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Systems Approach to Management of Disasters – A Missed Opportunity?

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Abstract Everyday life is overwhelmed by critical phenomena that occur on specific spatial and temporal scales. Typical examples are floods, landslides, storm surges, and similar. All these phenomena might have, whenever they occur, significant negative consequences for human lives. They often result from complex dynamics involving interaction of innumerable system parts within three major systems: (i) the physical environment; (ii) the social and demographic characteristics of the communities that experience them; and (iii) the buildings, roads, bridges, and other components of the constructed environment. In non-scientific terms, such events are commonly referred to as disasters. Proper management in the face of a natural disaster necessitates a transformation of attitude towards integration of economic, social and environmental concerns related to disasters, and of the actions necessary to deal with them.

Recent trends in confronting disasters include consideration of the entire region under threat, explicit consideration of all costs and benefits, elaboration of a large number of alternatives to reduce the damages, and the greater participation of all stakeholders in decision-making. Systems approaches based on simulation, optimization, and multi-objective analyses have great potential for providing appropriate support for effective disaster management in this emerging context.

The systems approach to managing disasters outlines proven strategies for pooling interdisciplinary resources more efficiently to boost emergency responses. Looking at the disaster management practice, with primary focus on Canada, this paper explores the question of why advances in systems theory have failed on a broader scale to majorly transform management of disasters. The paper identifies whether and how that knowledge and systems science can be deployed to improve disaster management in the face of rapid climate destabilization so that sustainability becomes the norm, not the occasional success story.

Key words: Natural disasters; Disaster management; Systems approach

1. INTRODUCTION

Number of disasters and total damage are on the rise as illustrated in Figures 1 and 2. Some of the main factors that are contributing to this increase are population growth, land use change, climate change and increase in wealth. Large and more frequent disasters in last few decades have brought a remarkable

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transformation of attitude by the disaster management community toward integration of economic, social and environmental concerns related to disasters, and of action to deal with them (Simonovic 2011).

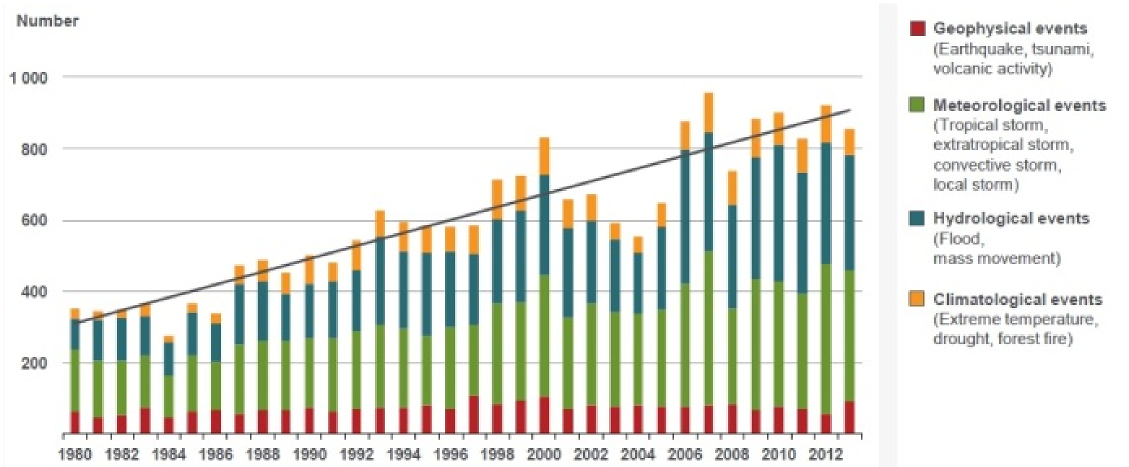

Figure 1. Number of disaster events 1980-2013 (Source: Munich Re. 2014)

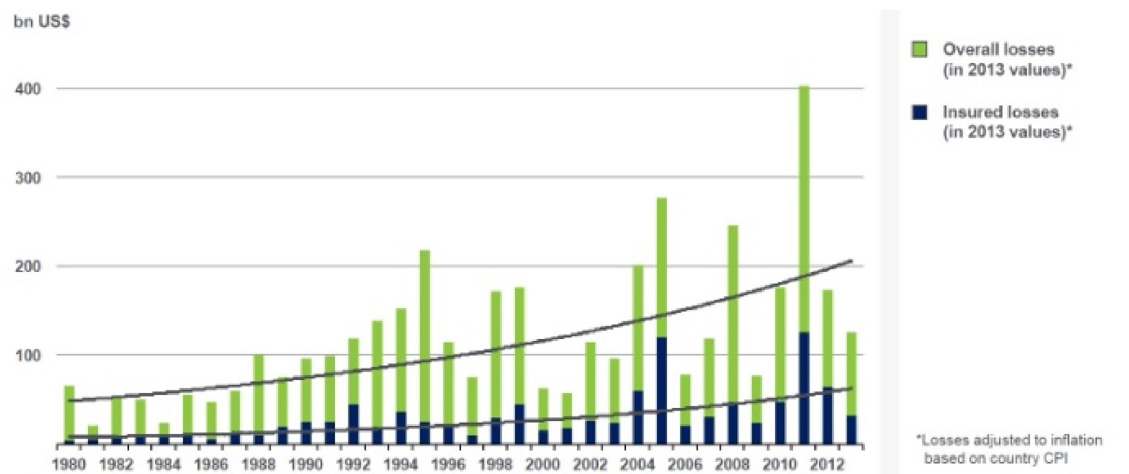

Figure 2. Overall and insured losses 1980-2013 (Source: Munich Re. 2014)

The early period of hazards research was characterized by taking knowledge from various fields of science and engineering that is applicable to natural and related technological hazards and using it in disaster management. The most significant characteristic of last 15 years is a fundamental shift in the character of how the citizens, communities, governments, and businesses conduct themselves in relations to natural environment they occupy. Past practice of disaster management being divided among disciplinary boundaries has faced an uphill battle with the regulatory approaches that are used in many countries around the world. They have not been conducive to the integrative character of systems approach that is inherent in various management models. Fortunately, recent trends in regulation include consideration of the entire region under threat, explicit consideration of all costs and benefits, elaboration of a large number of alternatives to reduce the damages, and the greater participation of all stakeholders in decision making. Systems approaches based on simulation, optimization, and multi-objective analyses have great potential for providing appropriate support for effective disaster management in this emerging

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context.

In 1987, with the publication of the Brundtland Commission's report Our Common Future, decision making in many fields began to be influenced by a sustainability paradigm. The original report introduced the concept of sustainable development as "the ability to meet the needs of the present without compromising the needs of future generations". This concept as applied to contemporary hazards mitigation aims at implementing approaches that could result in disaster-resilient communities.

Applying the principles of sustainability to disaster decision making requires major changes in the objectives on which decisions are based, and an understanding of the complicated interrelationships between existing ecological, economic, and social factors. The broadest objectives for achieving sustainability are equity, economic efficiency, and environmental integrity. In addition, sustainable decision making regarding natural hazards faces the challenge of time; that is, it must identify and account for long-term consequences.

To make disaster management decisions designed to produce sustainable disaster-resilient, communities also calls for a change in procedural policies and implementation. Sustainability is an integrating process. It encompasses technology, ecology, and the social and political infrastructure of society. It is not a state that may ever be reached completely. It is, however, one for which disaster management community and decision-makers strive.

The evolution of disaster management is occurring in the context of rapid technological change. In the same period that brought us the systems approach, environmental awareness, and sustainability, we were exposed to the dynamic development of computer hardware and software systems that made the computer acts as a partner for more effective decision making.

Considering that the roots of disaster management are in the social sciences it is important to make a distinction between a systems thinking – practiced by social sciences – and the systems approach considered in this paper. The term systems thinking is used as a broad catch-all heading for the process of understanding how systems behave, interact with their environment and influence each other. The term is also used more narrowly as a heading for thinking about social organizations, be they natural or designed. Despite of many efforts, systems thinking is in a less secure position in the social sciences than it was 30 years ago. Many theorists still write it off as another version of functionalism, discredited in their eyes because of its inability to deal with the details and dynamics of organizational processes and, in particular, power and conflict. Practitioners continue to see the approach as too theoretical to be helpful with their everyday concerns. Progress there might have been but the full potential of systems ideas still remains to be realized. It is my hope that the introduction of the broader concept of systems approach as a tool has much more significant potential in the management of disasters.

2. DISASTER MANAGEMENT AS A SYSTEMS PROBLEM

Systems can be defined as a collection of various structural and nonstructural elements that are connected and organized in such a way as to achieve some specific objective through the control and distribution of material resources, energy, and information. The systems approach is a paradigm concerned with systems and interrelationships among their components. Today, more than ever, we face the need for appropriate tools that can assist in dealing with difficulties introduced by the increase in the complexity of disaster management problems, consideration of environmental impacts, increase in resilience and the introduction of the principles of sustainability. The systems approach is one such tool. It uses rigorous methods to help determine the preferred plans and designs for complex, often large-scale systems. It combines knowledge of the available analytic tools, an understanding of when each is appropriate, and a skill in applying them to practical problems. It is both mathematical and intuitive, as is

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all disaster management cycle of hazard mitigation, preparation, emergency/event/crisis management, and recovery.

Integrated disaster management is an iterative process of decision making regarding prevention of, response to, and recovery from a disaster. This process provides a chance for those affected by a disaster to balance their diverse needs for protecting lives, property and the environment, and to consider how their cumulative disaster-related actions may affect long-term sustainability of the affected region. The guiding principles of the process are systems view, partnerships, uncertainty, geographic focus, and reliance on strong science and reliable data.

Integrated disaster management involves complex interactions within and between the natural environment, human population (actions, reactions, and perceptions), and built environment (type and location). A different thinking is required to address the complexity of the disaster management. Mileti (1999, p.26) is strongly suggesting adaptation of a global systems perspective and Simonovic (2011) provides an introduction of systems approach to managing disasters and shows how this approach can be the difference maker in time of crisis. Systems theory is based on the definition of a system. The basic idea is that all complex entities (biological, social, ecological, or other) are composed of different elements linked by strong interactions, but a system is greater than the sum of its parts. For example, an integrated emergency management system of health, safety and security services (components) is much more efficient in disaster emergency than not-connected use of each of the services. This is different view from the traditional analytical scientific model based on the law of additivity of elementary properties that view the whole as equal to the sum of its parts.

A systemic approach to problems focuses on interactions among the elements of a system and on the effects of these interactions. Systems theory recognizes multiple and interrelated causal factors, emphasizes dynamic character of processes involved, and is particularly interested in a system change with time—be it a flood, hurricane, or a disaster-affected community. Traditional view is typically linear and assumes only one, liner, cause-and-effect relationship at a particular time. A systems approach allows a wider variety of factors and interactions to be taken into account. Using a systems view, Mileti (1999, p.107) states that disaster losses are the result of interaction among three systems and their many subsystems: (i) the earth's physical systems (the atmosphere, biosphere, cryosphere, hydrosphere, and lithosphere); (ii) human systems (e.g., population, culture, technology, social class, economics, and politics); and (iii) the constructed systems (e.g., buildings, roads, bridges, public infrastructure, and housing).

All of the systems and subsystems are dynamic and involve constant interactions between and among subsystems and systems. All human and constructed systems and some physical ones affected by humans are becoming more complex with time. This complexity is what makes national and international disaster problems difficult to solve. The increase in the size and complexity of the various systems is what causes increasing susceptibility to disaster losses. Changes in size and characteristics of the population and changes in the constructed environment interact with changing physical systems to generate future exposure and define future disaster losses. The world is becoming increasingly complex and interconnected, helping to make disaster losses greater (Homer-Dixon 2006).

Integrated disaster management is a part of all social and environmental processes aimed at minimizing loss of life, injury, and/or material damage. A systems approach to disaster management allows us to address their complexities, dynamic character, and interdisciplinary needs of management options. A primary emphasis of systems analysis in disaster management is on providing an improved basis for effective decision making. A large number of systems tools, from simulation and optimization to multiobjective analysis, are available for formulating, analyzing, and solving disaster management problems and they are presented in details in Simonovic (2011, Chapters 5, 6 and 7).

Simulation can play an important role in disaster risk assessment, emergency management and mitigation planning. Early simulation models were constructed by a relatively small number of highly trained individuals. These models were quite complex, however, and their main characteristics were not readily understood by non-specialists. Also, they were inflexible and difficult to modify to accommodate site-specific conditions or planning objectives that were not included in the original model. The most restrictive factor in the use of simulation tools is that there is often a large number of feasible solutions to investigate. Even when combined with efficient techniques for selecting the values of each variable, quite substantial computational effort may lead to a solution that is still far from the best possible. Advances made during the last decade in computer software have brought considerable simplification to the development of simulation models (High Performance Systems, and Ventana Systems 1996 among others). Simulation models can be easily and quickly developed using these software tools, which produce models that are easy to modify, easy to understand, and that present results clearly to a wide audience of users. They are able to address disaster management problems with highly nonlinear relationships and constraints.

Numerous *optimization* techniques are available for use in disaster management too. Most resources allocation problems can be effectively addressed using linear programming (LP) solvers introduced in the 1950s. LP is applied to problems that are formulated in terms of separable linear objective functions and linear constraints. However, neither objective functions nor constraints are in a linear form in most practical disaster management applications. Many modifications can be used in real applications. In recent years, there has been a strong emphasis on developing high-quality, reliable software tools for general use such as GAMS (Brooke et al. 1996) among others.

One group of techniques, known as evolutionary algorithms, seems to have a high potential. Evolutionary techniques are based on similarities with the biological evolutionary process. In this concept, a population of individuals, each representing a search point in the space of feasible solutions, is exposed to a collective learning process, which proceeds from generation to generation. The population is arbitrarily initialized and subjected to the process of selection, recombination, and mutation through stages known as generations, such that newly created generations evolve toward more favorable regions of the search space. In short, the progress in the search is achieved by evaluating the fitness of all individuals in the population, selecting the individuals with the highest fitness value and combining them to create new individuals with increased likelihood of improved fitness. The entire process resembles the Darwinian rule known as “the survival of the fittest.”

Multi-objective analysis. Disaster management is by nature multi-organizational, but organizations are only loosely connected leading to managerial confusions and ambiguity of authority. Since 1970s, however, there has been an increased awareness of the need to identify and consider simultaneously several objectives in the analysis and solution of some disaster management problems, in particular those derived from the study of large scale disasters. For example, in a disaster recovery study we may not be satisfied with learning what actions lead to minimizing the recovery costs. Instead, the study may be conducted so that it identifies multiple objectives as these relate to recovery costs, short-term and long-term capital needs, population satisfaction and well-being, and future community resiliency. In disaster management, the design of projects and programs has focused traditionally on the estimation of benefits and costs. A more realistic analysis would include social, environmental, and regional objectives, as well.

Two paradigms are identified by Simonovic (2011) that are shaping contemporary disaster management. The first focuses on the complexity of the disaster management domain (increases with time), and the complexity of the modeling tools (decreases with time), in an environment characterized by continuous, rapid technological development (sharp increase in development over time). The illustrative presentation of the complexity paradigm is shown in Figure 3. The extension of temporal and spatial scales characterizing contemporary disaster management problems leads to an increase in the complexity of decision-making processes. The evolution of systems analysis with increasing computational power results in more complex analytical tools being replaced by simpler and more robust search tools.

The second deals with disaster-related data availability (decreasing) and the natural variability of domain variables (increasing) in time and space that affect the uncertainty (increasing) of disaster management decision making (Figure 4). Data necessary for management disasters are costly and collected by various agencies. The financial constraints of government agencies that are responsible for the collection of disaster-related data have resulted in reduction of data collection programs in many countries.

The question I would like to answer is: What are we trying to manage? We keep trying to manage environments (water, land, air, etc). We keep trying to manage people within environments. It seems that every time we push at one point, it causes unexpected change elsewhere—first fundamental systems rule. Perhaps it is time to sit back and rethink what we are trying to manage.

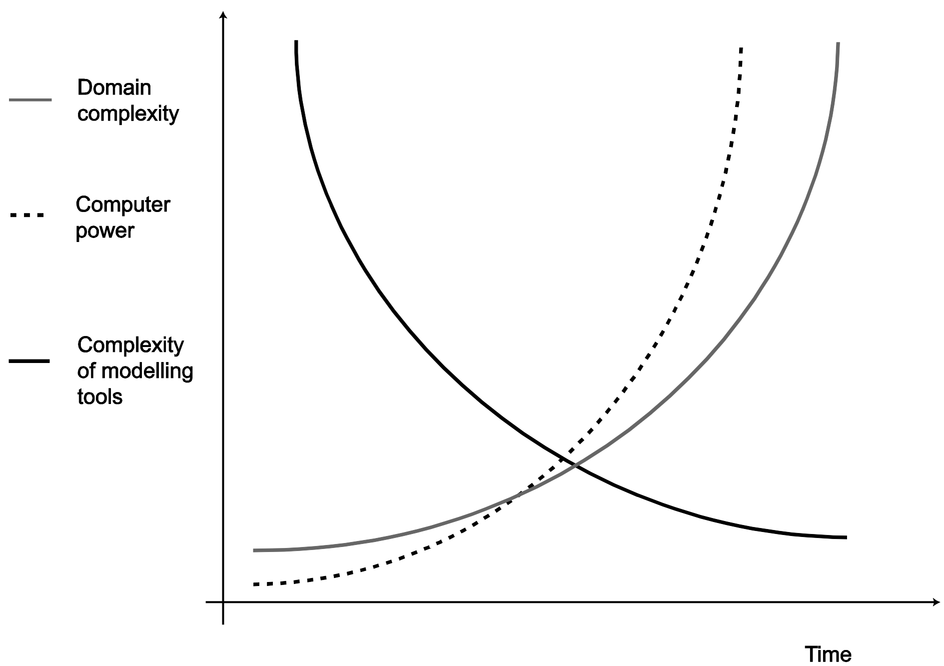

Figure 3. Illustrative representation of the complexity paradigm

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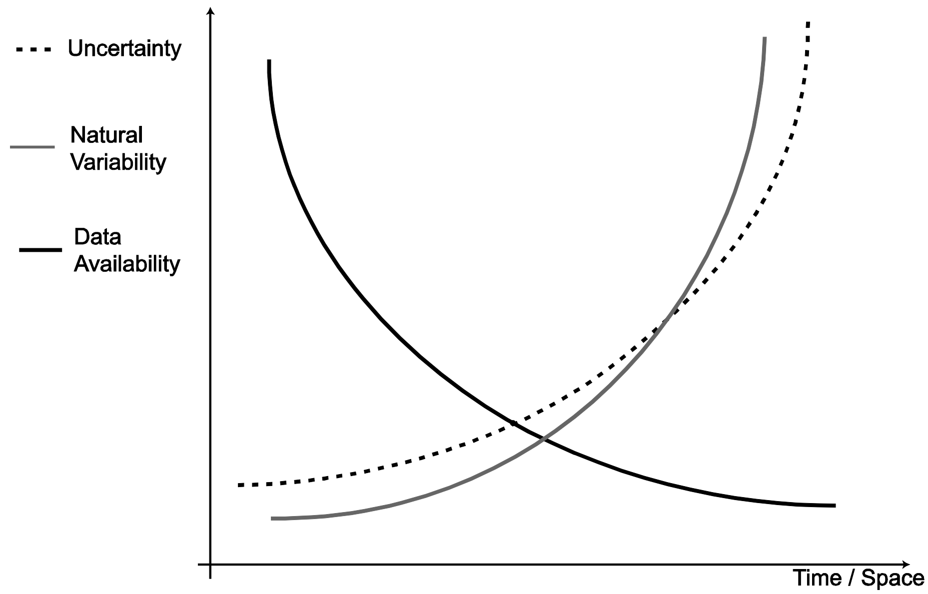

Figure 4. Illustrative representation of the uncertainty paradigm

In order to apply a continuous improvement approach to disaster management, it is essential to have a model of what is being managed. Models, or idealized representations, are an integral part of everyday life. The mathematical model is solved and its solution is applied to the system. Without the model, it is not possible to see where energy or resources are being wasted, or might significantly alter outcomes. Up to now, no generic model has been proposed, let alone accepted, as a basis for predicting outcomes from different disaster management interventions and their combinations.

The system in our focus is a social system. It describes the way disasters affect people. The purpose of describing the system is to help clarify the understanding and determine best points of systems intervention. For the implementation of the disaster management model Simonovic (2011) offers seven management principles (see the text box).

The disaster management system comprises four linked subsystems: individuals, organizations and society, nested within the environment. Individuals are the actors that drive organizations and society to behave in the way they do. They are decision makers in their own right, with a direct role in disaster mitigation, preparedness, response, and recovery. Organizations are the mechanism people use to produce outcomes that individuals cannot produce. Organizations are structured to achieve goals. Structure defines information and/or resource flows and determines the behavior of the organization. The concept of society is different from those of individuals and organizations, being more difficult to put

Management principle 1: To achieve sustainable disaster management, interactions between the four subsystems: individual, organization, society and environment, must be appropriately integrated.
Management principle 2: Two flows – resource flows and information flows – link the individual, organization, society, and environment subsystems. Value systems are the means through which different values are attached to information and resource flows.
Management principle 3: The ongoing need of subsystems for resources from one another sets the limits of their exploitation of one another and of the environment, and is a determinant of behavior within the system.
Management principle 4: Information is used by subsystems to make decisions intended to ensure fit with the needs of other subsystems and the environment.
Management principle 5: Values provide meaning to information flows that are then used to determine resource use by subsystems.
Management principle 6: The most effective management strategies for sustainable management of disasters are those that condition access to resources.
Management principle 7: More intensive focus on the systems view of disaster management will accelerate understanding of what management strategies work, and particularly why they might work.

boundaries around. In general, society itself is a system of which individuals and organizations are subsets and contains the relationships people have with one another, the norms of behavior, and the mechanisms that are used to regulate behavior. The environment includes concrete elements such as water and air, raw materials, and natural systems. It also encompasses the universe of ideas, including the concept of “future.” This concept is important in considering disaster management—it is the expectation of future damages and future impacts that drives concern for sustainable management of natural disasters.

3. HOW IS SYSTEMS APPROACH APPLIED TODAY IN MANAGEMENT OF DISASTERS?

Disaster management is a problem of organized complexity presenting situations in which a large number of variables are all varying simultaneously and in interconnected ways. Disaster management does not exhibit one problem in organized complexity, which if understood explains all. It can be divided into many smaller problems or segments which are also related with one another. There are many variables in disaster management that are interrelated into an organic whole.

All levels of governments involved in management of disasters are being stressed with the increase in frequency and magnitude of disasters, with more people, more “stuff,” and higher expectations − all moving at an increasing velocity. Peter Senge (1990) states “…humankind has the capacity to create far more information than anyone can absorb, to foster far greater interdependency than anyone can manage, and to accelerate change far faster than anyone’s ability to keep pace...”. The disaster managers require the capacity to shift from seeing parts to seeing wholes, from seeing people as helpless reactors to disasters to seeing them as active participants in managing them, from reacting to each new event to being prepared for future events. It is very clear that all of this is easier said than done. The disaster managers are well aware that disaster problems are dealing with self-organizing, nonlinear, feedback systems which are inherently hard to predict (or, are unpredictable).

Sustainable management of disasters requires full understanding of three kinds of non-linear systems: (i) socio-economic (for example, laws, regulations, policies, etc); (ii) natural systems (for example, land use, climatology, hydrology, geology, etc); and (iii) constructed systems (for example, transportation, water supply, drainage, electrical, etc). These systems work on different time scales and by different processes as parts of a whole. But they are not equal. Human activities (economies, technologies, politics, and social behavior) and constructed infrastructure ultimately must conform to biophysical realities or eventually face disintegration. Systems approach and management tools can help us better deal with the complexities of interacting non-linear systems. We designed the systems to manage disasters and we can redesign them, but the success will come only if the disaster managers and all other stakeholders pay close attention to system behavior, participate in the management, and respond to feedbacks.

Systems approach involves the use of rigorous methods to help determine preferred plans, designs, and operational strategies for complex disaster management systems. Its methods depend on the use of the computer for practical application. Variety of systems analysis tools like simulation, optimization and multi-objective analysis are readily available for the implementation in practice.

Altay and Green (2006) provide the most comprehensive review, that should be updated, of the progress of systems approach in management of disasters. They show that simulation is just at the beginning of making entry into the field of disaster management. Less than 2% of research effort included in their review deals with system dynamics simulation. Some examples include modeling of an accident and emergency department (Lane et al. 2000). Accident and emergency (A&E) units provide a route for patients requiring urgent admission to acute hospitals. This work discusses the formulation and calibration of a system dynamics simulation model of the interaction of demand pattern, A&E resource deployment, other hospital processes, and bed numbers; and the outputs of policy analysis runs of the model that vary a number of key parameters. Lane et al. (2003) extended their systems dynamics

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modeling to active involvement of clients—known as shared vision modeling. This work describes the collaborative process of building a systems dynamics simulation model in order to understand patient waiting times in an accident and emergency department. The purpose is to explore the issues that arise when involving clients, in this case healthcare professionals, in the process of model building. Given this study's first promising results, further collaborative studies are encouraged. Fawcett and Oliveira (2000) present a new approach to the casualty treatment problem following a large-scale disaster, based on a systems dynamics simulation model of how a regional health-care system responds to an earthquake event. The numbers and locations of casualties rescued alive, the scale of pre-hospital care, the post-earthquake hospital capacity, and the transport system are inputs to the model. The model simulates the movement of casualties from the stricken areas to hospitals. It predicts the number of casualties that die as well as other statistics about the healthcare system response, such as waiting time before treatment. The model can be run with varying input assumptions to simulate alternative disaster response strategies. Preliminary runs demonstrate the potential of the model as a tool for planning and training. Simonovic and Ahmad (2005) developed a flood evacuation simulation for the Red River basin in Manitoba, Canada. The model presents an interesting application of system dynamics simulation for capturing human behavior during emergency flood evacuation. The model simulates the acceptance of evacuation orders by the residents of the area under threat, the number of families in the process of evacuation, and the time required for all evacuees to reach safety. The model is conceptualized around the flooding conditions (both physical and management) and a core set of social and psychological factors that determine human behavior before and during the flood evacuation. The main purpose of the model is to assess the effectiveness of different flood emergency management procedures. Each procedure consists of the choice of a flood warning method, warning consistency, timing of evacuation order, coherence of the community, upstream flooding conditions, and a set of weights assigned to different warning distribution methods. The model use and effectiveness were tested through the evaluation of different flood evacuation options in the Red River basin, Canada.

Optimization applications using traditional algorithms are much more limited For example, Chen et al. (2009) offer an interesting application of dynamic programming in emergency recovery. A fast and efficient recovery is capable to reduce the disaster loss and prevent the public panic. In this work, an optimization model of recoverability process is established to minimize the recovery time and optimize the allocation of resources. However, the complexity of real disaster management problems today exceeds the capacity of traditional optimization algorithms. Altay and Green (2006) show that mathematical programming, including heuristics, is the most frequently utilized method, accounting for 50% of surveyed applications, in disaster management. About 44% of all examples address mitigation and only 11.9% of examples are on natural disasters.

Altay and Green (2006) show that only about 10% of research effort included in their review deals with multi-objective analysis. Most of the examples deal with evacuation planning. However, practical applications of multi-objective analysis in disaster management date back to early 1970s and show relatively strong presence in everyday practice. Here are some examples. Novoa and Halff (1977) report the use of multi-objective analysis in floodplain analysis of the lower reach of Peaks Branch, a stream in east Dallas, Texas. The original work considered eight alternative flood management options, ranging from no action to stream channelization to complete redevelopment. The alternates are evaluated in terms of their relative safety, effects on neighborhoods, required relocations of families and businesses, initial costs, and maintenance costs. Weighted average method from the group of methods with prior articulation of preferences has been applied in finding the most preferred alternative. Disaster managers are often faced with the task of identifying sites that are suitable for additional facilities as the demand for services increases. Many examples of multi-objective analysis exist in the area of public facilities location (health clinics, fire stations, energy plants, schools, etc.). A 15-month study conducted by the Johns Hopkins University for the City of Baltimore has applied a multi-objective facility location (MOFLO) model to investigate the location of new fire stations and the relocation of existing fire stations. Using a 0–1 integer programming formulation, the city was represented by a 600-point network, each of which was located in

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the centroid of an area roughly 9 square mile in size. Objectives were to maximize property value covered by the new fire stations, population coverage, expected fires covered, and property hazard covered. For a review of early facility location models, the reader is referred to a text by Cohon (1978). An interactive computer system for multi-objective facility location problems has been reported by Hultz et al. (1981) to conduct a heuristic search for non-dominated solutions. A recent detailed review of multi-objective tools for location problems is available in Captivo and Climaco (2008). Armstrong and Cook (1979) developed several variations of a goal programming multi-objective model for optimally allocating a fleet of search and rescue (SAR) aircraft to a fixed set of available and potentially available bases. Two types of models are presented—SAR resource allocation models, and fleet planning models. The strengths and weaknesses of these models as planning tools are discussed and the problems of data availability, data quality, impact of resources external to the system, are investigated. Although the models would apply in any SAR setting they use a Canadian problem as a particular case for the investigation. Price and Piskor (1972) have constructed a goal programming model of the manpower system for officers within the Canadian Forces. The model forms part of a control system for fixing promotion quotas and strengths for the various rank levels in many occupational classifications over a planning horizon of 3 years. The form of the constraints is set out, and the method used by the authors to determine the objective function weights is outlined. The control system provides a fast response time and measurements indicate that it is successful in attaining the aims of the planners. An example of the use of the system to evaluate proposed manning policies is given. Lee et al. (1979) utilize goal programming to assign division patrolmen to specific road segments in Nebraska. A force of 264 uniformed people must be allocated observing constraints on number of cars assigned to each road, maximum hours per work shift, overlapping of staggered shifts, and minimum level of protection. Every disaster event in recent history did include a task of patrolling the roads/streets in order to provide stability and safety after the disaster event. Passy and Levanon (1980) use a multi-attribute utility function in a model to recommend the distribution of added personnel among five investigative groups, as the department force increases from 190 to 310 police officers. Chow and Lui (2002) are addressing two key questions concerning (i) the effect of increasing the corridor width from 1.05 to 1.2 m and (ii) elimination of "dead ends" that are raised by the entertainment industry in order to meet the fire safety requirements. To answer these two questions, evacuation pattern in a typical karaoke establishment was studied numerically with the software building EXODUS. Six sets of scenarios were designed to study different layouts and occupancy levels. Evacuation times were studied for each scenario by changing the corridor width, exit access configurations such as the number of exits and their locations. In an emergency situation, evacuation is conducted in order to displace people from a dangerous place to a safer place, and it usually needs to be done in a hurry (Takasao et al. 1992; 1993). It is necessary to prepare evacuation plans in order to have a good response in an emergency situation. A central challenge in developing an evacuation plan is in determining the distribution of evacuees into the safe areas, that is, deciding where and from which road each evacuee should go. To achieve this aim, several objective functions should be brought into consideration and need to be satisfied simultaneously, though these objective functions may often conflict with each other. Saadatseresht et al. (2009) address the use of multi-objective evolutionary algorithms (MOEAs) and the geographical information system (GIS) for evacuation planning. The work proposes a three-step approach for evacuation planning. It explains that the last step, which corresponds to distribution of evacuees into the safe areas, is a spatial multi-objective optimization problem (MOP), because the objective functions and data required for solving the problem have a spatial component. To solve the MOP, two objective functions are defined, different algorithms for solving the problem are investigated, and the proper algorithm is selected. Narzisi et al. (2006) are presenting a new tool for multi-objective analysis based on agent-based models (ABMs) multi-agent systems (MASs) that are today one of the most widely used modeling analysis approaches for understanding the dynamical behavior of complex systems. These models are often characterized by several parameters with nonlinear interactions that together determine the global system dynamics, usually measured by different conflicting objectives. The problem that emerges is that of tuning the controllable system parameters at the local level, in order to reach some desirable global behavior. In this research, the tuning of an ABM for emergency response planning is defined as a multi-objective analysis problem. The authors propose the use of MOEAs for exploration and optimization of the resultant search space. Then they employ two well-known MOEAs, the Non-dominated Sorting Genetic Algorithm II and the Pareto Archived Evolution Strategy, and test their performance for different pairs of objectives for plan evaluation. In the experimental results, the approximate Pareto front of the non-dominated solutions is effectively obtained. Georgiadou et al. (2007) developed a model for the temporal and spatial distribution of the population under evacuation around a major hazard facility. A discrete state stochastic Markov process simulates the movement of the evacuees. The area around the hazardous facility is divided into nodes connected among themselves with links representing the road system of the area. Transition from node-to-node is simulated as a random process where the probability of transition depends on the dynamically changed states of the destination and origin nodes and on the link between them. Solution of the Markov process provides the expected distribution of the evacuees in the nodes of the area as a function of time. Natural disasters such as hurricanes, earthquakes, and tsunamis often cause large-scale destruction in residential areas. In the aftermath of these disasters, emergency management agencies need to urgently develop and implement a temporary housing plan that provides displaced families with satisfactory and safe accommodations. Work presented by El-Anwar et al. (2009a, 2009b) presents the computational implementation of a newly developed multi-objective optimization model to support decision makers in emergency management agencies in optimizing large-scale temporary housing arrangements. The model is capable of simultaneously minimizing (i) post-disaster social and economic disruptions suffered by displaced families, (ii) temporary housing vulnerabilities to post-disaster hazards, (iii) adverse environmental impacts on host communities, and (iv) public expenditures on temporary housing. The model is implemented in four main phases, and it incorporates four optimization modules to enable optimizing each of the aforementioned important objectives. A large-scale temporary housing application example is presented to demonstrate the unique capabilities of the model and illustrate the performed computations in each of the implementation phases.

Despite listed applications and a great deal of talk about systems approach, we continue to administer, organize, analyze, manage, and govern complex disaster events as if they were a collection of isolated problems and not a union of interconnected elements, activities, resources, stakeholders, and the surrounding environment (water, soils, land, forests, biota, and air). The sustainability as a goal would seem to imply that the solution is a systems approach to disaster process management, but the reality is otherwise. Efforts toward sustainability are also fragmented into particular issues of human impacts, economic losses, land degradation, air pollution, water pollution, and so on – so that the elements of the process do not support the larger whole.

4. A MISSED OPPORTUNITY?

Disaster management as a process is fully conceived by humanity − ignorant of ecology, and fearful of excessive authority. The current Canadian institutional disaster management context is decentralized, fragmented, and subject to incremental lawmaking. That makes it difficult to address serious disaster management decisions in a comprehensive, holistic (systematic) fashion. Current legislation (Simonovic 2011 – Chapter 2) further fragments responsibility favoring private rights as opposed to public goods. It seems that Canadian lawmaking institutions are not properly set for the task of managing large scale disaster problems and deriving legal solutions of the spatial and temporal scales necessary for sustainable disaster management. In other words, our way of governing is often disaster-inefficient. As a support let me mention that after the Canadian floods of 2013 (Alberta and Toronto) for the first time in our history the brief by the Minister of Public Safety Canada to the Prime minister included in his ‘Report on Plans and Priorities’ the following statement: …”The rising cost of natural disasters and the financial burden on Ottawa (the capital of Canada) is the country’s biggest public safety risk”…(Public Safety Canada 2013)

Serious review of disaster related legislation would be required in order to take advantage of a systematic, interdisciplinary approach which will insure the integrated use of the natural, social and applied sciences in the disaster related design, planning and operational decision-making. The application of systems approach is no solution for all difficulties related to disaster management, but it does offer at least six possibilities for improvement.

(1) Systems approach can help all levels of government to organize disaster related information in order to distinguish the important signals from the noise and improve decision-making across sectors, departments, and agencies.

(2) The data necessary to understand resource flows and the larger disaster context can be deployed to educate a public to understand the relationships between its behavior and environmental and economic consequences of natural disasters.

(3) Systems approach can help to improve planning and hazard forecasting. The use of models that clarify assumptions, identify feedback loops, and monitor system behavior can help decision-makers better anticipate change and to plan, tax, budget, and make smarter disaster management policies. Looking ahead, in a rapidly warming world we must prepare for larger storms, longer droughts, and more frequent and intense flooding. These, in turn, ought to affect decisions about zoning, land-use, location and type of infrastructure, building codes, food supply, economic development, taxation, and emergency preparedness.

(4) The tools of systems analysis (simulation, optimization and multi-objective analysis) can help to improve the quality of disaster related decision-making. Officials charged to manage the public business should be provided with full understanding of how the disaster affected regions work as physical systems or the dynamics that govern the interactions between the social (people and economy), natural (water, land and air) and constructed systems (buildings, roads, bridges etc.).

(5) Systems approach can contribute to the improvement in disaster emergency behavior by using systems thinking to build organizational community around common visions. The goal is to enable everyone involved in disaster risk management to see themselves as players in making decisions that involve feedbacks, step level changes, emergent situations, and advancing the awareness of causing one outcome or another.

(6) Systems approach can lead to greater realism and precautionary disaster risk management policies for the simple reason that most systems are nonlinear and therefore inherently unpredictable. Disaster management, being at the intersection of human action and biophysical realities requires smarter and more adaptable actors, capable of learning and having foresight.

5. CONCLUSIONS

Successful management of disasters requires integration of systems approach into the considerations of the daily activities of everyone who has an influence on future losses. This, in turn, represents a major shift in cultural approach to disasters and their management. Many systems tools are available to those who are ready to accept that shift. Some of the tools are simple, some are more difficult, but they are all providing strong support for the implementation of a systems approach of disaster management.

My experience is that the use of the tools leads to a higher knowledge and understanding of how to deal with complex issues involved in management of disasters. Some may be critical of taking this path to developing a different view of the disasters management. However, implementing the systems approach will train the mind of those who are using them. That training will lead to the switch in thinking—move from linear to systems thinking. Development of systems thinking will form a new culture of sustainable integrated disaster management.

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