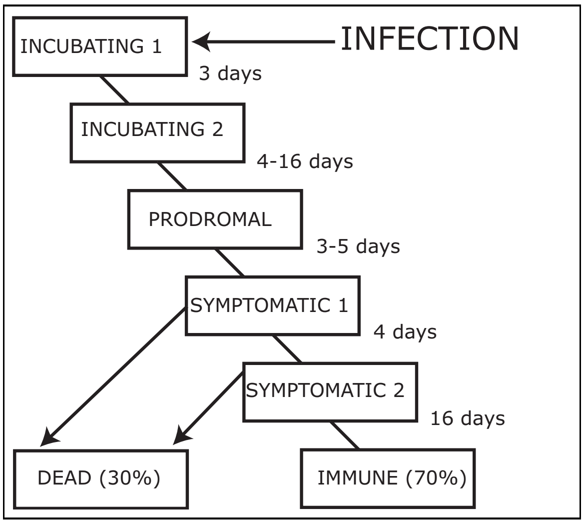

Figure 1.1: A general description of the how the disease (smallpox) was represented in the model.

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.

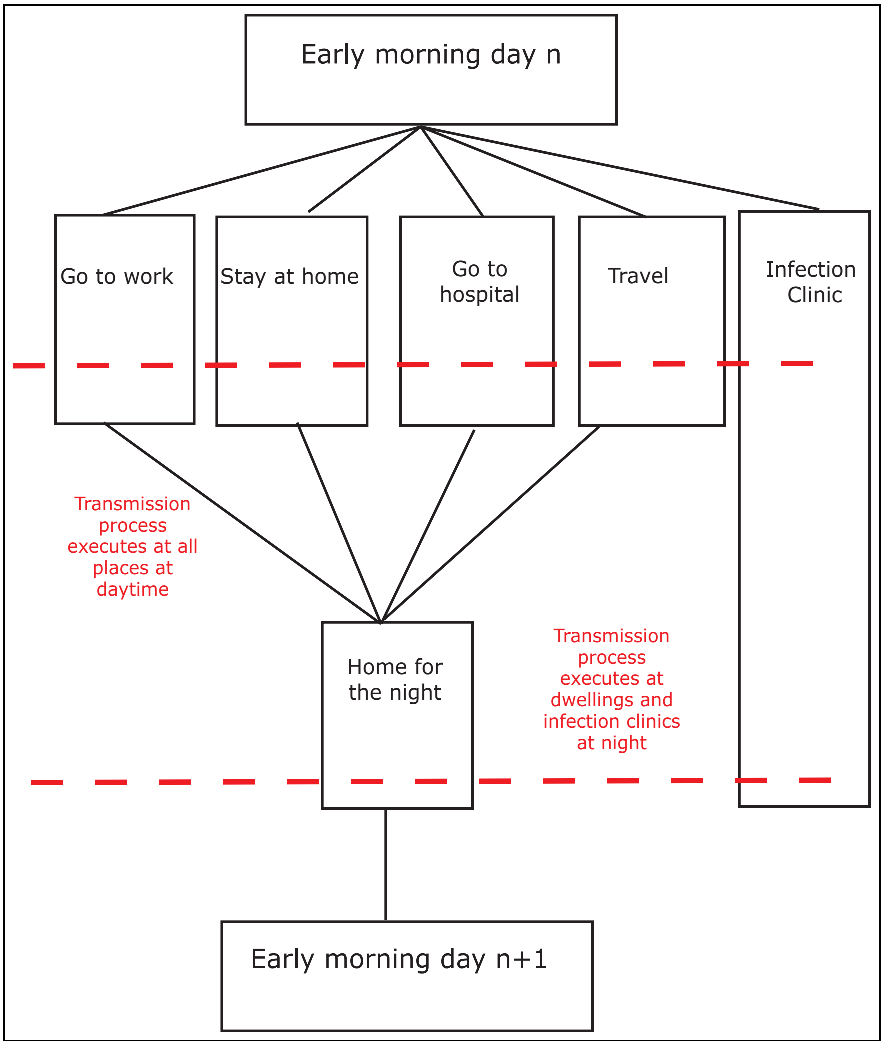

Figure 1.2: The daily routines for the simulated persons.

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

Article B

Simulation of Three Competing Flood Management Strategies—A Case Study

Article C

MicroWorlds as a Tool for Policy Making

Article D

Applying the Consumat Model to Flood Management Policies

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

Article G

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

Article H

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

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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