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NCEER Changes Name to Multidisciplinary Center for Earthquake Engineering Research

The National Center for Earthquake Engineering Research (NCEER), headquartered at the State University of New York at Buffalo, has been renamed the Multidisciplinary Center for Earthquake Engineering Research, a national center of excellence in advanced technology applications. The change was approved by University at Buffalo President William R. Greiner and the National Science Foundation (NSF), which is the Center's founding sponsor. The change in name will also include the center's Information Service, which will now be called the Multidisciplinary Center for Earthquake Engineering Research Information Service.

"This new name," said Center Director George C. Lee, "emphasizes what we feel is the key to our success—past, present and future—the integration of diverse disciplines to solve engineering and societal problems caused by earthquakes."

"In the months and years ahead, the Center seeks to increase multidisciplinary participation by further engaging manufacturers, practitioners and government officials to assist in the research and application processes," he added. "Our hope is that the new name will help encourage this collaboration."

The need for a change in name became apparent last fall when NSF expanded its national earthquake research program by establishing two new earthquake engineering research centers in addition to NCEER. These include the Pacific Earthquake Engineering

Research (PEER) Center, headquartered at the University of California at Berkeley, and the Mid-America Earthquake (MAE) Center, headquartered at the University of Illinois, Urbana-Champaign.

Dr. Lee noted that since its inception in 1986, NCEER has successfully integrated researchers from numerous disciplines, including civil, mechanical, electrical and computer engineering, as well as seismology, architecture, regional planning, sociology, economics, and policy and decision sciences. "Their combined knowledge produces a research team that is prepared for the challenge of developing sound engineering and disaster management solutions that are both economically feasible and socially acceptable," he said.

"We have never been interested in just solving an equation or studying the dynamic behavior of a beam," Dr. Lee added. "We want to make communities more earthquake-resistant through pre-event planning and mitigation, and post-event response. To do this, we must have multidisciplinary teams working together."

The \$10 million grant the Center received last fall from NSF (see *NCEER Bulletin*, Volume 11, Number 4, October 1997) supports a program to study the application of advanced and emerging technologies to minimize earthquake damage and losses nationwide.

The new name and logo will be phased in over the next few months.

INSIDE

Research Activities.....	2
Discussion.....	16
Obituary.....	21



Center Activities.....	22
Center Resources.....	27
Bulletin Board.....	30

Research Activities (Cont'd)

An Integrated Model of Highway Networks and the Spatial Metropolitan Economy:

Towards a General Model of How Earthquake Losses Affect the Economy

by Masanobu Shinozuka, James Moore, Peter Gordon, H.W. Richardson, Stephanie Chang and Sung-bin Cho

*This article describes work conducted at the University of Southern California to develop an integrated model of losses due to earthquake impacts, and how these losses affect the urban economy. A longer paper on this topic is included in *Proceedings of the Workshop on Earthquake Engineering Frontiers in Transportation Facilities*, NCEER-97-0005 (see review on page 27). The development of the overall model was supported by the NSF; its application to transportation systems is supported in part by the FHWA under the NCEER Highway Project. Comments and questions should be emailed to James Moore, jmoore@usc.edu, Peter Gordon, pgordon@usc.edu or Masanobu Shinozuka, shino@usc.edu.*

One of the benefits provided by any earthquake mitigation measure are the costs avoided if the measure is applied. What are the full costs of an earthquake? This cannot be known unless all of the interactions between infrastructure and the economy are understood.

Regional economic production is measured in terms of gross regional product (GRP). The impact of an earthquake on highway infrastructure productivity consists of the loss of GRP due to reduced transportation system performance.

This research traces the effects of an earthquake on the metropolitan economy, including its impact on the highway network. An integrated framework and innovative methodologies are developed for evaluating the effects of earthquakes on urban highway infrastructure productivity, with a focus on the Los Angeles region.

Procedure

Data

Available data includes:

- baseline 1990 census data describing the spatial distribution (by traffic analysis zone) of residences and workplaces by major economic sector;

- the 515 sector Regional Science Research Institute (RSRI) input output model of the Los Angeles metropolitan (five-county) economy based on 1992 economic census data;
- 1994 transportation planning network based data from the Southern California Association of Governments (SCAG) and Caltrans Headquarters;
- Southern California Planning Model (SCPM), a spatial allocation model of the same area that has been used to distribute aggregate input-output results (in \$ and/or jobs) to 308 zones (political jurisdictions) across 17 economic sectors (aggregated from RSRI's 515 sectors);
- 1991 SCAG Origin-Destination Survey data;
- interregional and international trade flows from a variety of sources, including studies by DRI-McGraw, Caltrans, and the Port of Los Angeles.

This research extends the SCPM by endogenizing otherwise exogenous matrices describing the travel behavior of households, achieving consistency across network costs and origin-destination requirements, and better allocating indirect and induced economic losses over zones in response to direct earthquake losses in industrial and transportation capacity.

Figure 1 summarizes the approach. SCPM aggregates the 515 sectors represented in the RSRI model to 17. Each sector uses the other sectors' outputs as inputs, and each sector supplies the other sectors with inputs. This input-output perspective implies accounting assumptions:

$$\begin{aligned} \text{Total Gross Regional Product} &= \text{Total Value Added} & (1) \\ &= \text{Total Final Demands} \end{aligned}$$

$$\text{Total Regional Production} > \text{Total Gross Regional Product} \quad (2)$$

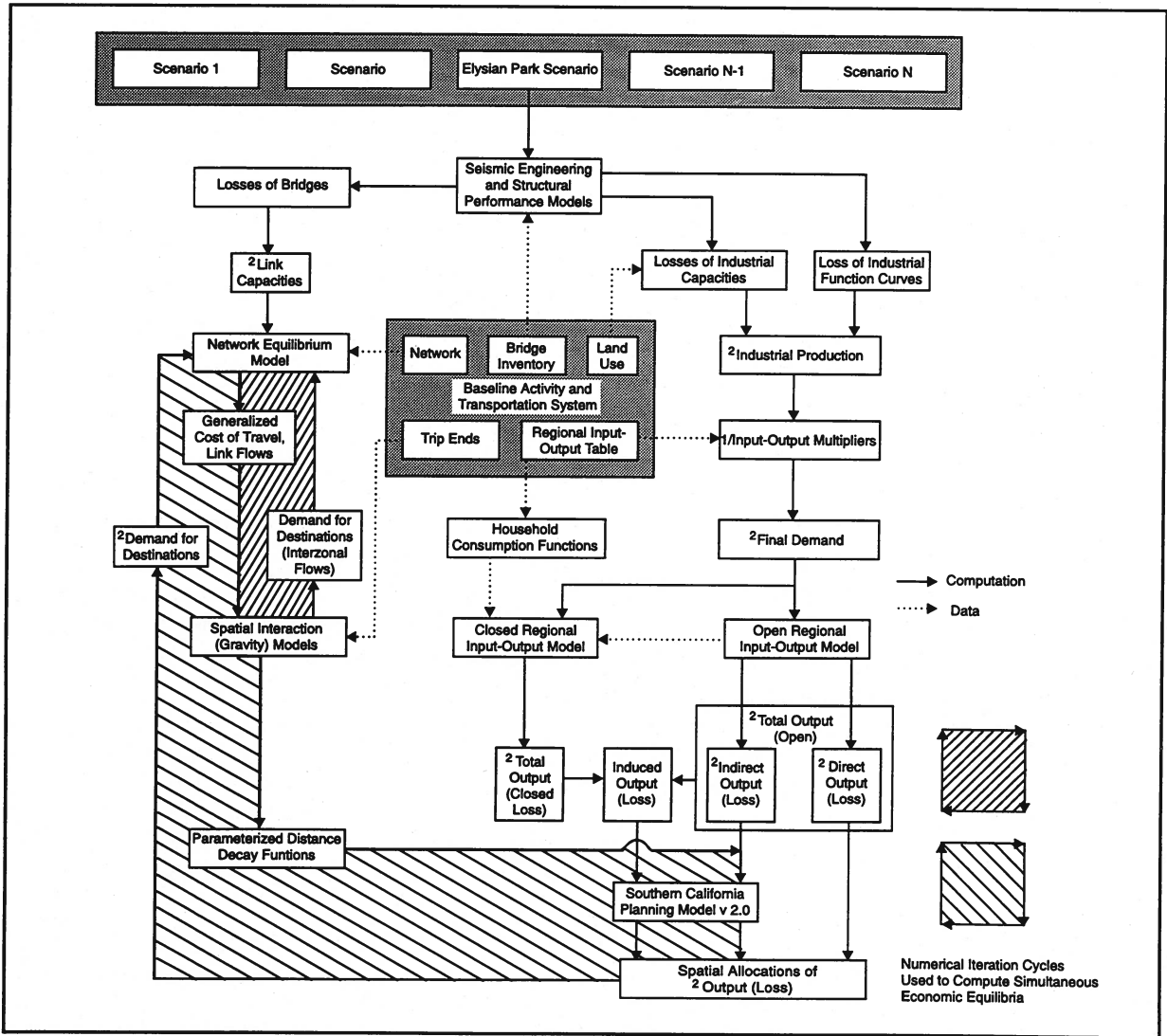


Figure 1: Summary of the Extended Southern California Planning Model

due to inter-industry requirements. The difference between *Total Regional Production* and *Total Final Demands* is *Total Inter-industry Demands*, ie.,

$$\text{Total Regional Production} = \text{Total Inter-industry Demands} \quad (3) \\ + \text{Total Final Demands}$$

In matrix terms, the standard demand driven input-output model is

$$X = AX + Y \quad (3a)$$

where:

$X = [X_j]$, a vector describing the value of *Total Regional Production* by economic sector j

$Y = [Y_j]$, a vector describing the value *Total Final Demands* by economic sector j

$A = [a_{ij}]$, a matrix of fixed value (demand) coefficients describing in \$ terms the values of the various outputs from each economic sector needed as inputs to produce \$1 of output in each sector j

$a_{ij} = x_{ij}/X_j$, the flow from i to j per unit output of j

x_{ij} = the value of the outputs from sector i used as inputs in sector j

In addition,

$$\sum_j x_{ij} = x_i \quad (4)$$

(continued on Page 10)

Research Activities (Cont'd)

(continued from Page 9)

which is *Total Inter-industry Demands* for outputs from sector i ; and

$$X_j = x_j + Y_j \quad (5)$$

which requires that total production sector j meet *Total Inter-industry Demands* plus *Total Final Demands* for outputs from sector j .

If *Total Final Demands* are given, this simultaneous system is fully identified and can be solved for total production. In the open version of the model, labor is not treated as a production activity. Instead, *Final Demand* includes a household component.

Knowledge of inter-industry transactions at the level of x_{ij} also makes it possible to formulate a supply driven input-output model, where:

$B = [b_{ij}]$, a matrix of fixed value (supply) coefficients describing in \$ terms the values of output from economic sector i used in each economic sector j per \$1 of output from each sector i

$b_{ij} = x_{ij} / X_i$, the flow from i to j per unit output of j

Establishing a Pre-Earthquake Baseline

The objective is to model the full economic impact of earthquakes on industrial capacity and system-wide transportation demand and supply. The first step is to compute a pre-earthquake baseline that is consistent with respect to equilibrium network costs, network flows, inter-zonal flows, and origin-destination requirements.

The five county, 1,527-zone SCAG transportation network is mapped to the five-county, 308 zone SCPM activity system. Each element in the SCPM journey-to-work (JTW) matrix describes the proportion of workers residing in zone i who work in zone j . Each element of the SCPM journey-to-shop (JTS) matrix describes the proportion of shoppers residing in zone i who shop in zone j . The SCPM JTW matrix is exogenous, and based on spatial distributions extracted from 1990 census data. In this case, a new JTS matrix is created by extracting matrices describing the journey-to-shop and journey-to-other (JTO) non-work

destinations from the scaled origin-destination requirements.

Some of the SCPM's 17 economic sectors involve freight flows. Freight flows include intermediate flows to production facilities, as well as flows to final demand sites inside and outside the system. This includes import and export flows, but not flows to and from residential sites. These latter flows correspond to shopping and work trips, respectively. Export flows satisfy final demand outside the region. Some import flows satisfy final demand within the region, and some imports are inputs to production processes. Some import and export flows also appear as throughputs.

Given the SCPM input/output relationships describing input requirements per unit of output, and given baseline jobs by economic sector and zone from the census, the next step is to compute total requirements of output i in zone z ,

$$D_i^z = \sum_j a_{i,j} \cdot X_j^z + \text{sector } i \text{ shipments to zone } z \text{ from transshipment zones (imports) and from other zones to accommodate local final demand not associated with households} \quad (6)$$

where:

$X_j^z =$ the total output of commodity j in zone z given base year employment in sector j and zone z

$a_{i,j} =$ is the i, j th element of A , the matrix of value demand coefficients for the (open) input output model

The first term on the right hand side of equation 6 accounts for inter-industry shipments out of all zones by aggregate freight sector i . D_i^z excludes shipments to households. In the open model, households generate local final demands, but no intermediate demands. Shipments associated with this element of final demand are treated as shopping trips.

Given baseline jobs by economic sector and zone from the census, the total supply of output i furnished by zone z is also computed as,

$$O_i^z = \sum_j b_{i,j} \cdot X_i^z + \text{sector } i \text{ shipments to transshipment zones from zone } z \text{ to accommodate nonlocal final demand (exports) and to other zones to accommodate local final demand not associated with households} \quad (7)$$

where:

X_i^z = the total output of commodity i in zone z given base year employment in sector i and zone z

$b_{i,j}$ = is the i, j th element of B , the matrix of value supply coefficients for the (open) input/output model

The first term on the right hand side of equation 7 accounts for inter-industry shipments out of zone z by aggregate freight sector i . Like D_i^z , O_j^z excludes shipments to households. As in the case of (6), these shipments consist of shopping trips. D_i^z and O_j^z are derived from inter-industry data, not spatial flow data.

Value flows O_i^z supplied by activity i and originating in zone z and value flows D_i^z demanded from activity i and terminating in zone z are translated into freight trip productions and freight trip attractions associated with activity i in zone z . These transportation demands are expressed in passenger car units (PCU).

Based on the vector of network equilibrium costs estimated by SCAG, and this transportation supply and demand vector, a set of spatial interaction models are calibrated that provide the inter-zonal flows for work trips, shopping trips, other household trips, and commodity movements. These models endogenize sensitivity to distance in a matrix form. Each of the JTW, JTS, and JTO, and four sectoral commodity flow matrices is estimated in response to a common measure of network equilibrium costs.

These singly constrained gravity models provide estimated distance decay parameters. Transportation network cost estimates are initialized based on link cost and flow data provided by SCAG. These initial flow and cost values are iteratively adjusted in response to the distance decay parameters.

The result is a set of seven endogenously determined trip matrices, each involving 308 zones. Summing these requirements produces a matrix of total transportation demands used to model network equilibrium flows, thus obtaining a new matrix of transportation costs. If these new inter-zonal costs are used to endogenize the JTW, JTS, JTO, and commodity flow matrices, the result is a set of master equilibrium link costs, flows and transportation demands.

Establishing the Status Quo: Earthquake Impacts without Mitigation

Following an earthquake, there will be losses of network capacity and simultaneous losses of industrial capacity. The former reduces transportation capacity and raises costs. The latter will reduce demands imposed on the network. Bridge performance models and fragility curve analyses ascribe consistent losses of both types to various scenarios. The spatial interaction elements of this model make it possible to capture the changes in transportation requirements associated with changes in network performance following an earthquake.

Earthquakes induce changes in industrial production due to effects on building stocks. Using loss-of-function curves available from EQE International, Inc., damage-to-building-stocks is converted to loss of production by zone and sector. A vector consisting of inverses of 515 RSRI multipliers is used to reduce output losses to corresponding reductions in final demands. This change in final demands drives SCPM, providing changes in output for 17 sectors and 308 zones, which modify the values D_i^z and O_i^z and related transportation demands.

Earthquakes also eliminate bridges from the network. Resulting changes in network configuration produces endogenous changes in transportation flows, costs and requirements. Costs are increased for missing transportation links to very large numbers.

The separate spatial interaction models are then re-estimated. The network flows and costs are re-estimated in light of these new inter-zonal requirements.

(continued on Page 12)

Research Activities (Cont'd)

(continued from Page 11)

This is iterated to achieve consistency, updating the cost data used to estimate the flows in the JTW, JTS, JTO, and commodity matrices; and then recomputing these matrices.

Once consistency across network costs and origin-destination requirements is achieved, SCPM is applied to reallocate changes in output over 17 sectors and 308 zones. The SCPM computes indirect and induced economic impacts associated with direct changes in final demand, and allocates these changes to zones. Economic activity induced by household consumption is treated with special attention. Outputs from two versions of the RSRI input/output model are computed and aggregated. In the first version, household demand is exogenous. In the second version, labor is treated as a production activity, making household demands endogenous. The input/output requirements associated with the production of labor are described by household consumption functions. The difference between the solutions to these open and closed models identifies the system wide impacts associated with household consumption.

The total economic impact associated with exogenous constraints on final demand is thus separable as follows.

$$\begin{aligned} \text{Total economic impact} &= \text{Total direct impact} \\ &+ \text{Total indirect impact} \\ &+ \text{Total induced impact} \end{aligned} \quad (8)$$

where:

Total Direct Impact = reduction in final demand accounted for by earthquake losses to industrial capacity (exogenous)

Total Indirect Impact = additional reductions in production of commodities other than labor due to inter-industry linkages in the economy (endogenous to the open model)

Total Induced Impact = additional reductions in production driven by endogenous changes in labor requirements (the difference between the solutions to the open and closed versions of the model)

Example

Consider an urban system consisting of seven geographic zones, a nearest-neighbor transportation network, four economic sectors, and labor (see figure 2). Table 1 describes an aspatial census of flows between the production sectors, and various sources of (net) final demand. Total production exceeds total final demand because the production activities also use each other's outputs as inputs. Import and export flows are spatially incident to external zones.

These spatial and aspatial representations of the economy are combined by accounting for transportation network costs. Earthquake damage to production facilities can be expressed in terms of exogenous changes in total production. The presence of economic linkages in the economy dictates that exogenous changes in any sector must produce endogenous changes in other sectors. These other sectors are constrained by reductions in the output supplied by the first sector, and by associated reductions in the demand for inputs supplied to the first sector.

Table 2 summarizes the indirect and induced impacts associated with an exogenous vector of direct impacts resulting from an earthquake. A direct reduction of \$1,000 in output from sector 1 results in additional indirect reductions of \$2,619. Recognizing the role of households in the production of labor accounts for an additional \$2,187 in induced reductions, for a total reduction of \$5,806.

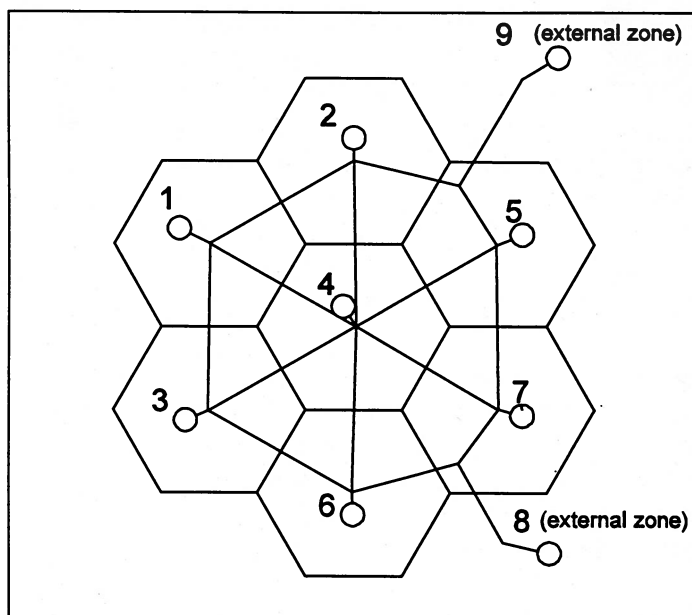


Figure 2: Analysis Zones and Transportation Network

Table 1: System Transactions Table (\$100,000)

	Sector 1	Sector 2	Sector 3	Sector 4	Labor	Other	Export	Import	Total Output
Sector 1	1,069	4,552	454	383	552	763	11,511	-512	18,772
Sector 2	2,317	67,703	22,026	44,768	26,856	58,891	90,746	-37,056	276,251
Sector 3	1,993	19,172	30,507	21,204	58,109	35,354	67,825	-11,539	222,624
Sector 4	291	4,758	8,125	11,828	17,755	174,896	57,666	-19,034	256,283
Other	13,102	180,088	161,514	178,101					
Total Output	18,772	276,273	222,625	256,284					773,931

These indirect and induced impacts are driven by more than just the inter-industry linkages in the economy. The earthquake also affects the performance of the transportation system, and choice of destinations. Table 3 translates the inter-sectoral flows in the pre-earthquake economy into trip ends (origins and destinations) associated with each zone. Inter-zonal path flows must respect both these origin-destination requirements, and endogenous network equilibrium conditions. The post-earthquake trip ends in Table 4 also respect these conditions, subject to changes imposed by the earthquake; and the parameterized distance-decay relationships revealed by the flows associated with Table 3. Figure 3 describes the pre- and post-earthquake network equilibrium flows, respectively.

Table 2: Economic Impacts Resulting from Earthquake Damage to Production Facilities and Transportation Infrastructure (\$100,000)

	Direct	Indirect	Induced	Total
Sector 1	1,000	2,619	2,187	5,806
Sector 2	50,000	76,252	34,152	160,404
Sector 3	7,000	17,791	14,130	38,921
Sector 4	12,000	15,125	4,025	31,150
Total	70,000	111,787	54,494	236,281

Figures 4 and 5 demonstrate the importance of this approach. Previous versions of the SCPM do not account for the role of equilibrium network costs in the calculation of indirect and induced impacts. Figures 4(a) and 5(a) describe the same set of direct impacts associated with an earthquake. Darker zones are areas subject to larger impacts. Comparing the remaining panels of figures 4 and 5 reveals that the calculation of direct and indirect impacts is clearly sensitive to the level of service available on the transportation network. The system used in this example is hypothetical and highly aggregated, but the input-output and transportation engineering relationships used here are sufficiently representative to indicate that transportation network effects are important determinants of total impacts.

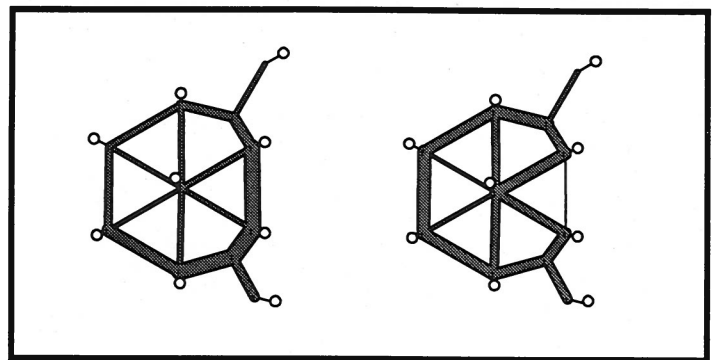


Figure 3: Pre-event (left) and Post-event (right) Traffic Volumes

(continued on Page 14)

Research Activities (Cont'd)

(continued from Page 13)

Table 3: Pre-event Origin-Destination Trip Ends by Economic Sector (Passenger Car Units)

	Sector 1		Sector 2		Sector 3		Sector 4	
	Origin	Destination	Origin	Destination	Origin	Destination	Origin	Destination
Zone 1	46.1	15.7	70.9	113.4	97.5	101.3	58.2	48.6
Zone 2	41.0	16.0	83.7	118.9	120.0	109.1	52.9	50.2
Zone 3	35.9	16.3	90.2	153.0	112.5	129.9	90.0	66.8
Zone 4	10.3	15.3	103.1	199.7	307.4	212.8	95.2	98.3
Zone 5	15.4	28.5	270.5	249.8	164.9	186.0	90.0	86.4
Zone 6	25.6	49.3	489.5	382.8	232.4	268.9	100.5	117.1
Zone 7	5.1	38.3	412.2	302.6	179.9	206.7	68.8	88.1

Table 4: Post-event Origin-Destination Trip Ends by Economic Sector (Passenger Car Units)

	Sector 1		Sector 2		Sector 3		Sector 4	
	Origin	Destination	Origin	Destination	Origin	Destination	Origin	Destination
Zone 1	43.7	14.1	58.0	103.7	94.4	95.1	55.5	45.9
Zone 2	38.8	14.3	68.6	108.1	116.2	102.3	50.4	47.3
Zone 3	34.0	14.5	73.9	140.1	108.9	121.9	85.7	63.1
Zone 4	9.7	13.5	84.4	184.4	297.7	201.9	90.8	93.4
Zone 5	14.6	24.1	221.6	220.7	159.8	170.7	85.7	80.2
Zone 6	24.3	41.5	400.9	333.0	225.1	244.0	95.8	107.6
Zone 7	4.9	31.9	337.6	261.6	174.3	186.5	65.6	80.6
Total	169.8	154.0	1,245.0	1,351.6	1,176.4	1,122.4	529.6	518.1

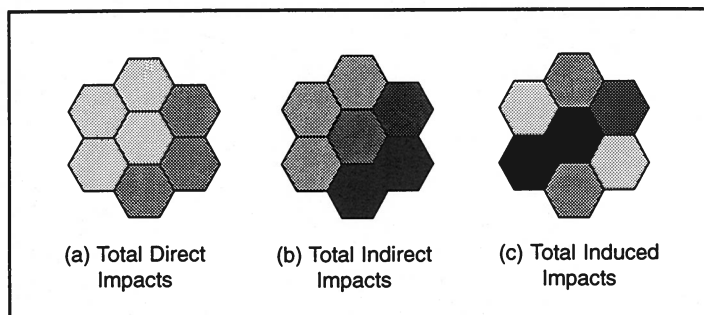


Figure 4: Predicted Impacts by Zone, Ignoring Transportation Network Costs and Remaining Holding Origin-Destination Requirements Fixed

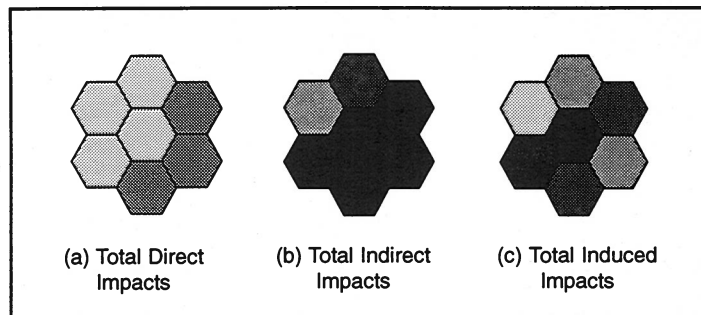


Figure 5: Predicted Impacts by Zone, Accounting for Transportation Network Costs and Endogenous Changes in Origin-Destination Requirements

Policy Tests: Earthquake Impacts with Alternative Mitigation Measures

The baseline exercise describes pre-earthquake conditions. The status quo exercise describes post-earthquake conditions with current levels of mitigation. The difference between baseline conditions and status quo conditions defines the baseline cost of the earthquake.

$$\text{Baseline cost | earthquake} = \text{Cost of post-event status quo conditions} \\ - \text{Cost of pre-event baseline conditions} \quad (9)$$

New mitigation efforts improve the performance of structures, institutional responses, or both. These changes will usually imply a new set of (improved) post-event conditions. The difference between the baseline conditions and the reduced costs associated with these new post-event conditions is the reduced cost of the earthquake.

$$\text{Reduced cost | earthquake} = \text{Cost of post-event conditions | mitigation} \\ - \text{Cost of pre-event baseline conditions} \quad (10)$$

The difference between the baseline cost given an earthquake and the reduced cost given an earthquake is the benefit associated with the mitigation measure, conditioned on the occurrence of the earthquake.

$$\text{Benefit of mitigation | earthquake} = \text{Reduced cost | earthquake} \\ - \text{Baseline Cost | earthquake} \quad (11)$$

The mitigation measure is a rational strategy if the expected benefit provided by the mitigation measure exceeds the deterministic cost of the mitigation.

$$E(\text{Benefit of mitigation}) > \text{Cost of mitigation} \quad (12)$$

Conclusions

These research results permit an assessment of the earthquake risk to the transportation system and the urban economy to be made by accounting for the full range of outcomes associated with damage to bridges and production facilities. This includes the regional productivity impacts associated with the damage to the transportation system.

Summary

This integration of transportation network, spatial allocation, and input/output models permits the study of how the economic impacts of industrial and transportation structure loss are distributed over metropolitan space. Some of this loss is produced directly by the earthquake. The procedure accounts for the impact of industrial structure losses on final demand. The model computes further indirect and induced losses, and makes the spatial distribution of these losses sensitive to increases in network costs resulting from transportation structure losses. The procedure does not yet account for the impact of transportation structure losses on final demand.

Extensions

Transportation systems are only one example of urban lifelines. Other networks perform according to other physical rules, but all are subject to modeling. The economic losses associated with earthquake impacts on other lifeline capacities can readily be incorporated into this framework.

Post-earthquake periods also provide important windows of opportunity to achieve mitigation objectives. An important set of post-disaster policies includes the sequence of post-event reconstruction efforts. In the case of the transportation network, these questions include which bridges and other transportation structures should be restored, in what order, how quickly, and at what expense. The same approach used to evaluate pre-earthquake mitigation strategies can be used to evaluate the alternatives associated with the relatively more discrete set of reconstruction decisions.

Published By:

National Center for Earthquake Engineering Research
State University of New York at Buffalo
Red Jacket Quadrangle
Box 610025
Buffalo, NY 14261-0025

Phone: (716) 645-3391
Fax: (716) 645-3399
email: nceer@acsu.buffalo.edu
World Wide Web site: <http://nceer.eng.buffalo.edu>

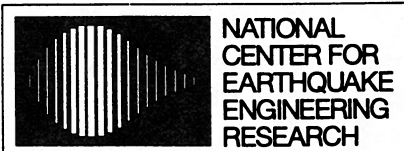
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Production and Mailing List: Jennifer Caruana

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Contributors:

S. Chang, University of Washington and EQE, Inc.
S-B. Cho, University of Southern California
H. Cochrane, Colorado State University
A. S. Dargush, NCEER
P. Gordon, University of Southern California
J. Moore, University of Southern California and the
California Research Bureau
H. W. Richardson, University of Southern California
M. Saiid Saiidi, University of Nevada, Reno
D. H. Sanders, University of Nevada, Reno
M. Shinozuka, University of Southern California
D. Tao, NCEER Information Service
K. Tierney, Disaster Research Center,
University of Delaware
D. Unnewehr, American Insurance Association
N. I. Wehbe, University of Nevada, Reno

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State University of New York at Buffalo
Red Jacket Quadrangle
Box 610025
Buffalo, NY 14261-0025

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MR YUH-WEN CHIEN
GRADUATE ASSISTANT
DEPT OF CIVIL ENGINEERING/KAP 210
UNIVERSITY OF SOUTHERN CALIFORNIA
3620 S VERMONT AVE HINGTON
LOS ANGELES CA 90007-3944 HINGTON