Modeling Community Recovery from Earthquakes

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This paper sets out the foundations for developing robust models of community recovery from earthquake disasters. Models that anticipate post-disaster trajectories are complementary to loss estimation models that predict damage and loss. Such models can serve as important decision support tools for increasing community resilience and reducing disaster vulnerability. The paper first presents a comprehensive conceptual model of recovery. The conceptual model enumerates important relationships between a community's households, businesses, lifeline networks, and neighborhoods. The conceptual model can be operationalized to create a numerical model of recovery. To demonstrate this, we present a prototype computer simulation model and graphical user interface. As the model is intended for decision support, it is important to involve potential users in model development. We conducted a focus group involving Puget Sound, Washington, area disaster management practitioners to elicit local insight about community recovery and model development needs, using the prototype as stimulus. Important focus group issues included potential model inputs, useful recovery indicators, potential uses of recovery models, and suitable types of software systems.
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INTRODUCTION

The ten-year anniversaries of the 1994 Northridge, California, and 1995 Kobe (Hyogo-Ken Nanbu), Japan, earthquakes remind us that losses to a community are not limited to the immediate physical aftermath of an earthquake. Indeed, socioeconomic losses accumulate over the course of what can sometimes be a long and complex recovery process. A decade after the earthquake, it is reasonable to say that, overall, the Los Angeles and, in many respects, Kobe regions have recovered. However, the speed and quality of recovery with respect to recovery indicators, such as population, number of household residences, and occupancy rates, varied across different neighborhoods, economic sectors, and socioeconomic groups. In Los Angeles, areas most adversely affected were found to have higher than average populations of Hispanic, renter, low-income, and non–English-speaking households (Loukaitou-Sideris and Kamel 2004). This disparity illustrates the strong geographic character of social vulnerability, and thus community recovery from earthquake and other disasters. Disparities in recovery were also evident in Kobe where, for example, overall gross city product (GCP) regained pre-disaster lev-

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els within three years, but certain sectors such as the Port of Kobe experienced long-term or permanent losses (Chang 2000, 2001). Fortunately, decisions made prior to and following an earthquake can significantly affect a community's resilience—its robustness against initial loss and its ability to recover rapidly. It is useful, then, to be able to model how a community's decisions may affect disaster losses and recovery trajectories.

Modeling and understanding community recovery remain significant challenges. No comprehensive model of disaster recovery currently exists in the literature. Loss estimation models either ignore the temporal dimension of post-disaster loss and recovery or, as in the case of the Federal Emergency Management Agency's (FEMA's) HAZUS™ model, treat it in a cursory and incomplete fashion. Very little research has been conducted on how recovery proceeds over time, on the spatial dimensions of recovery, or the interdependencies between economic sectors in the recovery process. Many studies touch upon facets of recovery, but none take it as their analytical focus. Recovery modeling should facilitate "what if" analyses through comparison of different pre- and post-disaster scenarios. Specifically, it is valuable to be able to characterize the effects of different policies and management plans. Such decisions range from choosing whether to retrofit a neighborhood's gas pipelines to planning to employ short-term housing instead of temporary shelters.

Here we take the critical first steps in model development by setting out a comprehensive and flexible conceptual model. The conceptual model addresses some of the shortcomings of existing disaster loss estimation models while incorporating theoretical and empirical findings about disaster recovery from the literature. It describes the relationships across different scales—socioeconomic agent, neighborhood and community—after an earthquake occurs. The conceptual model considers attributes and behaviors of socioeconomic agents (households and businesses) and how these affect and are affected by the built environment, policy decisions, and sociopolitical characteristics of a community. Complex and meaningful representations arise out of implementing the conceptual model to compute the socioeconomic interactions with time across multiple scales. Modeling down to the agent scale allows risk assessment to be compatible with theories of social vulnerability and risk because it facilitates questions about, for example, how disparities in household incomes within a community may affect differential experiences in damage, loss, and recovery.

The conceptual model presented here represents the foundation for integrating perspectives from engineering, earth science, social science, and local knowledge towards a new generation of disaster recovery simulation models. The primary aim of this paper is to discuss issues of community recovery and describe the conceptual model. In turn, earthquake engineers and social scientists can further specify or refine the conceptual model through post-disaster empirical research, while developing robust algorithms to operationalize the conceptual relationships. Towards this end, we have developed a prototype computer model of community recovery with a graphical user interface to demonstrate the feasibility and help identify needs for creating robust computer models in the future. In this paper, we only briefly introduce the computer model and interface. Details on model development, including sensitivity analysis, can be found in Miles and Chang (2003). Following this overview, we describe a focus group that involved Puget

Sound, Washington, area practitioners of disaster planning and management. The focus group was conducted to elicit practical insights about the recovery process and user needs to guide future model development efforts.

COMMUNITY RECOVERY FROM DISASTERS

The study of disaster recovery is characterized by a rich and growing literature that provides many useful insights but few, if any, robust conceptual models. The classic work by Haas et al. (1977) provides a generalized framework for disaster recovery in which a community undergoes four post-disaster stages in regular, predictable sequence. Subsequent studies have cast doubt on this idea of an orderly, inevitable progression of recovery stages (Hogg 1980, Rubin and Popkin 1990, Rubin 1991, Berke et al. 1993, Bolin 1993).

These more recent studies show disaster recovery to be a social process involving decision making, institutional capacity, and conflicts between interest groups. The outcomes of these social processes have often led to geographic disparities and social inequalities. These themes resonate with development of social vulnerability theory in disaster studies, which suggests that marginal groups may not only be especially vulnerable to suffering losses, but they are likely to have more difficulty in recovering (Hewitt 1997, Blaikie et al. 1994). They may, for example, have lesser access to insurance, loans, relief aid, or government bureaucracies and decision making, or face shortages in low-income housing (e.g., Bolin and Bolton 1986, Bolin and Stanford 1991, Hirayama 2000). The importance of disparities has also been borne out by studies of businesses in disasters. In various California earthquakes, researchers have found that small businesses and those that were generally marginal even before the disaster had the most difficulty in recovering (Durkin 1984, Kroll et al. 1991, Tierney and Dahlhamer 1998, Alesch and Holly 1998). Further, spatial effects have been found to be important in disaster recovery. Decentralization of population and economic activity may be accelerated (Chang 2001), business losses are correlated with disaster severity in the neighborhood (Tierney and Dahlhamer 1998), and retail and other locally oriented businesses generally lag in recovery (Alesch and Holly 1998, Kroll et al. 1991, Chang and Falit-Baiamonte 2003).

To date, few of the insights generated in such studies have been formalized within a modeling framework. Most efforts at modeling societal impacts of natural disasters have focused on economic losses (see Okuyama and Chang, 2004). In these studies, impacts are primarily driven by damage to various economic sectors and inter-industry linkages at the urban or regional scale. To the extent that dynamic processes have been incorporated, they have focused on limited facets of the recovery process such as the temporal distribution of reconstruction spending, production chronology factors (Okuyama et al. 2000), reconstruction borrowing and debt repayments over time (Brookshire et al. 1997), and prioritizing lifeline reconstruction to minimize economic disruption (Rose et al. 1997, Cho et al. 2001).

While the literature on loss modeling has been growing rapidly, modeling of recovery processes and time frames has been largely neglected. The significance of this dis-

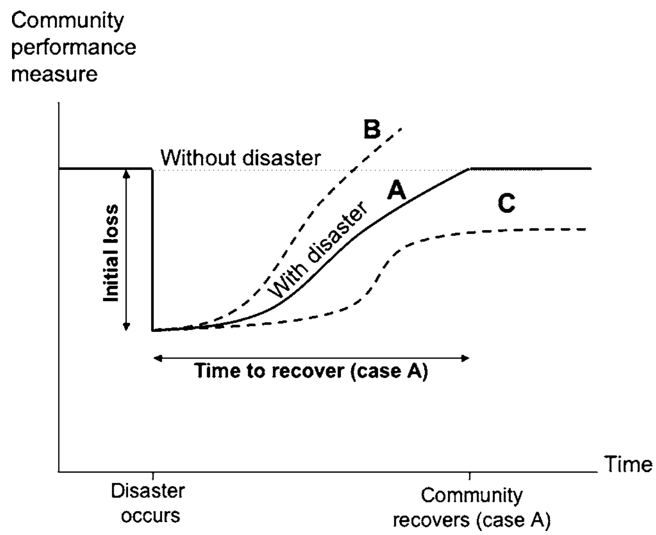

Figure 1. Schematic of disaster recovery.

tinction can be illustrated by the schematic diagram of recovery in Figure 1. Loss models generally focus on initial loss caused by a disaster where initial loss is measured in terms of some indicator of community performance (e.g., building stock or gross regional product) relative to what would have occurred without the disaster. (While sometimes loss is measured relative to pre-disaster conditions, this is only conceptually correct if without-disaster and pre-disaster conditions are the same, as in the figure.) A community's capacity to minimize this initial loss is referred to as robustness (Bruneau et al. 2003, Chang and Shinozuka 2004). As indicated in the figure, rapidity—the capacity to recover rapidly—comprises a second important dimension of resilience. The recovery time path itself clearly makes a great difference in determining overall loss. Unfortunately, most loss models, such as HAZUS (Whitman et al. 1997), treat the recovery time path in a summary fashion; in some models, for example, it is simply asumed that after one year, the affected economy returns to normal. Note that a community does not necessarily return to baseline performance; it may exceed it (case B in the figure) due to such factors as effective recovery planning or substantial inflow of disaster assistance, or it may suffer permanent losses and equilibrate below the baseline (case C).

The extent to which the recovery time path can be influenced by decision variables is of great interest to policy makers and disaster managers. A comprehensive model framework is needed to integrate the many aspects of community recovery.

A CONCEPTUAL MODEL OF RECOVERY

The methodology adopted for designing the recovery model is based on the object-oriented design technique introduced in Rumbaugh et al. (1991), which is the basis for the more sophisticated Universal Modeling Language (UML). With object-oriented design, the conceptual model comprises (1) the object (or static) model, (2) the dynamic model, and (3) the functional model, which together describe the real world system. There are several reasons why object-oriented analysis is appealing as a means of designing the disaster recovery simulation model. Perhaps most obvious is the paucity of numerical data that can be used in developing a model of such high detail and broad scope. There is a rich body of diverse knowledge, both in the literature and locally, on which to base a model. UML provides an effective way of incorporating this array of knowledge. Another significant reason for using object-oriented analysis is the desire for an implementation-independent design. That is, it is important to have a sound conceptual framework founded in the disaster recovery literature that can serve as a guide for multiple approaches to computer modeling, while facilitating easy model modifications.

The steps of object-oriented design are (1) problem definition, (2) object (static) modeling, (3) dynamic modeling, and (4) functional modeling. The goal of defining the problem is to identify all of the objects and relationships that exist within the system, which can be abstracted during subsequent stages of analysis. An object model captures the static structure of a system by showing the objects in the system, relationships between objects, and the attributes and operations that characterize each class of objects. Dynamic modeling is not needed for purely static systems (i.e., a database) or computational systems, but rather for interactive software systems. The functional model describes the flow of data within a system independent of the actual algorithms used for computing outputs.

The two most effective approaches to developing a detailed, unambiguous problem statement are to either write a requirements document of the model or compose a narrative of the real world system being modeled. For initial development of the conceptual model we constructed a narrative of community recovery based on the literature introduced above (see Miles and Chang [2003] for the problem narrative). From the narrative we extracted important agents, events, and interactions during an earthquake disaster. Some of these elements of recovery are presented in Figure 2, which provides a concise overview of the conceptual model of recovery described in more detail below.

STATIC MODEL

An object model captures the static structure of a system by showing the objects in the system, relationships between objects, and the attributes and behaviors that characterize each class of objects. An object can be anything that makes sense to the particular application: typically a concept, abstraction, or physical thing with well-defined boundaries. Modeled objects should promote understanding of the system (i.e., disaster recovery) and provide a sound basis for implementation.

The initial step in creating the object model was identifying important objects from the problem narrative. The potential objects were analyzed to determine what, if any, associations exist among the objects. With a short list of potential objects and their associations, the problem narrative was used to help determine important attributes of each object. Additional attributes of objects were obtained by considering likely decision options relevant to community recovery, which may not be clearly associated with any particular object. One design choice involved representing associated physical and eco-

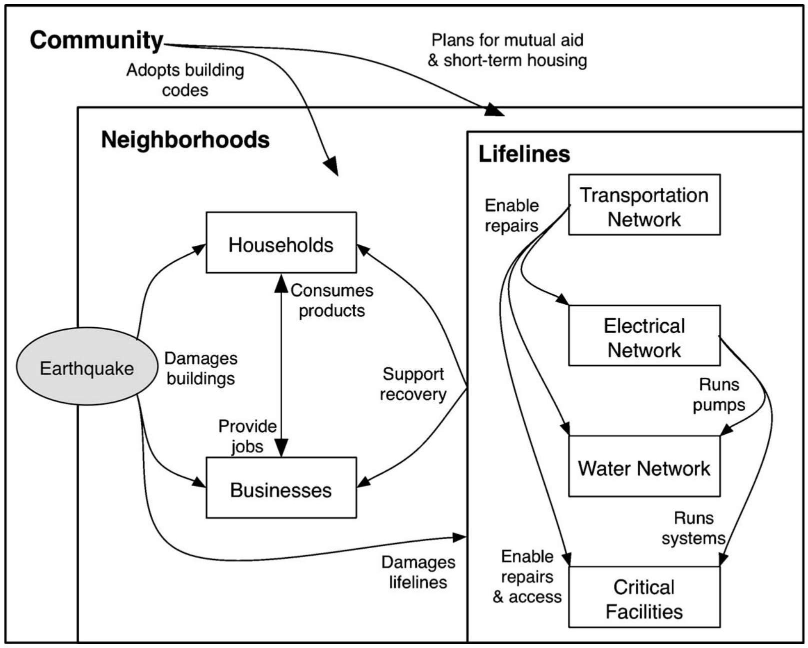

Figure 2. Overview of conceptual model of community recovery from earthquakes.

nomic objects (e.g., electric network and electric company, respectively) as a single economic object with attributes and functions that represent the important aspects of the associated physical object.

The static aspects of the conceptual model of disaster recovery are presented in Figure 3. The diagram describes the important object types of the conceptual model (the community, its neighborhoods, households, businesses, and lifelines) and lists the attributes and behaviors (model variables) of each type of object. For example, an object of type "household" has attributes of income (INC), year building of residence was built (BYR), and whether any building mitigation has been done (BMIT). Households then engage in behaviors that influence, for example, their health, level of indebtedness, and whether they remain in their particular neighborhood after the earthquake. These behaviors form the basis of the functions or algorithms for implementing the conceptual model. Within an implementation of the conceptual model there may be any number of households having the same data structure, but with different values for the respective attributes (and thus different output for the respective functions). The attributes and behaviors (or variables) are listed and defined in Table 1. Attributes within the conceptual model either are associated with agents (households, businesses, or lifelines) or correspond to decision variables. Several attributes are default restoration variables (e.g., DAID, DBL, and DHLTH). These attributes describe the "typical" capacity for restoration for an agent type with respect to some indicator. This can be modified to reflect the particular characteristics of the specific agent. Behaviors can be associated with any object type and are either aggregated or intermediate recovery indicators. Figure 3 shows a

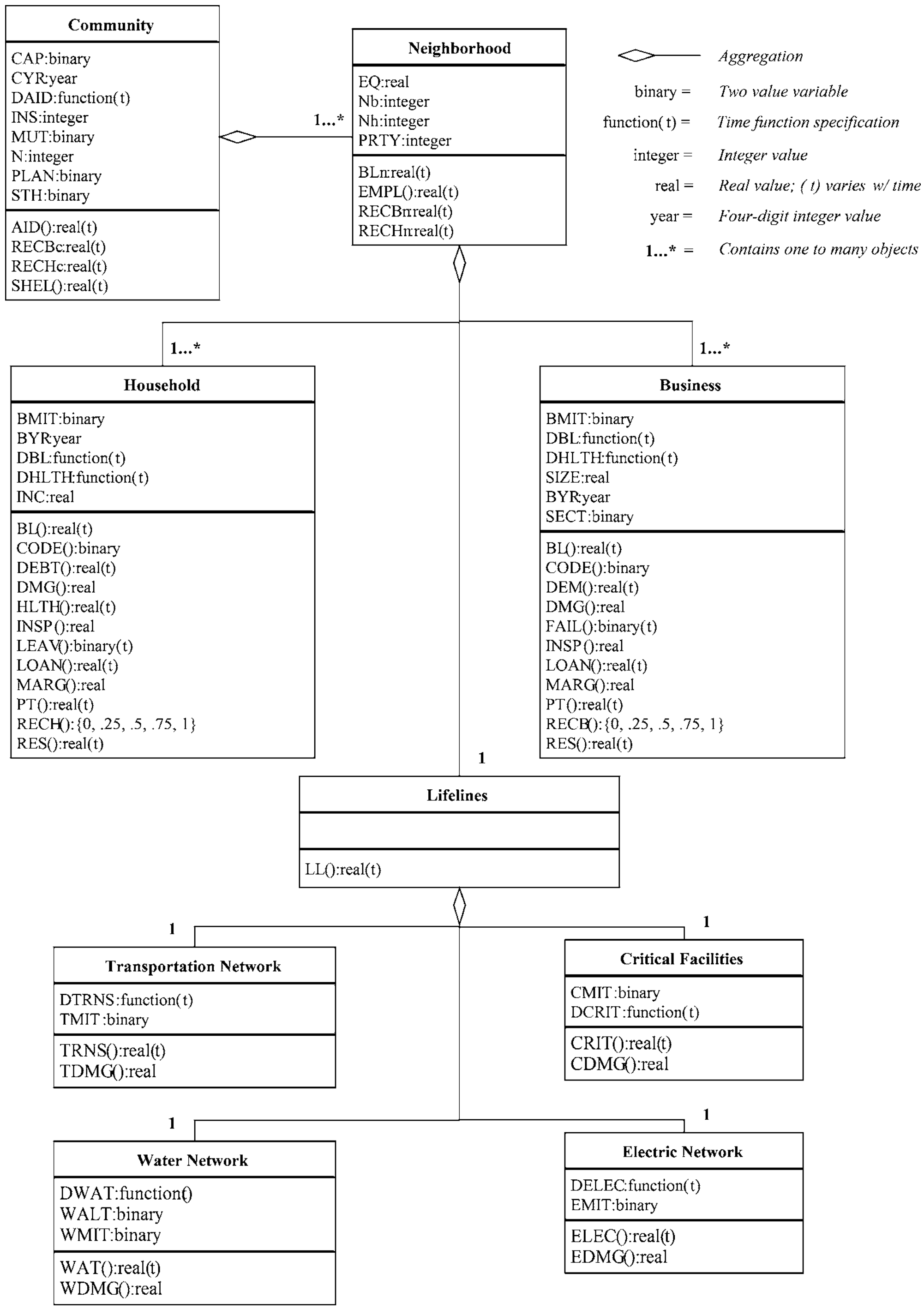

Figure 3. Main objects in conceptual model of recovery. The three parts of each box respectively indicate, from top to bottom, the object's name, attributes, and behaviors or functions.

Table 1. Variable definitions for conceptual model

AID	= availability of reconstruction aid in community
BL	= availability of building for use
BMIT	= pre-earthquake structural mitigation
BYR	= year building built
CAP	= political capacity of community (proxy for integration, consensus, etc.)
CDMG	= extent of damage to critical facilities
CMIT	= pre-earthquake mitigation to critical facilities
CODE	= compliance of building with seismic code
CRIT	= availability of critical facilities
CYR	= year seismic code effective
DAID	= default aid availability
DBL	= default building restoration
DCRIT	= default critical facility restoration
DEBT	= extent of indebtedness
DELEC	= default electricity restoration
DEM	= demand for product post-earthquake
DHLTH	= default health restoration
DMG	= damage state of building
DTRNS	= default transportation network restoration
DWAT	= default water network restoration
EDMG	= extent of damage to electricity network
ELEC	= availability of electricity
EMIT	= pre-earthquake mitigation to electric power system
EMPL	= availability of employment/income
EQ	= severity of earthquake's physical effects
FAIL	= occurrence of business failure
INC	= income of household
INS	= availability of insurance outlays
INSP	= speed of safety inspections
LEAV	= status of household leaving region
LL	= overall lifeline availability status
LOAN	= amount of reconstruction loan taken out
MARG	= pre-disaster financial marginality
MUT	= provision for mutual aid in restoration plan
PLAN	= availability of restoration and recovery plan
PRTY	= restoration priority accorded to neighborhood
PT	= probability of transition to next higher recovery level
RECB	= business economic recovery level
RECH	= household economic recovery level
$RECB_{n/c}$	= overall business recovery in neighborhood/community (proxy for suppliers)
$RECH_{n/c}$	= overall household recovery in/neighborhood/community (proxy for labor)
RES	= financial resources for recovery
SECT	= type of business sector
SHEL	= availability of temporary shelter
SIZE	= business size

Table 1. (cont.)

STH	= short-term housing provision in recovery plan
TDMG	= extent of damage to transportation network
TMIT	= pre-earthquake mitigation to transportation network
TRNS	= transportation accessibility
WALT	= provision for alternate water sources (water trucks) in plan
WAT	= availability of water supply
WDMG	= extent of damage to water network
WMIT	= pre-earthquake mitigation to water system

Notes: Agent attributes in **bold**. Decision variables in **bold underline**. Default restoration variables in ***bold italics***. Aggregated recovery indicators in *italic underline*. Secondary/intermediate recovery indicators in normal font.

simplified, though complete, version of the object model developed. Some secondary objects and associations are not shown. For example, the diagram does not show the inheritance association (i.e., "is a type of") between households and businesses, which are both socioeconomic agent objects and have many similar attributes and functions.

FUNCTIONAL MODEL

The functional model specifies the meaning of the behaviors described within the object model (Figure 3). The functional model shows the relationship between inputs and outputs without regard to the specific algorithms or order of computation. This modularity is important so that it can be carried over to the computer implementation. In this way, existing equations or algorithms can be used or experimented with without affecting the overall structure or function of the model. Functional dependencies (i.e., what inputs influence a particular output) were arrived at with reference to the literature, the problem narrative, and common sense. As with the object model, the functional model can be modified later in its development to reflect discipline-specific or local knowledge about recovery. Whereas the object model is represented using an object diagram, a functional model is typically represented using a data flow diagram. The data flows (i.e., object attributes) are passed between the functions of the different objects, represented by ellipses. The data flows are represented with an arrow indicating the direction of relationship (i.e., input or output). A plus sign (+) next to a data flow arrow indicates a positive relationship (i.e., increasing input value results in increasing output values), while a minus sign (−) indicates an inverse relationship.

The functional dependencies within the disaster recovery conceptual model are illustrated in the flow diagram in Figure 4, which describes the data flow for determining the recovery of an individual business within a given neighborhood. (Similar diagrams for household recovery, lifeline recovery, building damage, etc. can be found in Miles and Chang [2003])

The functional model describes five principal types of interrelated recovery influences: (1) dynamic effects, (2) agent-attribute effects, (3) interaction effects, (4) spatial

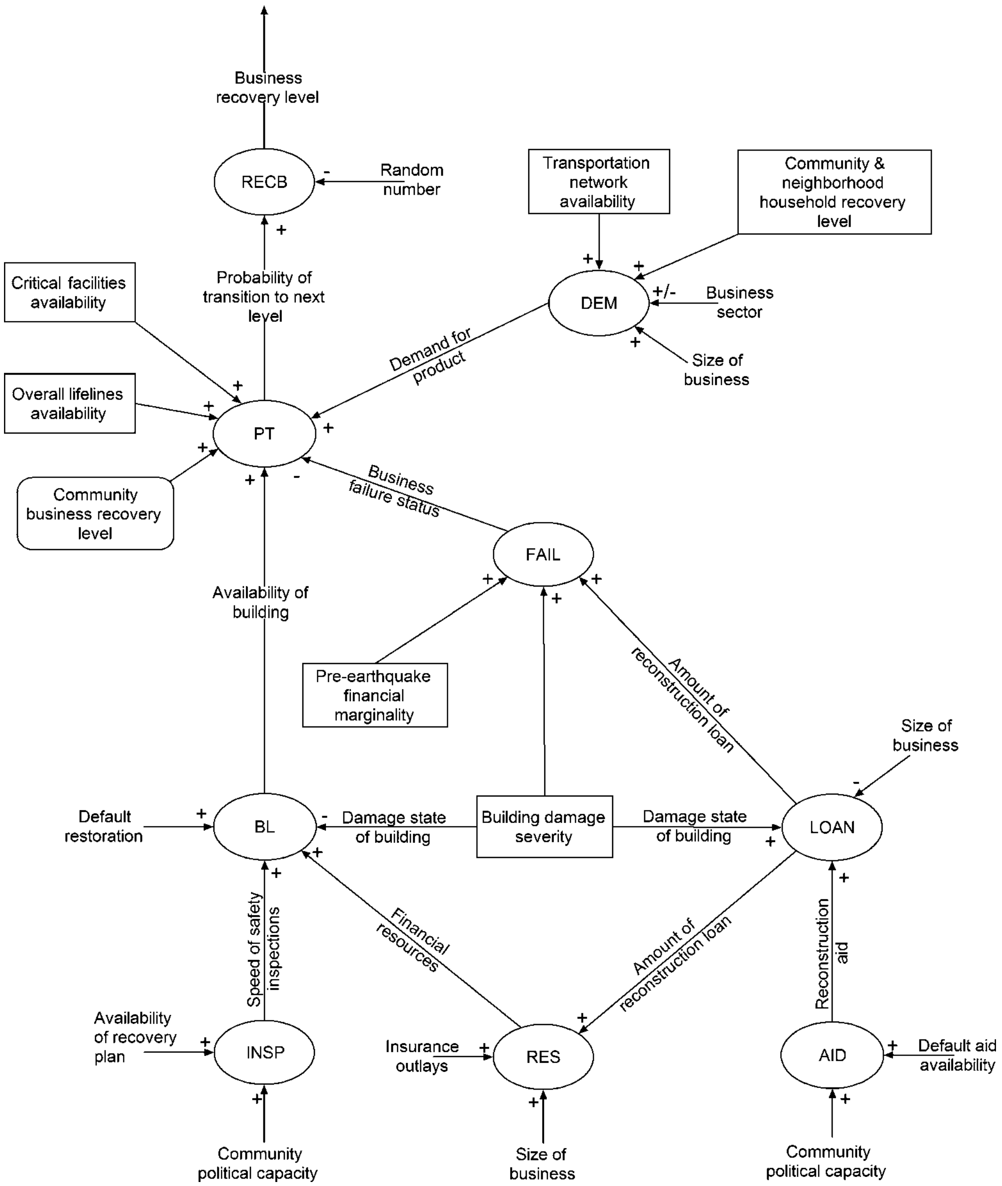

Figure 4. Flow diagram for business recovery component of the functional model. Arrows represent object attributes and the direction of their influence. Diagram elements are defined within the text.

effects, and (5) policy effects. Dynamic effects refer here to changes over time. In true dynamic processes, an indicator's current level depends upon its level in a previous period. What can be called pseudodynamic processes—changes over time that can proceed independently of indicator levels in previous periods—also play an important role.

In addition to temporal processes, a second type of recovery influence consists of agent-attribute effects. For example, in Figure 4, attributes of the business itself may influence its recovery trajectory pertaining to the post-earthquake demand for a business's product. Product demand depends upon on a business's attributes—whether it is in a locally oriented or export-oriented sector and whether it is a large or small business. In particular, if locally oriented, then the recovery of households in the neighborhood and community matters, as these are its customers. Similarly, local transportation conditions influenced locally oriented business's product demand. However, if a business is export-oriented, these local variables do not play as large a role and the demand for its product may remain unchanged by the disaster.

A third type of recovery influence consists of interaction effects. For example, water availability is influenced by the survival of the electric power and transportation systems. Electric power may be needed to drive pumps that enable the water system to function; transportation disruption can impede the ability of the water utility to make expedient repairs. Similarly, the relationships driving business product demand described in Figure 4 demonstrate some of the ways in which households, businesses, neighborhoods, and the community as a whole interact. Households influence business recovery through consumption demand. The availability of lifelines and critical facilities influences business recovery, as does the overall recovery level of households and businesses in the economy.

The fourth type of influence, spatial effects, can similarly be seen in the examples presented so far. Households and businesses are affected by conditions in their specific neighborhoods, whether in terms of water availability, transportation conditions, or local employment opportunities. Thus the same type of household or business may recover differently depending upon which neighborhood it is located in (see Figure 4).

The final type of influence consists of policy or decision effects. These are organizational decisions made either before the event, such as emergency planning and mitigation measures, or afterwards, such as restoration prioritization and recovery policy decisions. Other decisions represented in the conceptual model of recovery include the year that the community put into effect a seismic design code for its buildings (if it did); emergency planning for alternative water supplies such as water trucks; whether seismic mitigation has been conducted for lifeline systems; the availability of a disaster plan; use of short-term housing in place of temporary shelter; and a measure of a community's political integration and capacity for consensus. Modeling the influence of these decisions is critical in that implementation of the conceptual model will enable exploring the recovery consequences of different policy decisions.

PROTOTYPE IMPLEMENTATION

The goal of the conceptual model is to facilitate better understanding of the community recovery process in hopes that decision makers and citizens can increase their community's resilience against disaster. One way in which the conceptual model can be used towards this end is as the basis for a computer model or decision support system. In order to stimulate research and development on these much-needed tools, we have implemented the conceptual model described above in the form of a prototype computer model and graphical user interface (GUI). For brevity, only a general overview of the prototype development and specifications is given here. Specific details, including equations and sensitivity analysis, are given in Miles and Chang (2003). The prototype was developed towards two objectives. The first objective was to demonstrate the feasibility of implementing the complex set of relationships that make up the conceptual model for a community populated with a large number of households and businesses. The second objective was to elicit critical issues, needs, and applications for future development of a robust computer model and decision support tool.

The conceptual model enumerates relationships between many of the critical objects or agents within the recovery process, but does not specify the means for operationalizing these relationships. We devised a simple numerical framework to facilitate convenient implementation of the many relationships within the functional model. The framework takes the form of 32 unique equations, including 9 equations to define the behaviors of businesses and 10 for households. The total number of equations for a particular application of the model depends on the particular number of households and businesses. Operationalizing the diverse relationships of the functional model was done by specifying each model variable as a relative index that varies between 0 and 1, rather than in real world metrics, such as dollars. The approach taken is useful for integrating many metrics that would otherwise be difficult to combine mathematically. In many cases, the model variables do not have a common metric, for example, financial marginality or health. We derived basic first-order algebraic equations based on the relationships specified in the functional model.

The Simulink modeling environment for Mathwork's MATLAB software was chosen for implementing the prototype recovery model. Simulink is specifically designed for implementing complex, time-based simulations using a graphic language consisting of operators and data flows. Simulink affords significant advantages in terms of model building and execution, and easy-to-use tools for building GUI elements. A significant advantage of Simulink is the modularity it provides, which is compatible with an object-oriented model design. Simulink models can be built in a hierarchical and encapsulated manner, increasing the transparency of the computer model.

The prototype implemented in MATLAB Simulink is for a community consisting of four neighborhoods or analysis zones, each having 100 businesses and 100 households. The seismic hazard, community characteristics, and demographics within the prototype implementation are based on the city of Kobe, Japan, and the earthquake disaster of 1995 (see Miles and Chang [2003] for details). A graphical user interface (GUI), shown in Figure 5, was constructed to afford the posing of "what if" questions related to the community's demographics (agent attributes), lifeline networks, building infrastructure, and sociopolitical preparedness (decision variables). The questions are formed by indicating (via checkboxes) desired community or lifeline mitigation policies and by specifying the attributes of businesses (size, sector, and building condition) and households (income and building condition) as a percentage of the neighborhood population. Based on these specifications, a user can run the underlying prototype recovery model to graphically observe the possible influence on the degree and speed with which the community would recover from a significant earthquake.

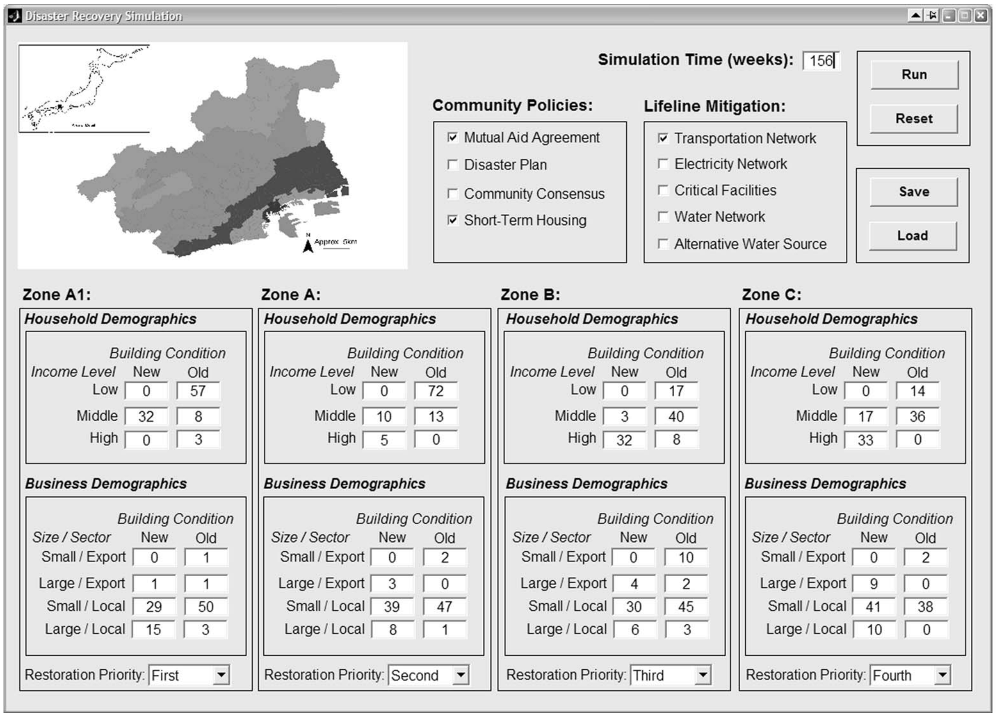

Figure 5. Graphic user interface of the recovery model prototype.

As Figure 6 illustrates, model users can explore the recovery disparity between neighborhoods (analysis zones) for different scenarios of disaster preparedness and mitigation decisions. In this example, comparing household recovery (the bottom graphs) in Figure 6 for the cases with (right) and without (left) disaster preparedness and lifeline mitigation, it can be seen that in the latter case, not only does recovery in all four zones proceed more rapidly, but it reaches higher levels and exhibits lesser disparity between zones.

PARTICIPATORY MODEL ASSESSMENT

Computational models are typically evaluated analytically through sensitivity analysis and empirical comparison, with the results of analysis being used to guide further model development. The analytical evaluation conducted on the prototype to date is described in Miles and Chang (2003). Because the recovery model is intended for supporting people in making collaborative decisions, it is important to continuously involve users and stakeholders in the development process of the prototype recovery model—indeed, all models intended for decision support (Miles 2000). Participatory model assessment elicits model development needs and perspectives on model appropriation that cannot be done using purely analytical techniques (Miles 2004, Hornecker et al. 2002, Durrenberger et al. 1999, Hennen 1999). With respect to the prototype recovery model, issues requiring feedback include the following: the most suitable uses for re-

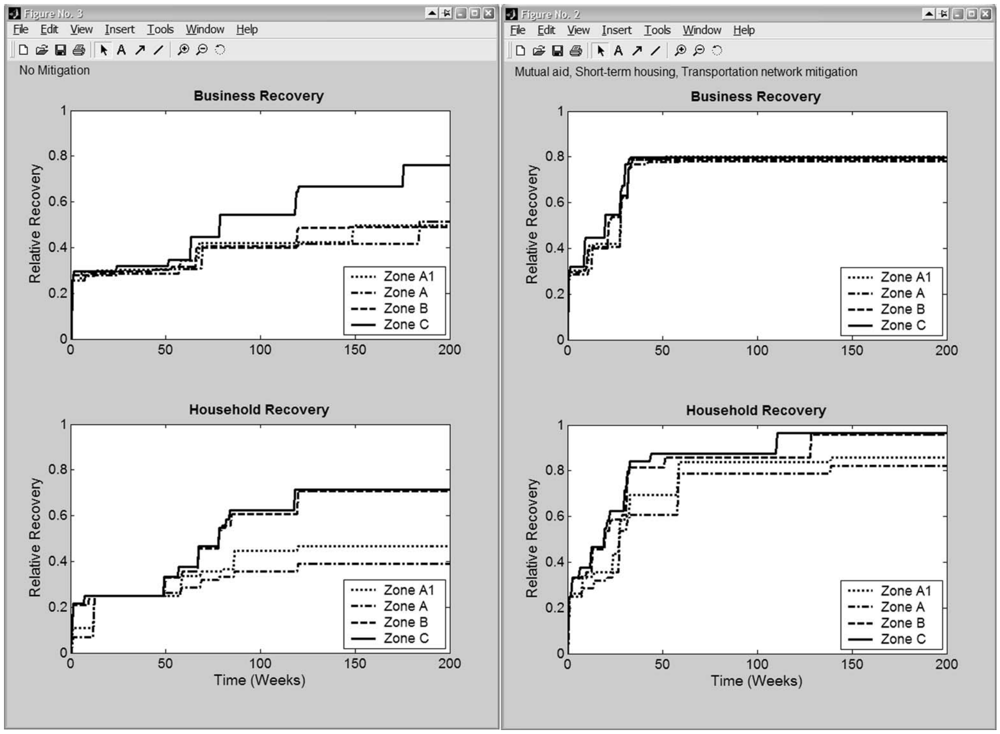

Figure 6. Graphical output generated using prototype recovery model and graphic user interface. The output on the left represents a "no mitigation" scenario, while the output on the right represents a scenario incorporating disaster preparedness and lifeline mitigation.

covery models; the best way of delivering the model (i.e., software development); what inputs the model needs to consider; and what indicators of recovery the model should predict. To solicit feedback on the prototype model, we designed and conducted a participatory assessment focus group based on strategies set out in Miles (2004) and Durrenberger et al. (1999). We invited Puget Sound, Washington, area disaster/emergency management practitioners who deal with recovery as part of their job responsibilities to participate in the focus group. The focus group involved nine participants, variously from the Federal Emergency Management Agency, county disaster management agencies, a city disaster management agency, a local public utility, University of Washington, a regional nonprofit organization for earthquake mitigation, and a local engineering and planning firm.

PARTICIPATORY ASSESSMENT FOCUS GROUP

The focus group was held in the Department of Geography's "collaboratory" at the University of Washington, which is specifically designed for computer-assisted group collaboration. The focus group lasted approximately three hours. The meeting began with introductions, review of the focus group's purpose, and presentation of the agenda. Participants were asked to provide a definition of community recovery from natural disasters to initiate a brief group discussion. Two presentations were then given on, respectively, concepts of community loss and recovery from the scientific literature, and the prototype recovery model, its development, the GUI, and evaluations to date.

Participants were then broken into two arbitrary groups of four or five people to receive a demonstration of the prototype. With project personnel serving as chauffeurs, focus group participants interacted with the prototype recovery model by suggesting scenarios for exploring. Notes on this interaction were taken discretely by designated notetakers. After participants had time to try out the prototype, they were asked to complete a questionnaire. The questionnaire first asked participants to describe their field of work. Then several Likert statements—multiple-choice questions based on an ordinal five-point scale—were presented to solicit responses about the best uses for the future model (or decision support system), what policy and decisions are most useful to model (i.e., input variables), and what indicators of recovery are most important. Each set of Likert questions was accompanied by a solicitation for free-form comments. Before wrapping up, participants engaged in a discussion on two general topics: (1) suggestions/ requirements for further development of the model and software, and (2) appropriate/ expected roles and applications for the decision support tool.

FOCUS GROUP OUTCOMES

After completing the introductory agenda items, we asked focus group participants to share their views on community recovery from disasters. We had expected their responses to focus on issues of loss, such as structural damage and direct loss due to, for example, business closure. Instead, we found that their conception of community recovery was well-informed with respect to the current research literature, including providing some nuanced perspectives. Participants first suggested that recovery is putting things back together again after earthquake ground motions have stopped. They noted, however, that no community returns to the way it was before the earthquake; rather, a new equilibrium is created and recovery does not necessarily mean that a community is made whole again. From their experience, recovery becomes, over the long term, a process of taking advantage of opportunities to fix pre-existing problems within the community. Participants stressed that the transition from putting the pieces back together again in the earthquake's aftermath and fixing problems in the long run is a fluid, multifaceted process. This view is counter to the idea of a set of phases with distinct beginnings and ends. Moreover, the more time that has passed after the earthquake, the more difficult it is to identify specific activities of recovery. Therefore, the group felt that it is difficult to define when the recovery process has stopped.

After the discussion on community recovery, participants provided feedback regarding the prototype recovery model in three ways: Likert statement responses, written comments, and observations articulated during interactions with the prototype and the group discussion. Responses to the Likert questions are only marginally useful. As a result, only the more insightful questionnaire responses are presented fully below. The questions (or question topics) were apparently not distinctive enough; for many ques-

Table 2. Summary of participants' responses to questions about potential uses of a community recovery model

	Strongly agree (5)	Agree (4)	Not Sure (3)	Disagree (2)	Strongly disagree (1)	**Avg. score**
1. Mitigation planning (n=9)	7	2	—	—	—	**4.78**
2. Recovery planning (n=9)	7	2	—	—	—	**4.78**
3. Training of emergency managers (n=9)	3	5	—	1	—	**4.11**
4. General education (K–12, college) (n=8)	1	3	4	—	—	**3.63**
5. Emergency response (n=9)	1	3	3	2	—	**3.33**
6. Public awareness (n=7)	1	1	4	1	—	**3.29**

tions, the responses were the same from all participants. Participants seemed to appreciate the free-form means of feedback, providing many written comments and enthusiastically engaging in all group discussions.

With respect to potential uses of the recovery model, mitigation and recovery planning were rated highest by participants (Table 2). The other suggested uses—emergency manager training, general (K-12) education, emergency response, and public awareness—on average scored increasingly lower. Participants commented that the technical model outputs would need to somehow be translated, simplified, or contextualized for educational or public awareness purposes.

Participants had many suggestions for roles and applications of the recovery model. If the model can be tied to cost-benefit analysis, it might be useful for communities applying for pre-disaster mitigation grants from FEMA. The model could be used to educate and raise awareness on the part of elected officials, business managers, and land-use and other planners whose decisions affect disaster resilience but who do not engage in disaster management on a routine basis. If adopted institutionally it might provide impetus for including more complete recovery modules in disaster training exercises. Insight gained from the model can help prioritize mitigation and other projects. Use as a planning tool would be particularly facilitated by tying the model or decision support system to federally mandated DMA2K (Disaster Mitigation Act of 2000) planning as much as possible. Ideally, the recovery model should guide comprehensive community planning by linking recovery interventions to general community health.

Overall, participants thought that all current decisions represented within the prototype are important. Participants expressed a need for more detailed and explicit definitions for the modeled decisions—impetus for further social science research on the influence of policies, plans, and mitigation strategies. On average, participants felt that the influence of decisions related to a community's political integration (capacity for consensus) and mutual aid agreements were least important. The former is likely because of the ambiguity of the decision variable as represented in the conceptual model; the latter perception reflects the wide spatial effect of severe earthquake shaking on a region's response and restoration capacity. Comments given indicated that disaster plans should be represented at finer scales, including the neighborhood level and within individual businesses or organizations. Other characteristics suggested by participants include some indication of a community's "repetitive loss knowledge" or experience with previous disasters and forecasts. One participant felt that it is important to represent the legal structures that are in place for implementing and enforcing recovery efforts. Lastly, it was suggested to include some measure of the strength of neighborhood organizations as a form of social capital.

Participants provided many insightful comments regarding potential modeling refinements. For example, they noted the importance of modeling business and household movements between neighborhoods and other communities. Further, the model must afford different definitions of neighborhoods or analysis zones to afford use by different organizations, such as counties, municipalities, or large businesses. More detailed characterization of the building(s) that a business occupies (e.g., physical characteristics, tenure, and number) as well as the business itself (e.g., economic sector) was thought to be needed. Similar suggestions were made for refining modeling of household recovery.

In terms of indicators or measures of recovery, several participants commented on the need to include some indicator of communication systems recovery. An additional suggested lifeline recovery indicator was capacity of solid waste and sewage service. Participants felt that critical facilities needed to be represented in more detail, modeling hospitals, fire, police, etc. separately within the recovery process. Participants indicated that economic indicators are critical to include in the recovery model, though with some ambivalence regarding unemployment rate, and suggested inclusion of the rate of small business failure. Conversely, participants brought up several social indicators including measures of a community's mental health, quality of life, or degree to which social support systems are in place. They observed that these indicators are necessary to temper unsustainable strategies for economic recovery. With respect to environmental indicators, one participant recommended specific measures of air and water quality, citing problems faced in New York City after the World Trade Center disaster.

To supplement the feedback obtained in the focus group, a shorter version of the questionnaire was also distributed at a regional conference for emergency managers (Partners in Emergency Management Conference, Bellevue, Washington, April 2004). In a one-hour session devoted to the recovery model, participants were asked to fill out the questionnaire after hearing an in-depth presentation. A total of 33 questionnaires were returned. Responses generally corroborated findings from the focus group. For example, participants agreed that the model would be useful for mitigation planning (average score $z=4.30$; compare to Table 2 above) and recovery planning ($z=4.27$), but were less certain about other potential uses such as public awareness ($z=3.81$), training of emergency managers ($z=3.72$), general education ($z=3.45$), or emergency response ($z=3.31$). As in the focus group, they considered the most important decision variables for inclusion in the model to be lifeline mitigation ($z=4.70$), critical facility mitigation ($z=4.70$), and seismic building code adoption ($z=4.47$). The practitioners further provided suggestions for model refinement through free-form responses.

CONCLUSION

This paper embodies a foundational effort towards developing robust models of community recovery from earthquakes and other disasters. The explicit conceptual model set out here is the first of its kind in specifying linkages between sectors, domains, scales, and processes in recovery. The conceptual model provides a common and flexible basis for building complementary computer models of socioeconomic recovery from disasters. Modelers can focus on developing algorithms for some subset of the relationships or indicators within the model or can use modeling methodologies to create an integrated set of algorithms. In parallel, software tools can be constructed for facilitating interaction with recovery models and communication of their results. Group decision support tools for organizing and choosing alternatives can be identified towards creating a comprehensive decision support system, which could possibly include the array of alternative models that researchers develop.

Further, our conceptual model provides a systematic framework for empirical research into the important actors and relationships in the recovery process. Which variables and relationships within the conceptual model are most important? Do the direction and sign of influence reflect future empirical findings? Which objects, attributes, or behaviors are not yet included? What empirical data is needed to make these assessments? Like the insights gained during the participatory assessment focus group, which can be integrated into the conceptual model, local knowledge from practitioners and citizens can be elicited to investigate and expand the conceptual model. The participatory model assessment focus group conducted as part of this work clearly demonstrates the value of this type of knowledge elicitation for future research and development efforts. Participation will also instill a sense of trust and familiarity on the part of users and stakeholders with the tools that are developed and, most importantly, the decision processes in which they are appropriated. Finally, participatory inquiry will help to build an understanding about how these tools should be used within different management and planning contexts towards reducing social vulnerability and increasing community resilience.

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