6. Estimates of Indirect Economic Losses

6.1 Introduction

Earthquakes produce both direct and indirect economic effects. The direct effects, such as dollar loss due to fires and collapsed structures, are obvious and dramatic. However, the indirect effects that these disruptions have on the ability of otherwise undamaged enterprises to conduct business may be quite significant. Although the concept of seismic disturbances and their effect on lifelines has been investigated for at least two decades, there is very little literature on indirect economic losses (Cochrane, 1975; Rose, in ASCE-TCLEE, 1981; Scawthorn and Lofting, 1984).

This study provides a first approximation of the indirect economic effects of lifeline interruption due to earthquakes. To accomplish this the relevant literature was surveyed. Then a methodology was developed to relate lifeline interruption estimates to economic effects of lifeline interruption in each economic sector. This required a two-step process:

1. Development of estimates of interruption of lifelines as a result of direct damage

2. Development of estimates of economic loss as a result of lifeline interruption

The general analytical approaches used to develop these estimates are discussed below and illustrated with example calculations. Results defining lifeline interruption and associated economic loss to specific facility types are also provided, but the bulk of this information is given in Appendices C and D. The chapter concludes with regional summaries of economic effects resulting from direct damage to the various lifelines in the eight scenario earthquakes.

6.2 General Analytical Approach for Estimating Lifeline Interruption

Lifeline interruption resulting from direct damage is quantified in this investigation in residual capacity plots that define percent of function restored as a function of time. The curves are estimated for each lifeline type and scenario earthquake using (1) the time-to-restoration curves discussed in Chapter 3 and provided in Appendix B, (2) estimates of ground shaking intensity provided by the seismic hazard model (from Chapter 4), and (3) inventory data specifying the location and type of facilities affected (from Chapter 2).

For site-specific systems (i.e., lifelines consisting of individual sited or point facilities, such as airports or hospitals) the time-to-restoration curves are used directly whereas for extended regional networks, special analysis procedures are used. These procedures consist of:

- connectivity analyses, and

- serviceability analyses.

Connectivity analyses measure post-earthquake completeness, "connectedness," or "cut-ness" of links and nodes in a network. Connectivity analyses ignore system capacities and seek only to determine whether, or with what probability, a path remains operational between given sources and given destinations.

Serviceability analyses seek an additional valuable item of information: If a path or paths connect selected nodes following an earthquake, what is the remaining, or residual, capacity between these nodes? The residual capacity is found mathematically by convolving lifeline element capacities with lifeline completeness.

A complete serviceability analysis of the nation's various lifeline systems, incorporating earthquake effects, was beyond the scope of this project. Additionally, capacity information was generally not available for a number of the lifelines (e.g, for the highway system, routes were available, but not number of lanes). Rather, for this project, a limited serviceability analysis has been performed, based on a set of simplifying assumptions.

The fundamental assumption has been that, on average, all links and nodes of a lifeline have equal capacities, *so that residual capacity has* *serviceable (i.e., surviving) links and nodes to the original number of serviceable links and nodes, for a given source/destination pair, or across some appropriate boundary.* For example, if the state of South Carolina has 100 airports, and 30 of these are determined to be unserviceable at some point in time following a major earthquake, then the air transport lifeline residual capacity is determined to be 70% of the initial capacity.

This assumption does not consider several important factors, including:

1. All nodes or links do not have the same capacities;

2. Links and nodes contributing most to the residual capacity are generally more distant from the heavily damaged area. Thus, the estimated lifeline residual capacity is generally overestimated in the area closest to the disaster area; and

3. Significant elasticity in capacity is generally available for most lifelines.

Factors 2 and 3 tend to offset each other. Further, factor 1 is probably acceptable for the purposes of this project, which aims to describe effects at the regional level.

The foregoing mode of analysis was employed for most of the regional network lifelines. One exception was the gas and liquid fuel transmission pipelines, where capacities were available and were employed, thus taking into account factor 1 above.

6.3 Residual Capacity Analysis of Site-Specific Systems

As indicated above, residual capacities for site specific lifelines were estimated using the restoration curves from Appendix B. For many of these facilities, only locational information was available (i.e., size or capacity information was not available). Because of this limitation, and because the general goal of this study was to determine impacts at the transmission or regional level (an approach that tends to average out differences in facility capacities), an assumption that all facilities of a particular class have the same capacity was often employed.

Using the curves provided in Appendix B, residual capacity was defined in "lifeline interruption plots" that define restoration in one-week-interval step functions. Initially, these step functions were computed for each facility in a region, and then averaged over all facilities of the same type in the region using the following equation:

$$R.C_j = \sum_{i=1}^{N} (C_i \, x \, R_i) / \sum_{i=1}^{N} C_i \qquad (6.1)$$

where $R.C_j$ is the residual capacity at time step j, C_i is the capacity of facility i, and R_i is the restoration of facility i at time step j. If all facilities have the same capacity, Equation 6.1 becomes

$$R.C_j = \sum_{i=1}^{N} R_i / N \qquad (6.2)$$

where N is the number of facilities. This calculation is illustrated in Example 6.1 (Figure 6-1).

Following is a discussion of results from the residual capacity analysis of each site-specific lifeline facility type considered in this investigation.

6.3.1 Airports

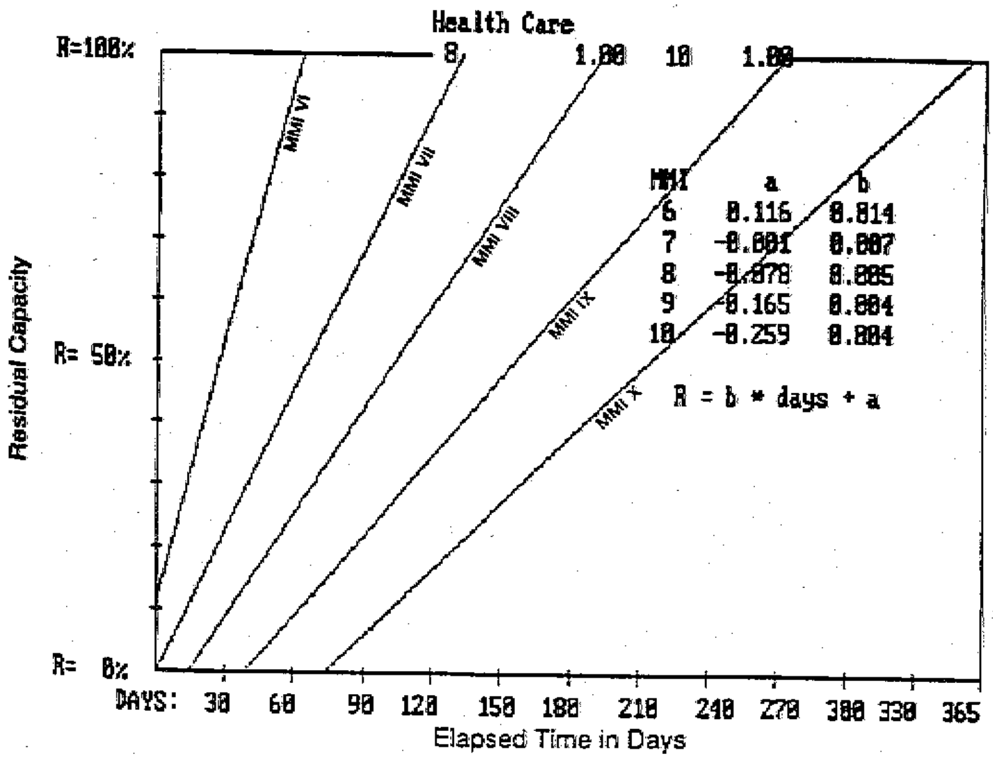
Residual capacities for airports were calculated assuming that all airports have the same capacity and the functionality of airports depends 20% on terminals and 80% on runways. The simplifying assumption that all airports have similar capacities is warranted due to the analysis seeking to determine regional air transport impacts, an approach that tends to average out extremes in airport capacities. Further rationales for this approach include: (1) the large number of general and civil aviation airports, (2) the relatively small difference in number of runways between many airports, (3) many runways have lengths sufficient for large commercial aircraft, (4) under emergency conditions, air traffic control capacity can be rapidly and significantly increased by deploying specialized military units, (5) airport through-put capacity is extremely elastic (under emergency conditions small airport cargo handling capacity can be significantly increased

Example 6.1

This example illustrates the residual capacity calculation algorithm for point source systems, using health care centers in Illinois as an example.

Assume that Illinois, located in "all other areas" of the NEHRP Map, has four health care centers. A scenario earthquake is estimated to result in shaking intensities at the four locations of MMI=5, 6, 7, and 8, respectively. Assume that no liquefaction hazard exists at the four sites. Estimate residual capacity at 0 days, 7 , 14 , 21 , 28 , and 196 days (the latter being the point of full restoration).

Procedure. Use the time-to-restore curve (below) for health care facilities (from Appendix B) for "all other areas" to determine the residual capacity at each health care facility.



This figure indicates residual capacities as follows:

		Elapsed time (days)					
	MMI	0	7	14	21	28	196
Facility 1	5	100%	100%	100%	100%	100%	100%
Facility 2	6	12%	21%	31%	41%	51%	100%
Facility 3	7	0%	5%	10%	15%	20%	100%
Facility 4	8	0%	0%	0%	3%	6%	100%
Average		**28%**	**32%**	**35%**	**40%**	**44%**	**100%**

The last row in the table provides the residual capacity of the example health care centers in Illinois, assuming that all facilities have the same capacity (i.e., per equation 6.4).

Figure 6-1: Analysis example illustrating residual capacity calculation algorithm for point source systems by staging cargo off-site, and apron space restrictions can be worked around through scheduling and staging aircraft at other airports).

Average residual capacity values over all airports in a given state at each time step were calculated using Equation 6.2. An example plot for Arkansas, one of the worst-case situations, is provided in Figure 6-2. In this example, the initial loss is approximately 31 percent of capacity, and full capacity is not restored until about day 290. Results for each state are plotted in Appendix C for each scenario earthquake (Figures C-1 through C-24). These data indicate that, of all the regional scenario events, the greatest impacts occur in the states of Arkansas, Mississippi, and Tennessee as a result of the New Madrid magnitude-8.0 event (Figures C-3, C-4, C-6). The states of Washington, Massachusetts, South Carolina, Utah, and California would experience the largest impacts due to the Seattle, Cape Ann, Charleston, Utah, and Fort Tejon, scenario events, respectively (Figures C-7, C-10, C-15, C-17, and C-18).

6.3.2 Ports

Residual capacities of Ports for all scenario events are presented in Figures C-25 to C-33. An example plot for South Carolina, the worst-case situation, is provided in Figure 6-3. In this example, the initial loss is nearly 100 percent of capacity, and full capacity is not restored until about day 200. Georgia would also experience similarly high losses due to the Charleston event (Figure C-27). Massachusetts and Rhode Island would experience the largest losses due to the Cape Ann event (Figures C-28 and C-29).

6.3.3 Medical Care Centers

Residual capacities of medical care centers were calculated using Equation 6.2 and are shown in Appendix C, Figures C-34 through C-57 for all states affected by all scenario events. All medical care centers were assumed to have the same capacity. One of the worst-case situations would occur in Arkansas for the New Madrid magnitude-8.0 earthquake (Figure 6-4). Similar long-term recovery periods are required in California for the Fort Tejon event (Figure C-51), South Carolina, for the Charleston event (Figure C-41), and in Washington, for the Puget Sound event (Figures C-52). Note also the initial high loss in capacity for medical care facilities in Massachusetts for the Cape Ann event (Figure C-44).

6.3.4 Fire Stations

Based on the assumption that fire stations have an average capacity, residual capacities of fire stations within the affected states were calculated using Equation 6.2, assuming that all fire stations are lumped at the center of Standard Metropolitan Statistical Areas (SMSAs). Results are presented in Figures C-58 through C-81. One of the worst case situations, which occurs in South Carolina as a result of the Charleston scenario event, is shown in Figure 6-5.

6.3.5 Police Stations

Residual capacities of police stations were calculated using Equation 6.2, assuming that all police stations have the same capacity and that stations were lumped at the center of the SMSAs. Results are presented in Appendix C, Figures C-82 to C-101, for all states affected by the scenario events. These plots indicate that, as in the case of fire stations, one of the worst-case situations occurs in Mississippi as a result of the New Madrid magnitude-8.0 scenario event (Figure 6-6).

6.3.6 Broadcast Stations

Based on the assumption that all broadcast stations have the same capacity, residual capacities within the affected states were calculated using Equation 6.2. For this facility type, the worst case situation occurs in South Carolina as a result of the Charleston event (Figure 6-7). See Appendix C, Figures C-102 to C-126, for plots of results for all eight scenarios and affected states.

6.4 Residual Capacity Analysis of Extended Regional Networks

In this investigation, residual capacity of extended regional networks (e.g., crude and refined oil pipelines; highways) has been estimated through the following sequence of operations:

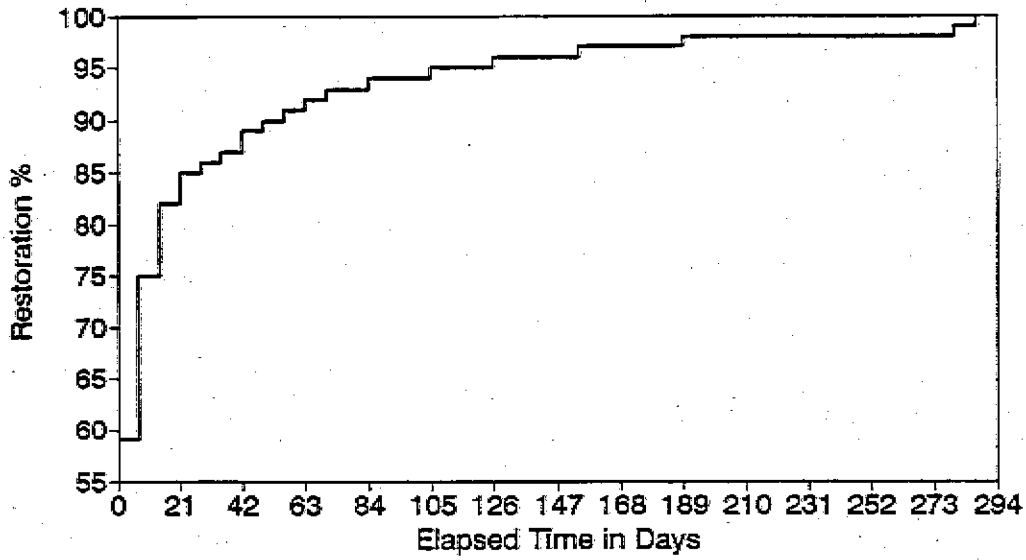


Figure 6-2 *Residual capacity of Arkansas air transportation following New Madrid event (M=8.0).*

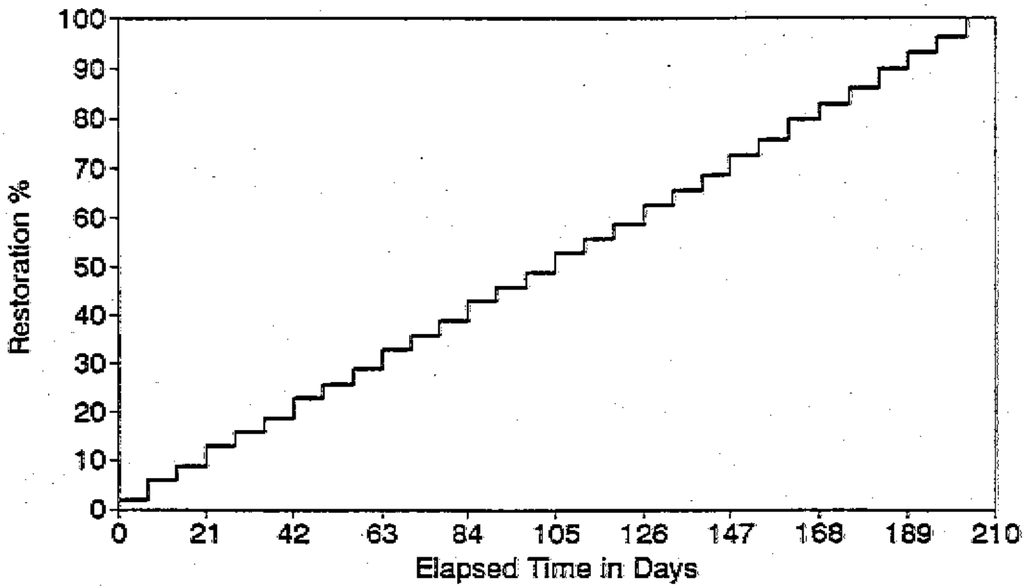


Figure 6-3 *Residual capacity of South Carolina ports following Charleston event (M=7.5).*

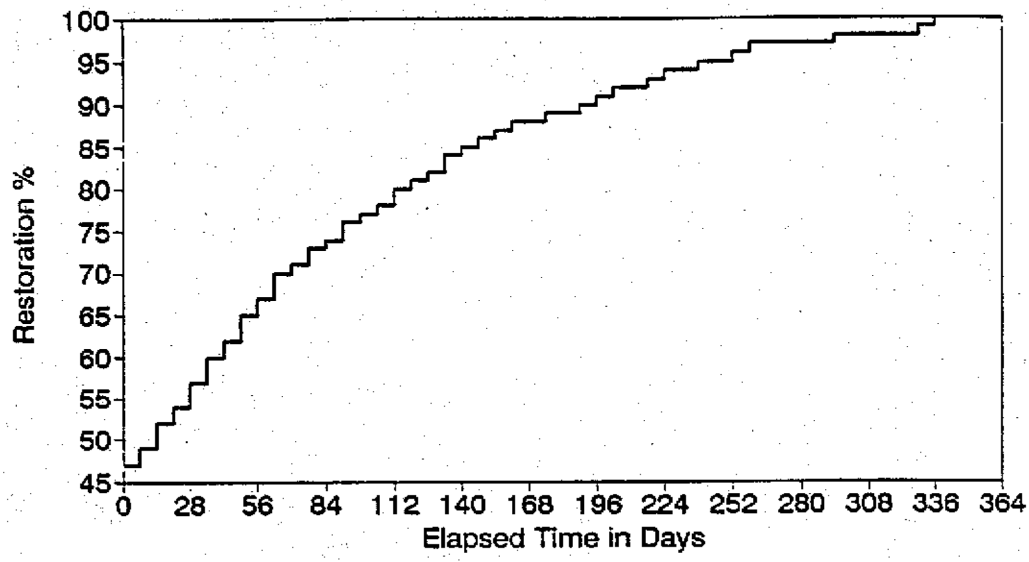


Figure 6-4 *Residual capacity of Arkansas medical care centers following New Madrid event (M=8.0).*

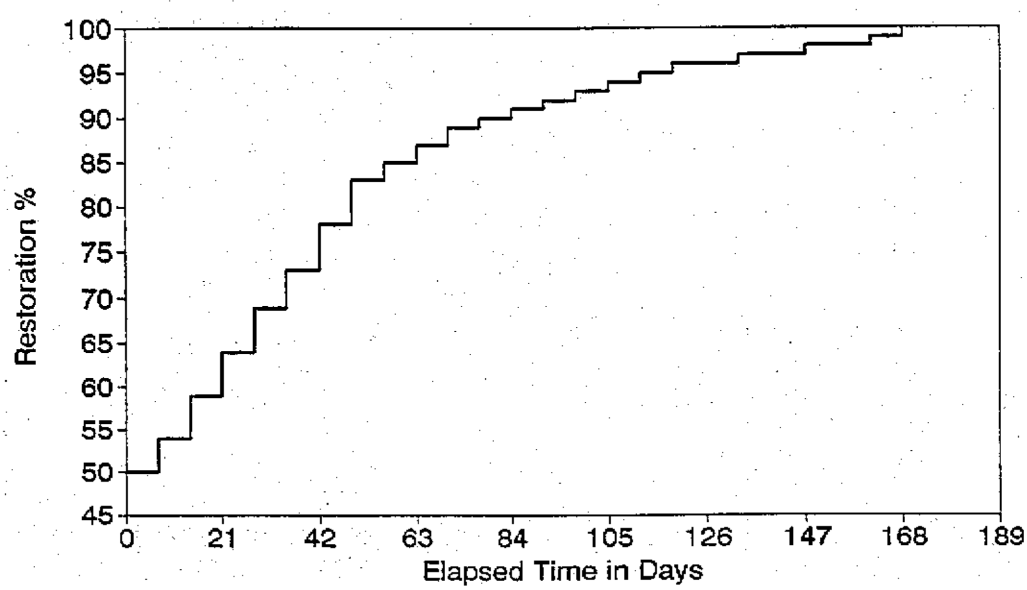


Figure 6-5 *Residual capacity of South Carolina fire stations following Charleston event (M=7.5).*

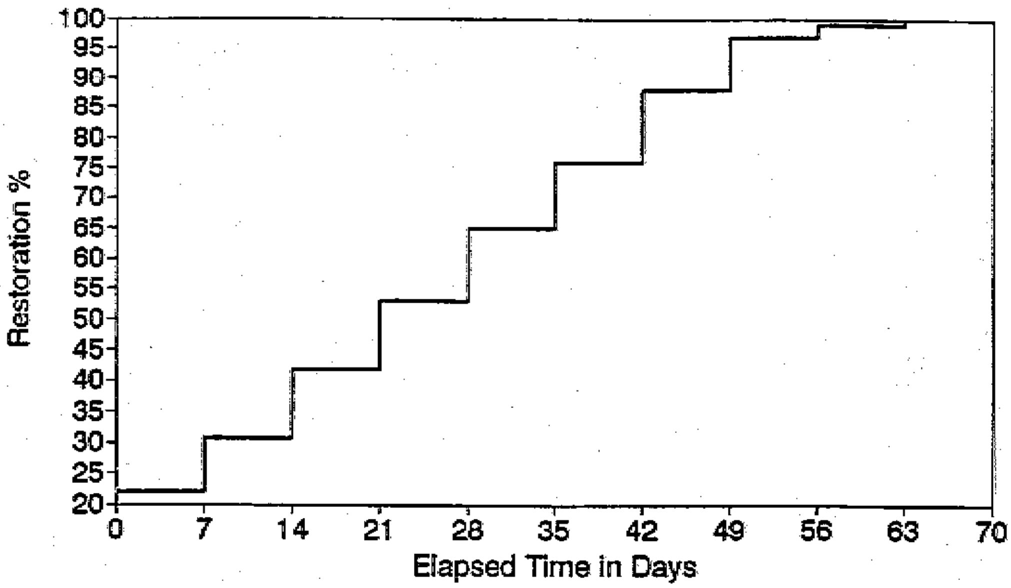


Figure 6-6 *Residual capacity of Mississippi police stations following New Madrid event (M=8.0).*

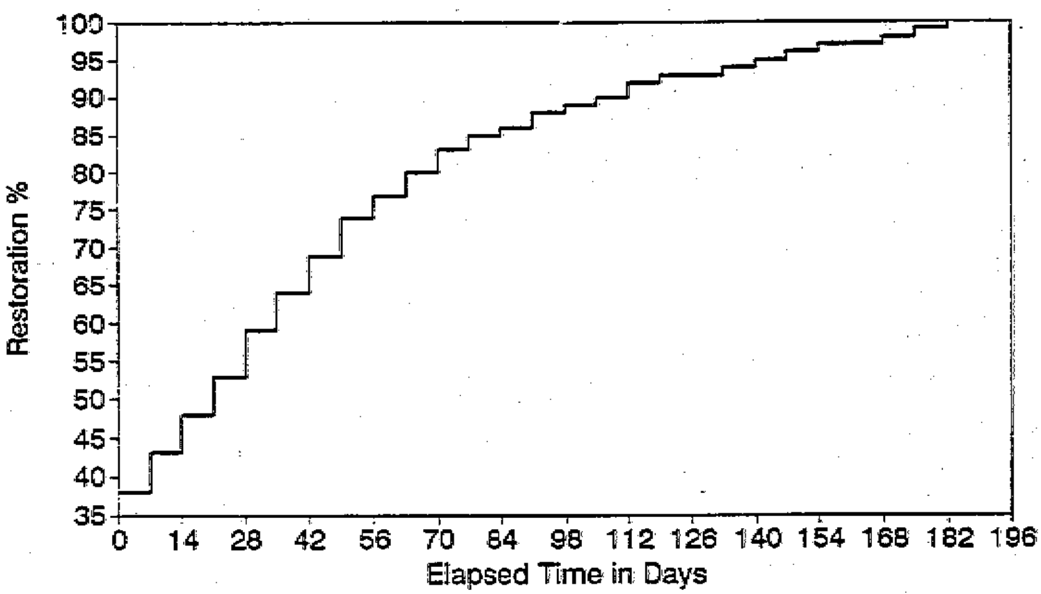


Figure 6-7 *Residual capacity of South Carolina broadcast stations following Charleston event (M=7.5).*

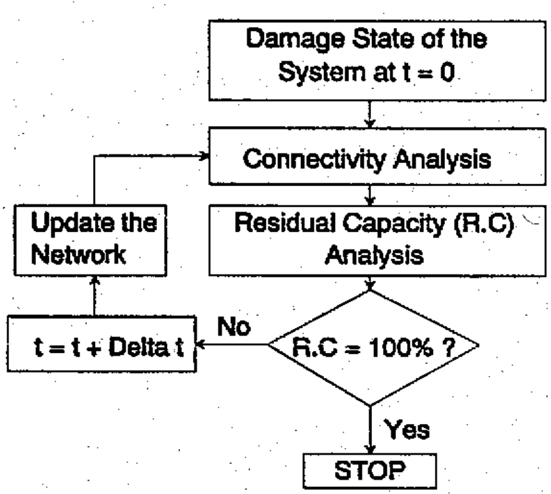
1. Maximum damage for every link in the network was first estimated using the procedures described in Chapter 5.

2. Connectivity analyses were then performed to identify nodes and links that are not connected to the source(s).

3. And finally, serviceability analyses were performed to determine residual capacity of the network as a whole, considering both damaged and undamaged links and nodes.

The networks are assumed to consist of sets of nodes and sets of links connecting these nodes. If a link has a direction, it is called a directed link; otherwise it is called an undirected link. A path is a sequence of nodes and links. The links can be directed in either direction (two-way links) or directed in one direction (one-way links).

Following is a flow chart showing the sequence of operations:



Connectivity Analyses. Connectivity analyses were performed using a technique called Depth-First-Search, or Backtracking (Tarjan, R., 1972). In this method, a network is connected if for every partitioning of the nodes of the network into subsets Y1 and Y2, there is either a link (i-j) or (j-i) between node $i \in Y1$ and node $j \in Y2$, where ε denotes membership.

For pipeline systems (crude oil and refined oil pipelines), pipeline sections (node-to-node) with probability of failure (i.e., probability of having at least one break) equal to or greater than about 60% were assumed to be closed until 100% restored. For natural gas systems, pipeline sections with probability of failure equal to or greater 30% were assumed closed until 100% restored. Bridges with more than 15% damage were also assumed out of service until fully restored.

Serviceability Analyses. Residual capacities between sources and destinations were estimated using the minimum-cut-maximum-flow theorem (Ford and Fulkerson, 1962; Hu, 1969; and Harary, 1972) which is the central theorem in network flow theory. This approach was generalized for this project to account for multiple-source multiple-destination problems.

The minimum-cut-maximum-flow theorem simply searches for the cut with the minimum capacity, i. e., the bottleneck, that completely separates the sources from the destinations. That is to say, the maximum flow in a network is always equal to the capacity of the cut that provides the minimum capacity of all cuts separating the source(s), S, and the destination(s), D.

A cut is defined by (Y1,Y2), where Y1 is a subset of nodes of the network and Y2 is its complement (i.e., the remaining subset of nodes). A cut (Y1,Y2) is a set of links (i-j) with either the node $i \in Y1$ and $j \in Y2$ or $j \in Y1$ and $i \in Y2$. Therefore, a cut is a set of links the removal of which will disconnect the network. A cut separating the source, S, and the destination, D, is a cut (Y1,Y2) with $S \in Y1$ and $D \in Y2$.

The capacity of a cut (Y1,Y2), denoted by C(Y1,Y2), is Σc_{ij} with $i \in Y1$ and $j \in Y2$, where c_{ij} is the capacity of the link (i-j). Note that in defining a cut, we count all the arcs that are between the set Y1 and the set Y2, but in calculating its capacity we count only the capacity of links from Y1 to Y2, but not the one way links from Y2 to Y1. i.e. C(Y1,Y2) not equal C(Y2,Y1). The cut with the minimum capacity is called the minimum cut.

For example, consider the network in Figure 6-8. Assume that all links are two way links, and that the numbers next to each link represent the capacity of that link. The set Y1 defined above consists of nodes S and 2, while the set Y2 consists of nodes 1 and D. The cut shown in Figure 6-8 is a minimum cut and has the capacity $C(Y1,Y2) = c_{S1} + c_{2D} = 2 + 4 = 6$, which

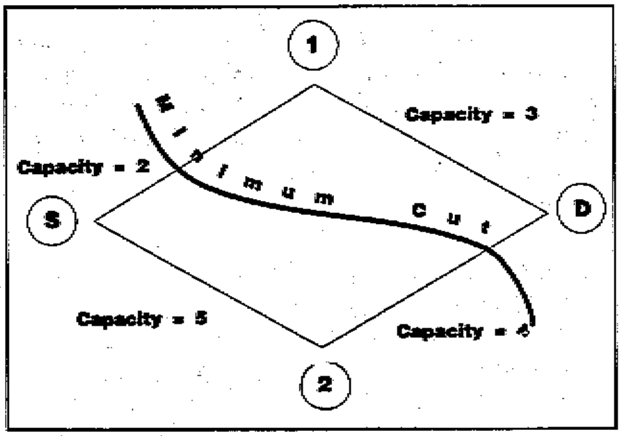


Figure 6-8 *Flow network to illustrate minimum-cut-maximum flow Theorem.*

is the maximum flow that can be delivered between the source S and the destination D.

The maximum flow is a linear programming problem with the objective function

$$Q = \Sigma X_{ij} \qquad (6.3)$$

and the constraints

$$\begin{aligned} X_{ij} - X_{jk} &= -Q \text{ if } j = S \\ &= 0 \text{ if } j <> S \text{ or } D \qquad (6.4) \\ &= Q \text{ if } j = D, \end{aligned}$$

and

$$0 < X_{ij} < c_{ij} \quad \text{for all } i,j \qquad (6.5)$$

where Q is the out flow value and X_{ij} is the flow in link (i-j). Equation 6.4 expresses conservation of flow at every node, and Equation 6.5 states that the link flow X_{ij} is always bounded by link capacity c_{ij}.

To apply the maximum flow theorem, sources and destinations have to be defined. For the oil systems and the natural gas system, nodes in Texas and Louisiana represent the sources, while nodes in Illinois, California, Seattle, Utah, and Massachusetts represent destinations. Source and destination are more difficult to define for the highway and railroad systems. These networks are highly redundant, so damage and losses are confined to the epicentral regions. In the residual capacity calculations for highway and railroad systems, sources are defined to be the outer nodes of all links that intersect with the smallest boundary around the epicentral area, such that all intersected links remain undamaged following an earthquake. Destinations are defined to be all nodes inside the largest boundary around the epicentral area such that all intersected links are damaged (intersection is assumed at the center of the links). For damaged links, restoration of each link is estimated at each time step using the appropriate restoration curve and the maximum intensity along the link.

The residual capacity at a given destination at any time step, t, is defined to be the ratio between the maximum available flow at the destination for the damaged system, Q_t, to the maximum available flow at the destination for the undamaged system, Q_o, i.e.

$$R.C. = Q_t/Q_o \qquad (6.6)$$

where Q_t and Q_o can be calculated using the min-max theorem discussed above, and R.C. is the residual capacity.

Example Calculations. Two examples are provided (Figs 6-9 and 6-10) that demonstrate residual capacity calculations for pipeline networks (Example 6.2) and for non-pipeline networks (Example 6.3).

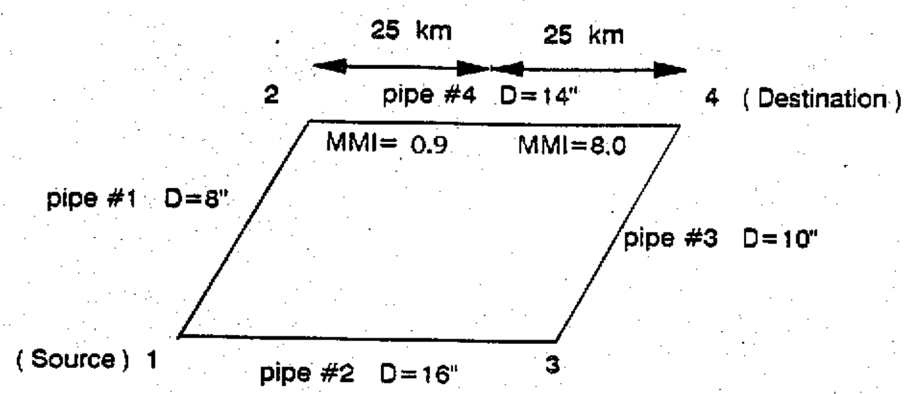
Software Employed. The calculations of damage state, connectivity, and residual capacity were performed using a proprietary computer program, *LLEQE* (*L*ife*L*ine *E*arth*Q*uake *E*ngineering). *LLEQE* employs state-of-the-art computer graphics and was developed to perform four tasks: (1) to perform seismic hazard analyses; (2) to generate lifeline damage states consistent with the calculated site-specific seismic intensities; (3) to perform connectivity analyses; and (4) to estimate residual capacities of lifeline components. Its capabilities include the following components/functions:

- Database. Database capacity can accommodate most major lifeline systems at the transmission level on the national scale, including: transportation, water, electric power generation and supply, gas and liquid fuel supply and emergency service facilities.

Example 6.2

This example illustrates the residual capacity calculation for pipelines systems (e.g., crude oil, refined oil, or natural gas).

Consider the following crude oil pipeline network:



Assume that pipe number 4 is subjected to intensity MMI = 8 along 25 km of its length, and MMI = 9 along 25 km of its length. The pipe lies in the non-California 7 portion of the NEHRP map. Assume the other pipes are unaffected and that there is no liquefaction. Find residual capacity at node 4 at the end of 7 days

Procedure. Use the damage curves for petroleum fuel transmission pipelines (from Appendix B) to determine mean break rate by intensity. Using the data on which this figure is based, the 25 km length of pipe, l_1, experiencing MMI = 8 has an expected mean break rate, λ_1, of 0.036 breaks/km. The 25 km length of pipe, l_2, experiencing MMI = 9 shaking has an expected mean break rate, λ_2, of 0.179 breaks/km. The probability of having at least one break in this pipe is given by equation 5.4, which is

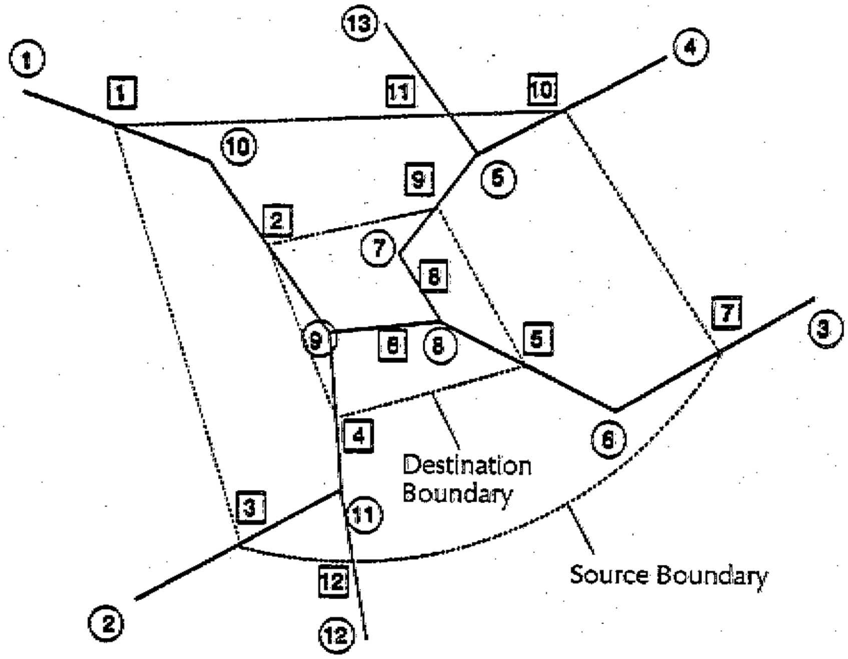
$$
\begin{aligned}
P_f &= 1 - \prod_{i=1}^{2} P_s \\
&= 1 - (\exp(-\lambda_1 \times l_1) \times \exp(-\lambda_2 \times l_2)) \\
&= 1 - (\exp(-0.036 \times 25) \times \exp(-0.179 \times 25)) \\
&= 0.99
\end{aligned}
$$

The diameter square of each pipe will be taken as a measure of capacity of the pipe. For the undamaged system using the min-max theory, the maximum flow Q_o at the destination (i.e., node 4) is 164 (the maximum flow at node 4 equals the capacity of link number 1, i. e. 64, plus the capacity of link number 3, i.e. 100). Since the probability of failure of pipe number 4 is greater than 60%, this pipe will assumed to be closed until it will be fully restored. For the damaged system, at the first time step (i. e., t=0 days) pipe 4 will be closed and the maximum flow Q_1 at node 4 is the capacity of the remaining system, which is 100. The residual capacity at time step t=0 can be estimated using Equation 6.6 and is given by Q_1/Q_o = 61.0%. Using the time-to-restore curve for petroleum transmission lines provided in Appendix B, the time to fully restore pipe sustaining MMI = 9 is 10 days. Thus, at the second time step (t = 7 days) the maximum flow at node 4 equals 100, and the residual capacity at the destination is still 61% (pipe 4 is still closed).

Figure 6-9: Analysis example illustrating residual capacity calculation for crude oil pipeline network.

Example 6.3

This example illustrates the damage and residual capacity calculation for non-pipeline network systems (e.g., railroad or highway system). Consider the following highway network (nodes denoted by circles, links by boxes):



The network lies in the "All Other Areas" portion of the NEHRP map; the intensity distribution for a given scenario earthquake is given below. Assume liquefaction does not occur and that Links 2 and 9 contain bridges. If a bridge experiences damage of 15% or more, it is assumed closed until 100% restored. Characterize restoration at various time intervals.

	Link Number									
	1	2	3	4	5	6	7	8	9	10
length, km	5	5	5	5	5	3	5	3	5	5
MMI	5	6	5	7	8	7	5	8	7	4

Procedure. Using the damage curves provided in Appendix B for highways/freeways, damage to the highway system is estimated as follows:

	Link Number									
	1	2	3	4	5	6	7	8	9	10
Damage, %	0	0	0	1	3	1	0	3	1	0

Using the damage curves for conventional bridges, "other" areas (Appendix B), damage to the bridges in Links 2 and 9 is estimated to be 10% and 30% damage, respectively.

Due to the assumption that a bridge is closed if damage exceeds 15%, the bridges in Link 9 are closed until 100% restored, while bridges in Link 2 are not. Restoration of the network links are estimated from the restoration curves for conventional bridges, "all other areas" (Appendix B) as follows (see following page):

Figure 6-10: Analysis example illustrating the residual capacity calculation for highway networks.

- Damage State. The *LLEQE* user can specify breaks, generate random breaks, or both. To generate a break in a link the user simply select "Specify Break" option and points to the link with a mouse. To simulate a seismic event, random breaks are generated using Monte Carlo simulation and a nonhomogeneous Poisson process with mean break rate based on data from previous earthquakes.

- Connectivity Analysis. Connectivity analysis is performed to identify disconnected regions of damaged systems, tag them with coded colors, and eliminate them from subsequent system analysis. Optimum path and shortest path from source to destination can also be defined.

- Serviceability Analysis. Analysis to estimate the serviceability of lifeline systems under seismic or other events. The process involves connectivity analysis of the system in simulated damage states consistent with site seismicity and statistical analysis of residual capacities available in these damage states. It can provide fragility curves to estimate the functionality and usability of the system.

Following are summaries of residual capacity analytical results for extended regional lifeline networks.

6.4.1 Railroad System

Residual capacities of the railroad system for all scenario earthquakes were estimated using the minimum-cut-maximum-flow theorem defined above; sources and destinations were also defined as above. Residual capacity plots for the railroad system are provided in Appendix C, Figures C-127 through C-134. An example (typical) plot for the Hayward earthquake scenario is provided in Figure 6-11.

6.4.2 Highway System

Residual capacities of the highway system were estimated using the minimum-cut-maximum-flow theorem and the sources and destinations as defined above. The residual capacities are shown in Figures C-135 to C-142. An example plot for the epicentral regional of the magnitude-8.0 New Madrid event, one of the worst case situations, is provided in Figure 6-12. In this case nearly 95% of the highway system capacity is initially lost, and full restoration of the system is not achieved until about day 420. Losses in highway system capacity are similar for Utah, as a result of the Wasatch Front scenario.

6.4.3 Electric System

Residual capacities of the electric system were estimated taking into account nodes only (i.e., transmission substations). The residual capacity for each node was estimated at each time step using the time-to-restore curves for transmission substations from Appendix B. Averages over all nodes in each state affected by the scenario events were calculated using Equation 6.2 and are plotted in Figures C-143 to C-166. One of the worst case situations occurs in Mississippi following the magnitude-8.0 New Madrid event (Figure 6-13). In this case, the initial loss is approximately 75% of capacity, and full restoration is not achieved until about day 130. Losses for Arkansas for this same event are similar.

6.4.4 Water System

Residual capacities of the water system (Figures C-167 to C-169) were estimated using the minimum-cut-maximum-flow theorem discussed above. For the Hayward event the San Francisco Bay area was assumed to be the destination and the outside world, the source. For the Fort Tejon event Los Angeles was assumed to be the destination and the Colorado River Aqueduct (1056 hm^3), California Aqueduct South Coast (692 hm^3), and Los Angeles Aqueduct (574 hm^3) were assumed to be the sources. The worst case situation occurs in Los Angeles as a result of the Fort Tejon event (Figure 6-14).

6.4.5 Crude Oil System

For the residual capacity calculations for the crude oil system, Texas and Louisiana were assumed to represent the source region, while Chicago, Southern and Northern California represented the destinations. Residual capacities of the crude oil system were estimated using the minimum-cut-maximum-flow theorem discussed above. Links with probability of failure greater than or equal to 60% were assumed closed until 100% restored.

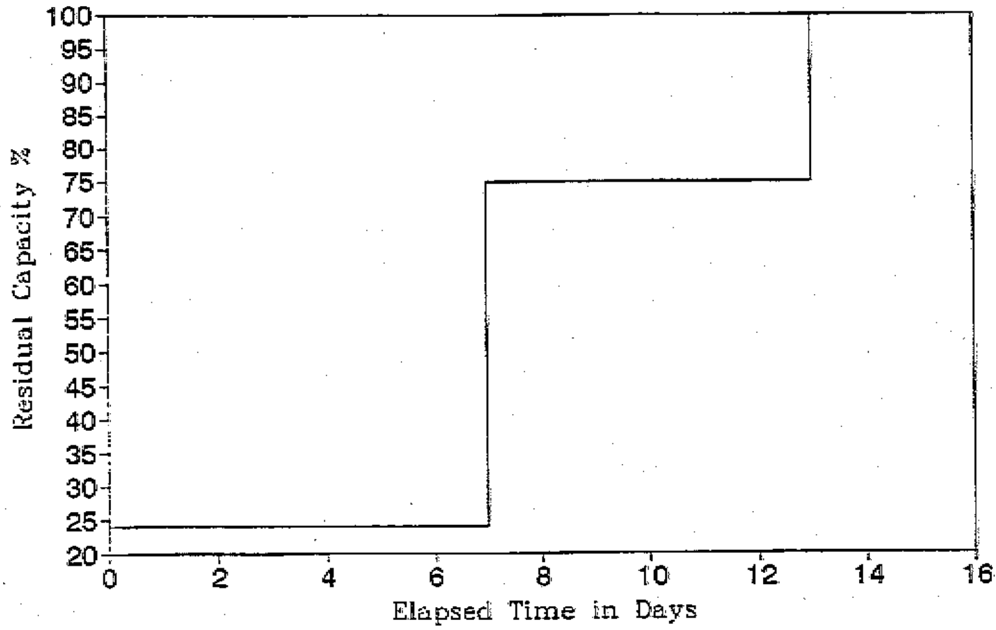


Figure 6-11 *Residual capacity of San Francisco Bay area railroad system following Hayward event (M=7.5).*

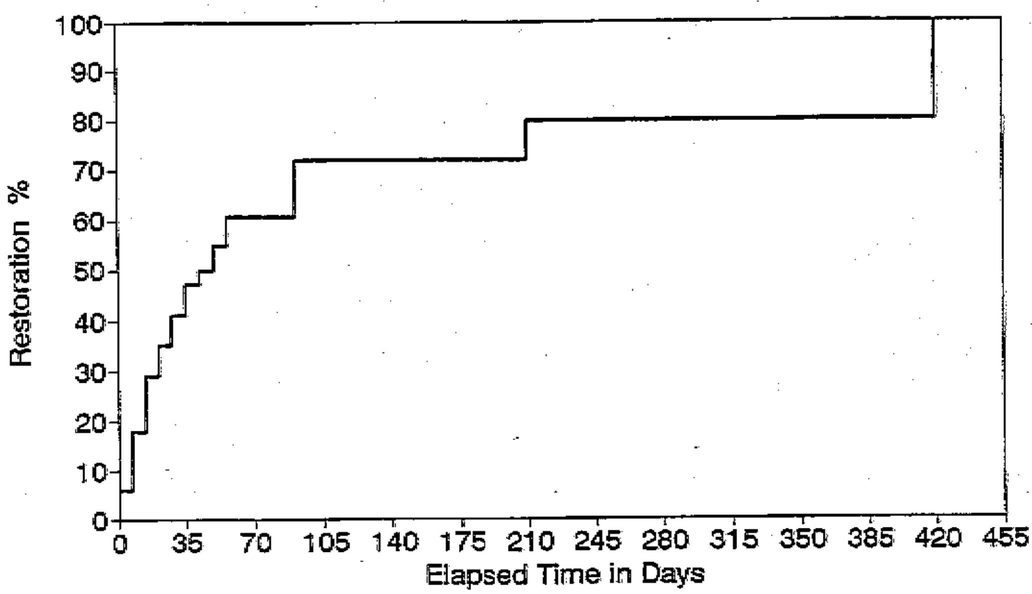


Figure 6-12 *Residual capacity of epicentral region highways following New Madrid event (M=8.0).*

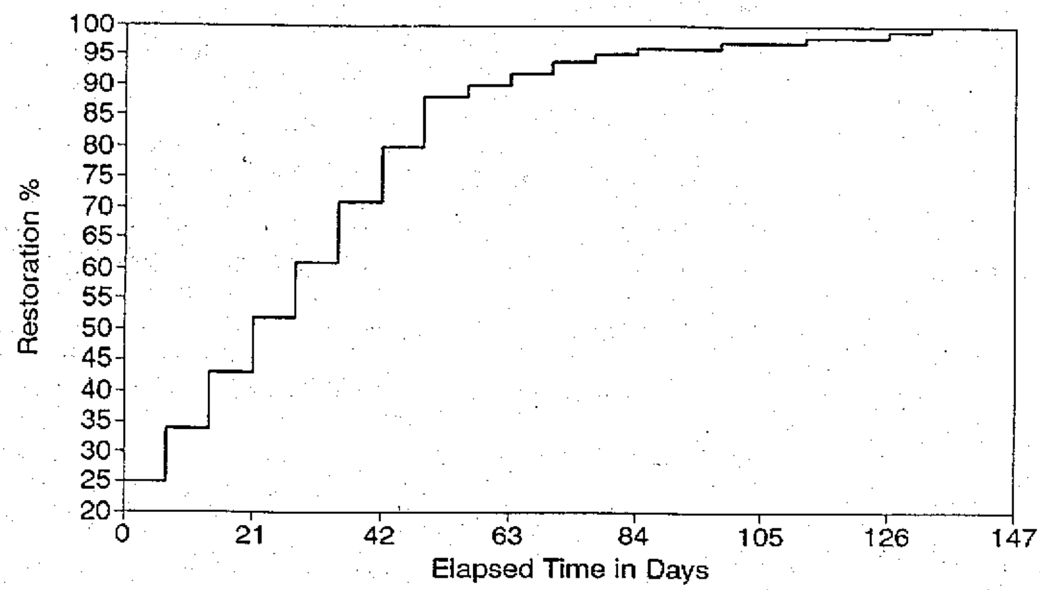


Figure 6-13 *Residual capacity of Mississippi electric system following New Madrid event (M=8.0).*

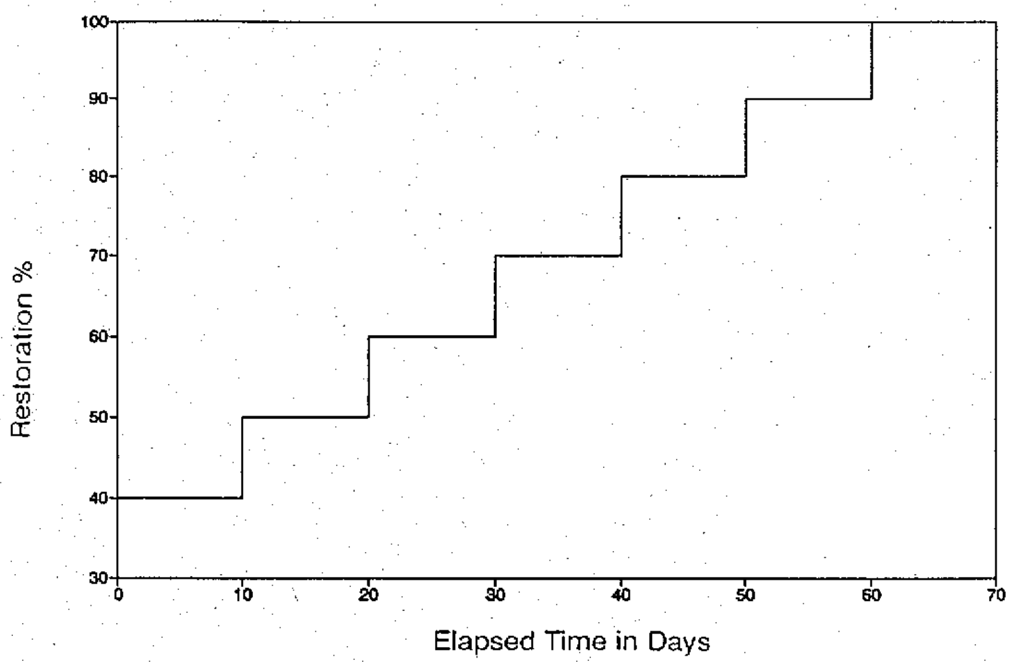


Figure 6-14 *Residual capacity of epicentral region water system following Fort Tejon event (M=8.0).*

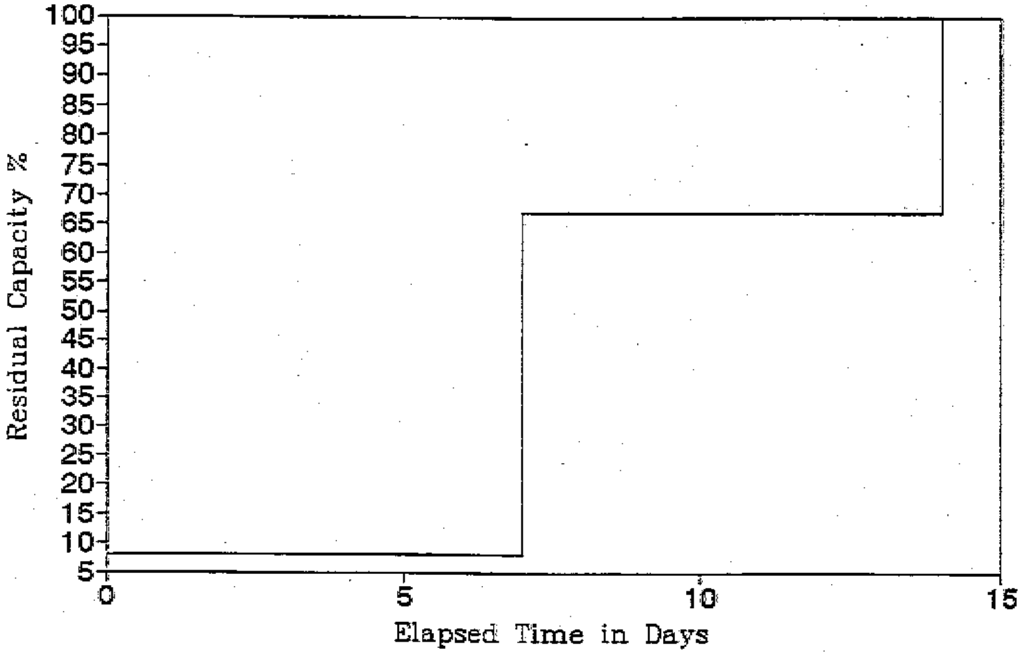


Figure 6-15 *Residual capacity of crude oil delivery system from Texas to Northern California following Fort Tejon event (M=8.0).*

The residual capacities are shown in Figures C-170 to C-173. One of the worst-case situations occurs in California as a result of the Fort Tejon earthquake scenario (Figure 6-15). In this case crude oil delivery capacity from Texas to Northern California is initially reduced to less than 10 percent, and full restoration of capacity is not achieved until about day 14. A similar situation occurs in this same scenario earthquake for crude oil delivery from Texas to Southern California.

6.4.6 Refined Oil System

For the residual capacity calculations for the refined oil system, Texas was assumed to be the source, and Chicago was the destination. Residual capacities were estimated using the minimum-cut-maximum-flow theorem discused above. Links with probability of failure greater than or equal to 60% were assumed closed until 100% restored. The residual capacities are shown in Figures C-174 and C-175. Residual capacity plots for the two New Madrid events considered are similar. The plot for the New Madrid magnitude-8.0 event is provided in Figure 6-16.

6.4.7 Natural Gas System

For the residual capacity calculations for the natural gas system, Texas and Louisiana were considered as the sources, and Illinois, Massachusetts, Utah, Washington, and California represented the destinations. Residual capacities of the natural gas system were estimated using the minimum-cut-maximum-flow theorem discused above. The residual capacities are shown in Figures C-176 through C-184. An example plot for the Hayward scenario, one of the worst case situations, is provided in Figure 6-17. In this case the capacity for natural gas delivery from Texas to Northern California is reduced to zero for the first seven days after the earthquake; full capacity is restored at about day 14. Losses in delivery capacity to Seattle from Texas, as a result of the Puget Sound scenario, and to California from Texas, as a result of the Fort Tejon event, are similar.

6.4.8 Distribution Systems

Residual capacities of the electric, water, and highway distribution systems were estimated using the time-to-restore curves provided in

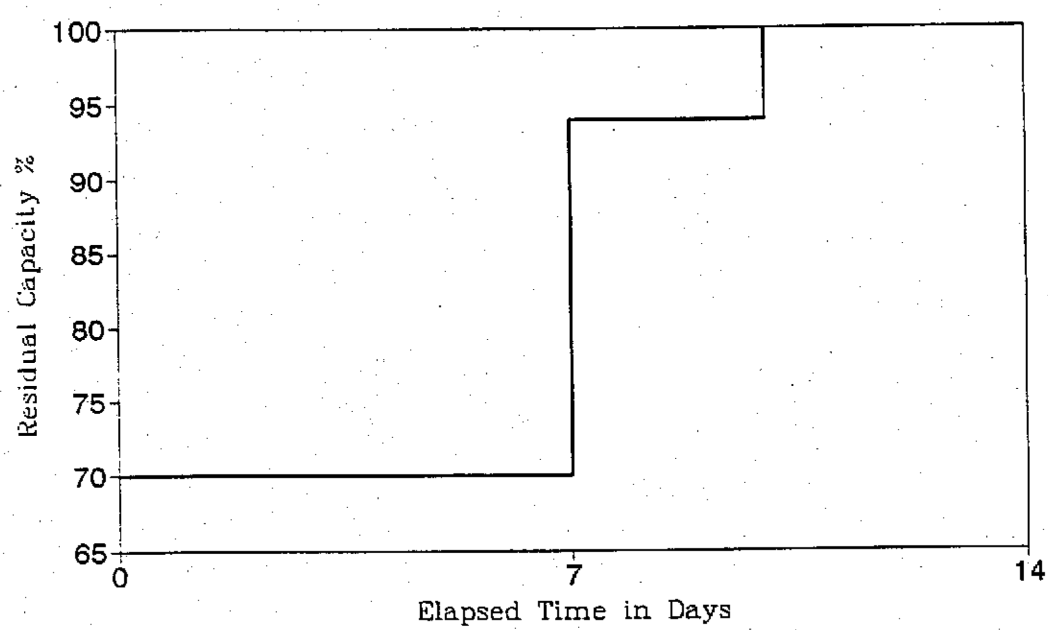


Figure 6-16 *Residual refined oil delivery from Texas to Chicago following New Madrid event (M=8.0).*

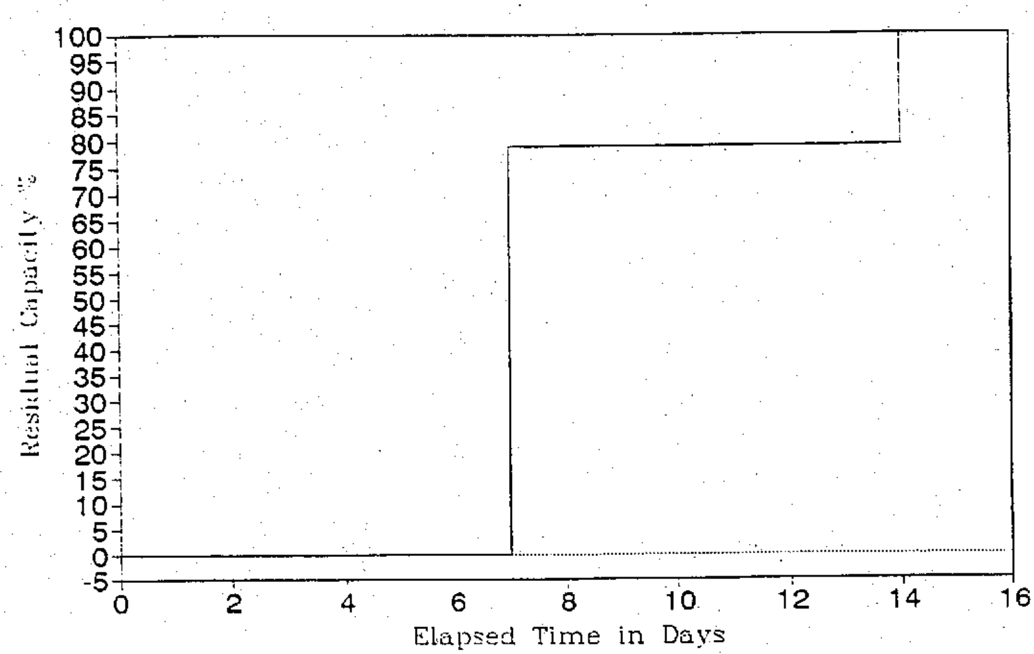


Figure 6-17 *Residual capacity of natural gas delivery from Texas to Northern California following Fort Tejon event (M=8.0).*

Appendix B. Distribution systems were assumed to be lumped at the center of the Standard Metropolitan Statistical Areas (SMSAs), and intensities were estimated at each SMSA for every scenario event. Residual capacity plots for distribution systems have not been included in this report. Economic losses resulting from damage to these systems, however, are included in the summaries provided later in this chapter.

6.5 General Analytical Approach for Estimating Indirect Economic Losses

In order to develop the relationship between lifeline interruption and indirect economic losses it was necessary to generate a set of simplifying assumptions. The general assumptions that apply to all lifelines are listed below.

6.5.1 General Assumptions

1. Duration. The interruption of the lifeline element/system that gives rise to the economic loss is assumed to extend over one or more consecutive month-long time periods. The functionality loss assigned to each month is the average for that month.

2. Independence. Lifeline elements are assumed to be independent. Interruptions in elements of one lifeline do not produce interruptions in other lifeline elements. That is, we ignore lifeline interaction effects, which are sometimes non-trivial.

3. Lifeline Functionality. The quantity under examination here is lifeline functionality as opposed to lifeline capacity. For example, assume the water supply lifeline sustains a loss of 20 percent of its capacity locally, but, because of redundancy and looping, water remains fully available. The functionality loss and consequent indirect economic loss would both be zero. Conversely, if all water supply and transmission facilities remain intact, but damage to the distribution system cuts off water to 20 percent of the industries served, the functionality loss is 20 percent.

4. Distribution of Incidence of Interruption. Lifeline interruptions are assumed to be prioritized as follows:

   Primary: Emergency response and human needs

   Secondary: Industrial needs (Within this class non-interruptible service customers share the loss in capacity equally)

   Tertiary: Interruptible service customers

5. Secondary Impacts Ignored. The loss of capacity in one (non-lifeline) industry would likely reduce the productivity of other industries that obtain inputs from the first industry. These reverberations, which are typically measured using input-output analysis, will be ignored for this first approximation. To the extent that these reverberations are ignored, impacts are understated.

6. Functional Relationships. Each industrial sector of the economy was considered separately with respect to each lifeline. The maximum impact, which would be expected to result from a prolonged total lifeline failure was estimated for each lifeline/sector pair. The effect of less-than-total failure of the lifeline was estimated using the following assumptions:

   - The first 5% interruption could be absorbed without economic loss

   - Subsequent losses would result in proportionate economic losses. Thus as lifeline capacity falls from 95 to 0%, the economic impact is assumed to increase linearly from zero to the maximum effect for each sector/lifeline pair.

   - The product of the percent loss of value added for each sector was summed over all sectors for each decile and lifeline. This sum represents the value-added weighted average of the economic impact of the lifeline for that decile.

7. Linearity. The linearity assumption mentioned above implies that remaining lifeline capacity could be used productively; limited lifeline damage would not cause a complete cessation of economic activity in

the sector. This assumption may unrealistically underestimate the effects of lifeline interruptions in industries (such as primary metals) that might be unable to scale back operations or to close and restart operations in response to reduction and restoration of lifeline capacity.

6.5.2 Data Sources and Methodology

Value Added Data. Economic activity within each industrial sector was measured in terms of value added. Value added refers to the value of shipments (products) less the cost of materials, supplies, contract work and fuels used in the manufacture or cultivation of the product. The United States Bureau of Economic Analysis publishes annual data for value added for each industrial sector. For simplicity, data from the 99 sectors were collapsed into 36 sectors. Data for 1983 were the latest available (published by BEA, 1989), and were used in this study.

As a first approximation, data on the national economy were used to assess the relative economic importance of each sector. The value added for each of the 36 sectors of the economic model is expressed as a percentage of the nationwide total. These data are presented in Table 6-1. For comparison, comparable data for the local San Francisco Bay Area economy (which comprises Santa Clara County and parts of Alameda County) are shown on the same table.

Lifeline Importance Factors. The economic impact of each lifeline was estimated by modifying estimates from ATC 13 (ATC, 1985). Table 9.8 of ATC 13 presents the lifeline importance factors for each social function. To adapt these estimates to the present study, the "social functions" were assigned to each industrial sector. The importance weights provided in ATC-13 distinguish between main and distribution systems for each lifeline. For the present study, the two figures were averaged to produce an importance weight for the entire lifeline system. Further modification of the ATC-13 estimates were made to reflect the difference between the importance of the lifeline and its impact on the economy if it were totally disrupted. These modifications, generally in the upward direction, constitute first approximations of economic impacts. The maximum impact estimates by sector and lifeline are shown in Table 6-2.

Reduction in Value Added Due to Lifeline Interruption. Table 6-3 presents the percent reduction in value added for each sector resulting from increasingly severe crude oil lifeline interruptions. (Similar tables are shown for all lifelines in Appendix D.) Values are shown for each decile of lifeline interruption and are assumed to pertain to *monthly* Gross National Product (GNP). As noted in the assumptions cited above, these percentages are linearly interpolated between the reduction in value added when the lifeline experiences 5% interruption (for a 5% lifeline interruption, there is no reduction in value added) to the reduction in value added when the lifeline experiences 100 percent interruption (maximum impact).

Table 6-4, also assumed to pertain to *monthly* GNP, presents the remaining value added of each sector under alternative levels of crude oil lifeline interruption. Similar tables are shown for all lifelines in Appendix D. These value added estimates are calculated by finding the percent value added of the sector within the total economy (Table 6-1, right column) and the percentage reductions in value added (e.g., Table 6-3 for oil supply). The product of these two variables is subtracted from the uninterrupted value-added for each decile. In the case of oil supply and the livestock sector, the residual valued-added after 10% of loss of capacity = (0.45%) - ((0.45%) x (2.63%)) = (0.45) - (.01) = 0.44% These sums thus represent the weighted average of the sectorial impacts of interruptions to the lifeline.

Figure 6-18 illustrates the value added weighted average economic impacts of crude oil lifeline interruptions (taken from totals at bottom of Table 6-4). Similar figures are shown for all lifelines in Appendix D. The Y-intercept reflects the estimate of the maximum impact, due to total disruption of the lifeline for an extended period of time.

Further Refinements. As noted at the outset, this brief study constitutes a first approximation of the economic effects of lifeline interruption. A number of explicit and implicit assumptions were made in order to simplify the analysis. Using these assumptions limits the accuracy of

Table 6-1 Relative Importance of Industry Sections--U. S. and Santa Clara County, California

	Sector	Santa Clara & Part Alameda Value Added (Mil $1986)	U.S. Econ Value Added (Mil $1983)	U.S. Econ. Value Added Pct. of Tot.	U.S. Econ. Value Added Pct. of Tot.
1	Livestock	4	0.01%	15,227	0.45%
2	Agr. Prod.	78	0.13%	35,567	1.06%
3	AgServ For. Fish	115	0.20%	3,705	0.11%
4	Mining	92	0.16%	130,577	3.89%
5	Construction	1,973	3.39%	185,326	5.52%
6	Food Tobacco	593	1.02%	80,810	2.41%
7	Textile Goods	10	0.02%	12,515	0.37%
8	Misc Text. Prod.	11	0.02%	24,397	0.73%
9	Lumber & Wood	50	0.09%	17,319	0.52%
10	Furniture	60	0.10%	11,378	0.34%
11	Pulp & Paper	153	0.26%	29,253	0.87%
12	Print & Publish	413	0.71%	44,053	1.31%
13	Chemical & Drugs	492	0.84%	47,144	1.40%
14	Petrol. Refining	3	0.01%	32,332	0.96%
15	Rubber & Plastic	127	0.22%	34,579	1.03%
16	Leather Prods.	1	0.00%	4,119	0.12%
17	Glass Stone Clay	199	0.34%	20,758	0.62%
18	Prim. Metal Prod	95	0.16%	34,951	1.04%
19	Fab. Metal Prod.	538	0.92%	55,094	1.64%
20	Mach. Exc. Elec.	5,789	9.95%	52,384	1.56%
21	Elec. & Electron	5,603	9.63%	84,697	2.52%
22	Transport Eq.	924	1.59%	87,942	2.62%
23	Instruments	1,416	2.43%	22,807	0.68%
24	Misc. Manufact.	113	0.19%	23,080	0.69%
25	Transp & Whse.	533	0.92%	116,193	3.46%
26	Utilities	1,173	2.02%	197,676	5.89%
27	Wholesale Trade	4,034	6.93%	189,178	5.63%
28	Retail Trade	2,567	4.41%	189,178	5.63%
29	F.I.R.E. *(Finance, Insurance, Real Estate)*	10,250	17.62%	558,851	16.64%
30	Pers./Prof Serv.	8,755	15.05%	269,683	8.03%
31	Eating Drinking	1,556	2.67%	71,217	2.12%
32	Auto Serv.	1,137	1.95%	36,761	1.09%
33	Amuse & Rec.	223	0.38%	23,385	0.70%
34	Health Ed. Soc.	4,650	7.99%	211,503	6.30%
35	Govt & Govt Ind.	3,870	6.65%	395,936	11.79%
36	Households	574	0.99%	8,442	0.25%
	Inventory & Leak	0.00%	39,135		
	TOTAL	58,174	100.00%	3,397,151	100.00%

Sources: Santa Clara: Dames & Moore, 1987. Regional Economics Of Water Supply Shortages in the South Bay Contractors' Service Area U.S.: U.S. Dept. of Comm. Bureau of Econ. Analysis, 1989 Suvey of Current Business. Input Output Accounts of the U.S. Economy, 1983 Collapsed from 99 to 36 sectors.

Table 6-2 Importance Weights of Various Lifeline Systems on Economic Sectors (Modified ATC-13 Table 9.8 (ATC, 1985))

	Water	*Waste*	*Electric*	*Natural Gas*	*Oil*	*Highway*	*Railways*	*Air Transportation*	*Water Transportation*	*Phone*
1 Livestock	0.45	0.20	0.50	0.10	0.50	0.50	0.40	0.10	0.40	0.20
2 Agr. Prod.	0.70	0.50	0.50	0.30	0.80	0.80	0.40	0.10	0.40	0.20
3 AgServ For. Fish	0.45	0.50	0.50	0.30	0.80	0.80	0.40	0.10	0.40	0.20
4 Mining	0.15	0.10	0.90	0.10	0.90	0.35	0.35	0.10	0.20	0.10
5 Construction	0.50	0.20	0.40	0.00	0.90	0.40	0.05	0.00	0.20	0.10
6 Food Tobacco	0.70	0.70	0.90	0.25	0.50	0.80	0.20	0.20	0.20	0.15
7 Textile Goods	0.70	0.70	1.00	0.20	0.50	0.75	0.20	0.20	0.20	0.15
8 Misc Text. Prod.	0.70	0.70	1.00	0.20	0.50	0.75	0.20	0.20	0.20	0.15
9 Lumber & Wood	0.50	0.50	1.00	0.20	0.50	0.90	0.40	0.20	0.20	0.15
10 Furniture	0.50	0.50	1.00	0.20	0.50	0.75	0.20	0.20	0.20	0.15
11 Pulp & Paper	0.60	0.80	1.00	0.40	0.50	0.80	0.45	0.10	0.30	0.10
12 Print & Publish	0.30	0.30	1.00	0.20	0.50	0.75	0.20	0.20	0.20	0.15
13 Chemical & Drugs	0.80	0.80	0.90	0.90	0.50	0.80	0.20	0.20	0.20	0.15
14 Petrol. Refining	0.50	0.50	1.00	0.50	1.00	0.90	0.40	0.00	0.80	0.10
15 Rubber & Plastic	0.50	0.50	1.00	0.50	0.50	0.75	0.20	0.20	0.20	0.15
16 Leather Prods.	0.50	0.50	1.00	0.20	0.50	0.75	0.20	0.20	0.20	0.15
17 Glass Stone Clay	0.50	0.50	1.00	0.50	0.50	0.75	0.20	0.20	0.20	0.15
18 Prim. Metal Prod.	0.90	0.80	0.90	0.50	0.90	0.80	0.50	0.10	0.20	0.15
19 Fab. Metal Prod.	0.80	0.80	1.00	0.50	0.50	0.80	0.45	0.10	0.30	0.10
20 Mach. Exc, Elec.	0.60	0.80	1.00	0.50	0.50	0.80	0.45	0.20	0.30	0.10
21 Elec. & Electron	0.90	0.90	1.00	0.50	0.50	0.75	0.20	0.30	0.20	0.15
22 Transport Eq.	0.60	0.80	1.00	0.50	0.90	0.80	0.45	0.30	0.30	0.10
23 Instruments	0.90	0.60	1.00	0.75	0.50	0.80	0.05	0.40	0.10	0.30
24 Misc. Manufact.	0.60	0.60	1.00	0.50	0.50	0.75	0.20	0.20	0.20	0.15
25 Transp & Whse.	0.20	0.10	0.30	0.00	0.90	0.80	0.30	0.30	0.30	0.30
26 Utilities	0.40	0.24	0.80	0.40	0.50	0.40	0.00	0.00	0.00	0.30
27 Wholesale Trade	0.20	0.10	0.90	0.10	0.50	0.70	0.15	0.20	0.20	0.50
28 Retail Trade	0.20	0.20	0.90	0.20	0.90	0.55	0.20	0.20	0.00	0.50
29 F.I.R.E.	0.20	0.20	0.90	0.20	0.60	0.45	0.10	0.20	0.00	0.60
30 Pers./Prof Serv.	0.20	0.20	0.90	0.20	0.60	0.45	0.10	0.20	0.00	0.40
31 Eating Drinking	0.80	0.80	0.80	0.40	0.80	0.50	0.05	0.40	0.00	0.40
32 Auto Serv.	0.10	0.20	0.90	0.05	0.90	0.55	0.00	0.00	0.00	0.40
33 Amuse & Rec.	0.80	0.80	0.80	0.40	0.90	0.50	0.05	0.40	0.00	0.40
34 Health Ed. Soc.	0.40	0.80	0.80	0.20	0.20	0.55	0.05	0.10	0.00	0.15
35 Govt & Govt Ind.	0.25	0.20	0.60	0.20	0.20	0.30	0.10	0.20	0.00	0.20
36 Households	0.40	0.75	0.80	0.35	0.50	0.40	0.00	0.00	0.00	0.20
TOTAL	0.51	0.51	0.86	0.32	0.62	0.67	0.22	0.18	0.19	0.22

Table 6-3 Percent Value-Added Lost Due to Specified Percent Loss of Oil Supply Lifeline

L/L Capacity Loss-->	*U.S. Econ. Value Added (Percent)*	*10%*	*20%*	*30%*	*40%*	*50%*	*60%*	*70%*	*80%*	*90%*	*100%*
1 Livestock	0.45%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
2 Agr. Prod.	1.06%	4.21%	12.63%	21.05%	29.47%	37.89%	46.32%	54.74%	63.16%	71.58%	80.00%
3 AgServ For. Fish	0.11%	4.21%	12.63%	21.05%	29.47%	37.89%	46.32%	54.74%	63.16%	71.58%	80.00%
4 Mining	3.89%	4.74%	14.21%	23.68%	33.16%	42.63%	52.11%	61.58%	71.05%	80.53%	90.00%
5 Construction	5.52%	4.74%	14.21%	23.68%	33.16%	42.63%	52.11%	61.58%	71.05%	80.53%	90.00%
6 Food Tobacco	2.41%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
7 Textile Goods	0.37%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
8 Misc Text. Prod.	0.73%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
9 Lumber & Wood	0.52%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
10 Furniture	0.34%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
11 Pulp & Paper	0.87%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
12 Print & Publish	1.31%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
13 Chemical Drugs	1.40%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
14 Petrol. Refining	0.96%	5.26%	15.79%	26.32%	36.84%	47.37%	57.89%	68.42%	78.95%	89.47%	100.00%
15 Rubber & Plastic	1.03%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
16 Leather Prods.	0.12%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
17 Glass Stone Clay	0.62%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
18 Prim. Metal Prod.	1.04%	4.74%	14.21%	23.68%	33.16%	42.63%	52.11%	61.58%	71.05%	80.53%	90.00%
19 Fab. Metal Prod.	1.64%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
20 Mach. Exc. Elec.	1.56%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
21 Elec. & Electron	2.52%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
22 Transport Eq.	2.62%	4.74%	14.21%	23.68%	33.16%	42.63%	52.11%	61.58%	71.05%	80.53%	90.00%
23 Instruments	0.68%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
24 Misc. Manufact.	0.69%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
25 Transp & Whse.	3.46%	4.74%	14.21%	23.68%	33.16%	42.63%	52.11%	61.58%	71.05%	80.53%	90.00%
26 Utilities	5.89%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
27 Wholesale Trade	5.63%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
28 Retail Trade	5.63%	4.74%	14.21%	23.68%	33.16%	42.63%	52.11%	61.58%	71.05%	80.53%	90.00%
29 F.I.R.E.	16.64%	3.16%	9.47%	15.79%	22.11%	28.42%	34.74%	41.05%	47.37%	53.68%	60.00%
30 Pers./Prof. Serv.	8.03%	3.16%	9.47%	15.79%	22.11%	28.42%	34.74%	41.05%	47.37%	53.68%	60.00%
31 Eating Drinking	2.12%	4.21%	12.63%	21.05%	29.47%	37.89%	46.32%	54.74%	63.16%	71.58%	80.00%
32 Auto Serv.	1.09%	4.74%	14.21%	23.68%	33.16%	42.63%	52.11%	61.58%	71.05%	80.53%	90.00%
33 Amuse & Rec.	0.70%	4.74%	14.21%	23.68%	33.16%	42.63%	52.11%	61.58%	71.05%	80.53%	90.00%
34 Health Ed. Soc.	6.30%	1.05%	3.16%	5.26%	7.37%	9.47%	11.58%	13.68%	15.79%	17.89%	20.00%
35 Govt & Govt Ind.	11.79%	1.05%	3.16%	5.26%	7.37%	9.47%	11.58%	13.68%	15.79%	17.89%	20.00%
36 Households	0.25%	2.63%	7.89%	13.16%	18.42%	23.68%	28.95%	34.21%	39.47%	44.74%	50.00%
TOTAL	100.00%	3.25% Avg.	9.74% Avg.	16.23% Avg.	22.72% Avg.	29.21% Avg.	35.70% Avg.	42.19% Avg.	48.68% Avg.	55.18% Avg.	61.67% Total V.A Pct. V.A.

Table 6-4 Residual Value-Added After Loss of Capacity of Oil Supply Lifeline

0%	*10%*	*20%*	*30%*	*40%*	*50%*	*60%*	*70%*	*80%*	*90%*	*100%*
0.45%	0.44%	0.42%	0.39%	0.37%	0.35%	0.32%	0.30%	0.27%	0.25%	0.23%
1.06%	1.01%	0.93%	0.84%	0.75%	0.66%	0.57%	0.48%	0.39%	0.30%	0.21%
0.11%	0.11%	0.10%	0.09%	0.08%	0.07%	0.06%	0.05%	0.04%	0.03%	0.02%
3.89%	3.70%	3.34%	2.97%	2.60%	2.23%	1.86%	1.49%	1.13%	0.76%	0.39%
5.52%	5.26%	4.73%	4.21%	3.69%	3.17%	2.64%	2.12%	1.60%	1.07%	0.55%
2.41%	2.34%	2.22%	2.09%	1.96%	1.84%	1.71%	1.58%	1.46%	1.33%	1.20%
0.37%	0.36%	0.34%	0.32%	0.30%	0.28%	0.26%	0.25%	0.23%	0.21%	0.19%
0.73%	0.71%	0.67%	0.63%	0.59%	0.55%	0.52%	0.48%	0.44%	0.40%	0.36%
0.52%	0.50%	0.48%	0.45%	0.42%	0.39%	0.37%	0.34%	0.31%	0.29%	0.26%
0.34%	0.33%	0.31%	0.29%	0.28%	0.26%	0.24%	0.22%	0.21%	0.19%	0.17%
0.87%	0.85%	0.80%	0.76%	0.71%	0.66%	0.62%	0.57%	0.53%	0.48%	0.44%
1.31%	1.28%	1.21%	1.14%	1.07%	1.00%	0.93%	0.86%	0.79%	0.72%	0.66%
1.40%	1.37%	1.29%	1.22%	1.15%	1.07%	1.00%	0.92%	0.85%	0.78%	0.70%
0.96%	0.91%	0.81%	0.71%	0.61%	0.51%	0.41%	0.30%	0.20%	0.10%	0.00%
1.03%	1.00%	0.95%	0.89%	0.84%	0.79%	0.73%	0.68%	0.62%	0.57%	0.51%
0.12%	0.12%	0.11%	0.11%	0.10%	0.09%	0.09%	0.08%	0.07%	0.07%	0.06%
0.62%	0.60%	0.57%	0.54%	0.50%	0.47%	0.44%	0.41%	0.37%	0.34%	0.31%
1.04%	0.99%	0.89%	0.79%	0.70%	0.60%	0.50%	0.40%	0.30%	0.20%	0.10%
1.64%	1.60%	1.51%	1.42%	1.34%	1.25%	1.17%	1.08%	0.99%	0.91%	0.82%
1.56%	1.52%	1.44%	1.35%	1.27%	1.19%	1.11%	1.03%	0.94%	0.86%	0.78%
2.52%	2.46%	2.32%	2.19%	2.06%	1.92%	1.79%	1.66%	1.53%	1.39%	1.26%
2.62%	2.49%	2.25%	2.00%	1.75%	1.50%	1.25%	1.01%	0.76%	0.51%	0.26%
0.68%	0.66%	0.63%	0.59%	0.55%	0.52%	0.48%	0.45%	0.41%	0.38%	0.34%
0.69%	0.67%	0.63%	0.60%	0.56%	0.52%	0.49%	0.45%	0.42%	0.38%	0.34%
3.46%	3.30%	2.97%	2.64%	2.31%	1.99%	1.66%	1.33%	1.00%	0.67%	0.35%
5.89%	5.73%	5.42%	5.11%	4.80%	4.49%	4.18%	3.87%	3.56%	3.25%	2.94%
5.63%	5.49%	5.19%	4.89%	4.60%	4.30%	4.00%	3.71%	3.41%	3.11%	2.82%
5.63%	5.37%	4.83%	4.30%	3.77%	3.23%	2.70%	2.16%	1.63%	1.10%	0.56%
16.64%	16.12%	15.07%	14.01%	12.96%	11.91%	10.86%	9.81%	8.76%	7.71%	6.66%
8.03%	7.78%	7.27%	6.76%	6.26%	5.75%	5.24%	4.73%	4.23%	3.72%	3.21%
2.12%	2.03%	1.85%	1.67%	1.50%	1.32%	1.14%	0.96%	0.78%	0.60%	0.42%
1.09%	1.04%	0.94%	0.84%	0.73%	0.63%	0.52%	0.42%	0.32%	0.21%	0.11%
0.70%	0.66%	0.60%	0.53%	0.47%	0.40%	0.33%	0.27%	0.20%	0.14%	0.07%
6.30%	6.23%	6.10%	5.97%	5.83%	5.70%	5.57%	5.44%	5.30%	5.17%	5.04%
11.79%	11.67%	11.42%	11.17%	10.92%	10.67%	10.43%	10.18%	9.93%	9.68%	9.43%
0.25%	0.24%	0.23%	0.22%	0.21%	0.19%	0.18%	0.17%	0.15%	0.14%	0.13%
100.00%	96.94%	90.83%	84.71%	78.60%	72.48%	66.37%	60.25%	54.14%	48.02%	41.91%
100%	97%	91%	85%	79%	72%	66%	60%	54%	48%	42%

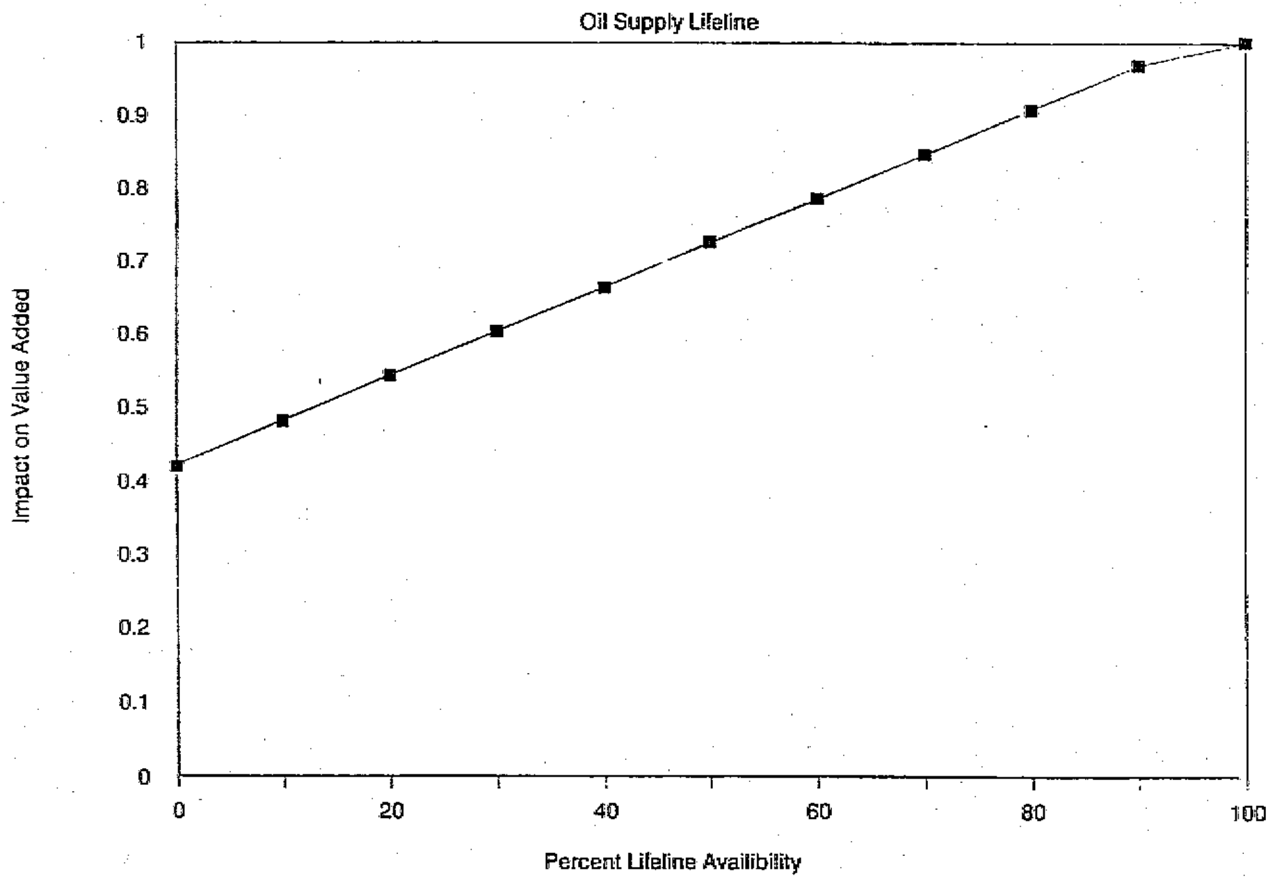


Figure 6-18 Residual Value Added as a function of crude oil lifeline residual capacity

the results. However, the model's parameters could be refined to produce more accurate results, which might also better represent regional and local economic diversity. The following refinements are suggested:

- <u>Regionalization</u>. Data on value added are available on a county-by-county basis for the entire United States. This data could be used in place of the national data presented here to produce local area models of county or multiple-county areas. Such a localized model would more accurately reflect the impacts weighted by the local importance of each of the industrial sectors.

- <u>Maximum Economic Impacts</u>. The estimates of the maximum impacts of lifeline disruptions were modified from the ATC-13 data, based on the judgment of the authors. These estimates could be improved by research into the use of each of the lifeline inputs within each of the economic sectors.

- <u>Linearity Assumption</u>. The economic impact of lifeline interruption was assumed to vary linearly between no impact at 5% interruption, to maximum impact at 100% interruption. This assumption could be investigated and modified as appropriate. Some industries may require uninterrupted use of lifelines in order to operate; they may be unable to operate under certain conditions of reduced lifeline capacity. The linearity assumption ignores these possible threshold effects. Furthermore, many or all industries might respond non-linearly to interruptions. Smaller percentage interruptions might cause a less than proportional impact on value added as lower valued functions or product line are cut first, or as other factors of production are substituted for the damaged lifeline. At high percent interruptions, the response might be more than proportional, as vital functions cannot be maintained. Further research into industry response to scarcity might suggest a convex rather than linear response function.

- Interindustry Effects. The scarcity of productive factors other than lifelines could have major impacts on a regional economy. These interactions were ignored in the present study, thus understating impacts of lifeline interruptions. As noted in Scawthorn and Lofting (1984), input-output economic models could be used to solve for these interactions. Building such a model would be difficult because the impacts caused by lifeline disruptions and the non-lifeline scarcity impacts would have to be solved simultaneously. However, the basic modeling approach proposed in this study is consistent with the type of regional data necessary to drive an input-output model.

6.6 Indirect Economic Loss Estimates

Indirect economic losses were estimated for each lifeline system and scenario event using the residual capacity plots provided in Appendix C and the economic tables described above. The calculation procedure was as follows:

1. Determine the monthly loss in capacity for the lifeline and scenario earthquake under consideration using the appropriate residual capacity plot (Appendix C).

2. Determine Percent-Value-Added Lost for each month and sector of the economy for the lifeline under consideration, using the estimates obtained from Step 1 above and the Percent-Value-Added Lost Tables provided in Appendix D (Table 6-3 is an example). Sum the percentages for all months in each sector to obtain the total Value-Added-Lost in that sector during the time period the lifeline had loss in capacity. Multiply this sum by the percent U. S. Economic Value Added for that sector.

3. Sum the products calculated in Step 2 for each sector to estimate the total percentage value added lost for all economic sectors; multiply this percentage by the percent of U. S. population affected and by the monthly Gross National Product to obtain the total indirect economic loss for the lifeline and earthquake scenario under consideration.

The equation used to calculate indirect economic losses (IEL) is as follows:

$$IEL = \sum_{i=1}^{N1} \sum_{j=1}^{N2} \sum_{k=1}^{N3} (A)(B)(C)(D) \quad (6.7)$$

where:
- IEL = Indirect Economic Loss
- N1 = number of affected regions
- N2 = number of economic sectors
- N3 = number of months the lifeline has a loss in capacity
- A = percent Value-Added-Lost per month
- B = percent U. S. Economy Value Added
- C = percent of U. S. population affected
- D = monthly Gross National Product

We note that an average value of loss of functionality during each month of the restoration period is used when estimating the overall indirect economic impact (from Table 6-3 and similar tables in Appendix D). This aspect of the computation is illustrated in Example 6.4 (Figure 6-19), which illustrates the economic loss calculation for a specific lifeline, economic sector, and hypothetical earthquake. Shown in Example 6.5 (Figure 6-20) is an example calculation for estimating total indirect dollar loss in all economic sectors due to damage of the electric system in the state of Utah as a result of the Wasatch Front scenario event.

We have also calculated values of "Percent of Monthly Economic Loss" in each economic sector due to interruption to each lifeline system for each scenario earthquake using the "Residual Capacity Plots" provided in Appendix C and the "Percent Value Added Lost" tables provided in Appendix D. These data are provided in Tables 6-5 through 6-11. Values in these tables are percentage of the monthly GNP of each economic sector that is lost due to the

Example 6.4

For the pipeline network described in Example 6.2 and using the residual capacity results determined there, determine indirect economic losses to the livestock sector for the first month.

Procedure. Immediately following the earthquake, this network experiences a 39% loss of functionality. Ten days later the loss of functionality is 0%. Thus, the average loss of functionality during the first 10 days is about 20%, and for the first month it is 20%/3, or 7%. From Table 6-3, which pertains to average loss of functionality for one month, the Value Added lost for a 7% loss in functionality for the live stock sector of the economy is 1.8%, i.e., 0.7 of 2.63% corresponding to 10% loss of oil supply lifeline for one month. To determine the economic losses in dollars, this percentage would first need to be multiplied by the percent U. S. Economy Value Added for the livestock sector (0.45%) and then prorated by the percent of the national population affected. Actual economic losses in this economic sector due to loss of functionality of this particular pipeline would then be determined by multiplying this prorated percentage by the monthly gross national product

Figure 6-19. Analysis Example Illustrating Economic Loss Calculation for Crude Oil Pipeline Network.

scenario earthquake and resulting lifeline interruption. In Table 6-6, for example, 141% of the monthly GNP of livestock is lost as a result of damage to water transportation systems during the Charleston earthquake scenario. The actual dollar loss would be the product of 1.41 x .0045 x monthly national GNP x percent of national population affected.

Summaries of the total indirect economic losses resulting from damage to site-specific systems and extended regional networks, based on 1986 GNP data, are provided in Table 6-12. Total indirect economic losses resulting from damage to local distribution systems are presented in Table 6-13. We note that Table 6-12 contains total loss amounts expressed in terms of lower bound, upper bound, and best estimate. The lower bound represents economic loss caused by the singular lifeline system causing the greatest loss; the upper bound is the sum of losses caused by all systems; and the best estimate is the square root of the sum of the squares (SRSS) of losses caused by each lifeline. We note also that the SRSS procedure was used to estimate total indirect economic losses resulting from damage to local distribution networks (Table 6-13).

By combining like system data from Tables 6-12 and 6-13 in a least squares (SRSS) fashion, we estimate the total indirect economic losses for the eight scenario earthquakes as follows:

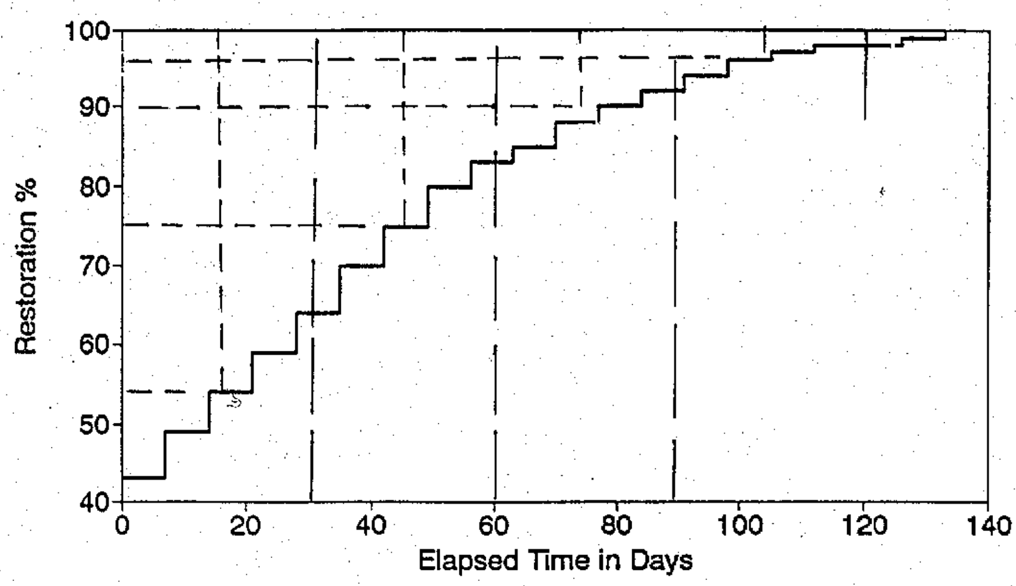
Earthquake	Indirect Loss (in Billions, 1991$)
Cape Ann	$9.1
Charleston	$10.2
Fort Tejon	$11.7
Hayward	$11.1
New Madrid, M = 8.0	$14.6
New Madrid, M = 7.0	$4.9
Puget Sound	$6.1
Wasatch Front	$3.9

Bar charts showing the indirect losses caused by transmission lines (upper bound data) by state for each scenario earthquake are provided in Figures 6-21 through 6-28. We note that estimates of indirect economic losses for each state are sensitive to the assumed location of the source zone for large-magnitude events (e.g., had the assumed source zone for the magnitude-8 New Madrid event been located further north, estimates of direct damage in Missouri would have been substantially larger). Estimates of direct damage (Chapter 6) are similarly affected.

The data provided in Figures 6-21 through 6-28 suggest that Massachusetts would experience the highest indirect losses due to the Cape Ann event with the electric system contributing the highest portion; Mississippi and Arkansas would experience the highest indirect losses due to the magnitude-8.0 New Madrid event; and South Carolina, Utah, Washington, Northern and Southern California would experience the highest indirect losses due to the Charleston, Utah, Seattle, Hayward, and Fort Tejon events, respectively. The electric system contributes the highest indirect losses, among all systems, for most of the events.

Example 6.5

Using the Restoration Capacity Plot shown below for Utah electric power following the scenario Wasatch Front event, estimate the indirect economic losses due to damage of the electric system in the state of Utah.



STEP 1: Estimate the average loss for each month, which is as follows:

Month	Percent Loss
1	45%
2	25%
3	10%
4	5%

STEP 2: From Table D-2, *Percent Value-Added Lost Due to Specified Percent Loss of Electricity Lifeline*, extrapolate percent Value Added Lost for each sector of the economy for each month and sum the results to obtain the estimated percent of Value Added Lost for the entire period. For the livestock sector, this calculation is as follows:

(23.68+18.42)/2 + (13.16+7.89)/2 + 2.63 + 2.63/2 =

21.05 + 10.53 + 2.63 + 1.32 = 35.53%

Figure 6-20. Analysis Example Illustrating Economic Loss Calculation for Electric System in State of Utah for the Wasatch Front Scenario Event.

STEP 3: Multiply the sum from Step 2 by the percent of the economy for that sector and sum the products for all economic sectors to obtain the total Percent-Value-Added lost (for all economic sectors):

	Economic Sector	(1) U. S. Economy Value-Added (percent)	(2) Utah Value-Added Lost (percent)	(3) Product of (1)x(2) (percent)
1	Livestock	0.45	35.53	0.16
2	Agr. Prod.	1.06	35.53	0.38
3	AgServ. For. Fish	0.11	35.53	0.04
4	Mining	3.89	63.95	2.49
5	Construction	5.52	28.42	1.57
6	Food Tobacco	2.41	63.95	1.54
7	Textile Goods	0.37	71.05	0.26
8	Misc. Text. Prod.	0.73	71.05	0.52
9	Lumber & Wood	0.52	71.05	0.37
10	Furniture	0.34	71.05	0.24
11	Pulp & Paper	0.87	71.05	0.62
12	Print & Publish	1.31	71.05	0.93
13	Chemical & Drugs	1.40	63.95	0.90
14	Petrol. Refining	0.98	71.05	0.68
15	Rubber & Plastic	1.03	71.05	0.73
16	Leather Prods.	0.12	71.05	0.09
17	Glass Stone Clay	0.62	71.05	0.44
18	Prim. Metal Prod.	1.04	63.95	0.67
19	Fab. Metal Prod.	1.64	71.05	1.17
20	Mach. Exc. Elec.	1.56	71.05	1.11
21	Elec. & Electron	2.52	71.05	1.79
22	Transport Eq.	2.62	71.05	1.86
23	Instruments	0.68	71.05	0.48
24	Misc. Manufact.	0.69	71.05	0.49
25	Transp & Whse.	3.46	21.32	0.74
26	Utilities	5.89	56.84	3.35
27	Wholesale Trade	5.63	63.95	3.60
28	Retail Trade	5.63	63.95	3.60
29	F.I.R.E.	16.64	63.95	10.64
30	Pers./Prof. Serv.	8.03	63.95	5.14
31	Eating Drinking	2.12	56.84	1.21
32	Auto Serv.	1.09	63.95	0.70
33	Amuse & Rec.	0.70	56.84	0.40
34	Health Ed. Soc.	6.30	56.84	3.58
35	Govt & Govt Ind.	11.79	42.63	5.03
36	Households	0.25	56.84	0.14
	Total			**57.63**

The total indirect economic loss resulting from damage to the electric system in the state of Utah is computed as follows:

= 57.63% (Utah population/U.S. population) (U.S. GNP)/12

= 57.63% (1.68/242) ($4,881/12) = $1.63 Billion

where U.S. GNP = $4,881 Billion (1986)

Figure 6-20 (Continued)

Table 6-5 Indirect Economic Loss due to Damage to the Air Transportation Lifeline (Percent Monthly GNP)

			NEW MADRID (M=8.0)				CHARLESTON (M=7.5)		CAPE ANN	WASATCH	HAYWARD	FORT TEJON	PUGET SOUND	NEW MADRID (M=7.0)
		U.S. Econ. Value Added (Percent)	Arkansas	Tennessee	Kentucky	Mississippi	South Carolina	Georgia	Massachusetts	Utah	California	California	Washington	Arkansas
1	Livestock	0.45%	4.74%	1.58%	0.37%	3.42%	2.11%	1.05%	2.95%	1.79%	0.53%	1.79%	3.16%	2.11%
2	Agr. Prod.	1.06%	4.74%	1.58%	0.37%	3.42%	2.11%	1.05%	2.95%	1.79%	0.53%	1.79%	3.16%	2.11%
3	AgServ For. Fish	0.11%	4.74%	1.58%	0.37%	3.42%	2.11%	1.05%	2.95%	1.79%	0.53%	1.79%	3.16%	2.11%
4	Mining	3.89%	4.74%	1.58%	0.37%	3.42%	2.11%	1.05%	2.95%	1.79%	0.53%	1.79%	3.16%	2.11%
5	Construction	5.52%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
6	Food Tobacco	2.41%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
7	Textile Goods	0.37%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
8	Misc Text. Prod.	0.73%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
9	Lumber & Wood	0.52%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
10	Furniture	0.34%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
11	Pulp & Paper	0.87%	4.74%	1.58%	0.37%	3.42%	2.11%	1.05%	2.95%	1.79%	0.53%	1.79%	3.16%	2.11%
12	Print & Publish	1.31%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
13	Chemical & Drugs	1.40%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
14	Petrol. Refining	0.96%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
15	Rubber & Plastic	1.03%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
16	Leather Prods.	0.12%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
17	Glass Stone Clay	0.62%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
18	Prim. Metal Prod.	1.04%	4.74%	1.58%	0.37%	3.42%	2.11%	1.05%	2.95%	1.79%	0.53%	1.79%	3.16%	2.11%
19	Fab. Metal Prod.	1.64%	4.74%	1.58%	0.37%	3.42%	2.11%	1.05%	2.95%	1.79%	0.53%	1.79%	3.16%	2.11%
20	Mach. Exc. Elec.	1.56%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
21	Elec. & Electron	2.52%	14.21%	4.74%	1.11%	10.26%	6.32%	3.16%	8.84%	5.37%	1.58%	5.37%	9.47%	6.32%
22	Transport Eq.	2.62%	14.21%	4.74%	1.11%	10.26%	6.32%	3.16%	8.84%	5.37%	1.58%	5.37%	9.47%	6.32%
23	Instruments	0.68%	18.95%	6.32%	1.47%	13.68%	8.42%	4.21%	11.79%	7.16%	2.11%	7.16%	12.63%	8.42%
24	Misc. Manufact.	0.69%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
25	Transp & Whse.	3.46%	14.21%	4.74%	1.11%	10.26%	6.32%	3.16%	8.84%	5.37%	1.58%	5.37%	9.47%	6.32%
26	Utilities	5.89%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
27	Wholesale Trade	5.63%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
28	Retail Trade	5.63%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
29	F.I.R.E.	16.64%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
30	Pers./Prof Serv.	8.03%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
31	Eating Drinking	2.12%	18.95%	6.32%	1.47%	13.68%	8.42%	4.21%	11.79%	7.16%	2.11%	7.16%	12.63%	8.42%
32	Auto Serv.	1.09%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
33	Amuse & Rec.	0.70%	18.95%	6.32%	1.47%	13.68%	8.42%	4.21%	11.79%	7.16%	2.11%	7.16%	12.63%	8.42%
34	Health Ed. Soc.	6.30%	4.74%	1.58%	0.37%	3.42%	2.11%	1.05%	2.95%	1.79%	0.53%	1.79%	3.16%	2.11%
35	Govt & Govt Ind.	11.79%	9.47%	3.16%	0.74%	6.84%	4.21%	2.11%	5.89%	3.58%	1.05%	3.58%	6.32%	4.21%
36	Households	0.25%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 6-6 Indirect Economic Loss due to Damage to the Water Transportation Lifeline (Percent Monthly GNP)

	U.S. Econ. Value Added (Percent)	CHARLESTON			CAPE ANN			HAYWARD	FORT TEJON	PUGET SOUND
		South Carolina	North Carolina	Georgia	Massachussetts	Rhole Island	New Hampshire	California	California	Washington
1 Livestock	0.45%	141.05%	5.47%	103.16%	14.74%	12.63%	1.58%	11.58%	21.05%	27.37%
2 Agr. Prod.	1.06%	141.05%	5.47%	103.16%	14.74%	12.63%	1.58%	11.58%	21.05%	27.37%
3 AgServ For. Fish	0.11%	141.05%	5.47%	103.16%	14.74%	12.63%	1.58%	11.58%	21.05%	27.37%
4 Mining	3.89%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
5 Construction	5.52%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
6 Food Tobacco	2.41%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
7 Textile Goods	0.37%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
8 Misc Text. Prod.	0.73%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
9 Lumber & Wood	0.52%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
10 Furniture	0.34%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
11 Pulp & Paper	0.87%	105.79%	4.11%	77.37%	11.05%	9.47%	1.18%	8.68%	15.79%	20.53%
12 Print & Publish	1.31%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
13 Chemical & Drugs	1.40%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
14 Petrol. Refining	0.96%	282.11%	10.95%	206.32%	29.47%	25.26%	3.16%	23.16%	42.11%	54.74%
15 Rubber & Plastic	1.03%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
16 Leather Prods.	0.12%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
17 Glass Stone Clay	0.62%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
18 Prim. Metal Prod.	1.04%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
19 Fab. Metal Prod.	1.64%	105.79%	4.11%	77.37%	11.05%	9.47%	1.18%	8.68%	15.79%	20.53%
20 Mach. Exc. Elec.	1.56%	105.79%	4.11%	77.37%	11.05%	9.47%	1.18%	8.68%	15.79%	20.53%
21 Elec. & Electron	2.52%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
22 Transport Eq.	2.62%	105.79%	4.11%	77.37%	11.05%	9.47%	1.18%	8.68%	15.79%	20.53%
23 Instruments	0.68%	35.26%	1.37%	25.79%	3.68%	3.16%	0.39%	2.89%	5.26%	6.84%
24 Misc. Manufact.	0.69%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
25 Transp & Whse.	3.46%	105.79%	4.11%	77.37%	11.05%	9.47%	1.18%	8.68%	15.79%	20.53%
26 Utilities	5.89%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
27 Wholesale Trade	5.63%	70.53%	2.74%	51.58%	7.37%	6.32%	0.79%	5.79%	10.53%	13.68%
28 Retail Trade	5.63%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
29 F.I.R.E.	16.64%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
30 Pers./Prof Serv.	8.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
31 Eating Drinking	2.12%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
32 Auto Serv.	1.09%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
33 Amuse & Rec.	0.70%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
34 Health Ed. Soc.	6.30%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
35 Govt & Govt Ind.	11.79%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
36 Households	0.25%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 6-7 Indirect Economic Loss due to Damage to the Oil System (Percent Monthly GNP)

			CRUDE OIL				REFINED OIL	
			New Madrid		Fort Tejon		New Madrid	
		U.S. Econ. Value Added (Percent)	(M=8.0) Chicago	(M=7.0) Chicago	(M=8.0) South California	(M=8.0) North California	(M=8.0) Chicago	(M=7.0) Chicago
1	Livestock	0.45%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
2	Agr. Prod.	1.06%	4.21%	1.05%	12.63%	14.32%	2.11%	1.47%
3	AgServ For. Fish	0.11%	4.21%	1.05%	12.63%	14.32%	2.11%	1.47%
4	Mining	3.89%	4.74%	1.18%	14.21%	16.11%	2.37%	1.66%
5	Construction	5.52%	4.74%	1.18%	14.21%	16.11%	2.37%	1.66%
6	Food Tobacco	2.41%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
7	Textile Goods	0.37%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
8	Misc Text. Prod.	0.73%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
9	Lumber & Wood	0.52%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
10	Furniture	0.34%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
11	Pulp & Paper	0.87%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
12	Print & Publish	1.31%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
13	Chemical & Drugs	1.40%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
14	Petrol. Refining	0.96%	5.26%	1.32%	15.79%	17.89%	2.63%	1.84%
15	Rubber & Plastic	1.03%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
16	Leather Prods.	0.12%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
17	Glass Stone Clay	0.62%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
18	Prim. Metal Prod.	1.04%	4.74%	1.18%	14.21%	16.11%	2.37%	1.66%
19	Fab. Metal Prod.	1.64%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
20	Mach. Exc. Elec.	1.56%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
21	Elec. & Electron	2.52%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
22	Transport Eq.	2.62%	4.74%	1.18%	14.21%	16.11%	2.37%	1.66%
23	Instruments	0.68%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
24	Misc. Manufact.	0.69%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
25	Transp & Whse.	3.46%	4.74%	1.18%	14.21%	16.11%	2.37%	1.66%
26	Utilities	5.89%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
27	Wholesale Trade	5.63%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%
28	Retail Trade	5.63%	4.74%	1.18%	14.21%	16.11%	2.37%	1.66%
29	F.I.R.E.	16.64%	3.16%	0.79%	9.47%	10.74%	1.58%	1.11%
30	Pers./Prof Serv.	8.03%	3.16%	0.79%	9.47%	10.74%	1.58%	1.11%
31	Eating Drinking	2.12%	4.21%	1.05%	12.63%	14.32%	2.11%	1.47%
32	Auto Serv.	1.09%	4.74%	1.18%	14.21%	16.11%	2.37%	1.66%
33	Amuse & Rec.	0.70%	4.74%	1.18%	14.21%	16.11%	2.37%	1.66%
34	Health Ed. Soc.	6.30%	1.05%	0.26%	3.16%	3.58%	0.53%	0.37%
35	Govt & Govt Ind.	11.79%	1.05%	0.26%	3.16%	3.58%	0.53%	0.37%
36	Households	0.25%	2.63%	0.66%	7.89%	8.95%	1.32%	0.92%

Table 6-8 Indirect Economic Loss due to Damage to the Natural Gas System (Percent Monthly GNP)

	U.S. Econ. Value Added (Percent)	NEW MADRID (M=8.0)		WASATCH	HAYWARD		FORT TEJON		NEW MADRID (M=7.0)	
		Texas to Chicago	Louisiana to Northeast	Utah	Texas to North Carolina	Texas to Washington	Texas to California	Texas to Seattle	Texas to Chicago	Louisiana to Northeast
1 Livestock	0.45%	0.26%	0.53%	0.74%	2.11%	0.37%	2.11%	2.11%	0.21%	0.26%
2 Agr. Prod.	1.06%	0.79%	1.58%	2.21%	6.32%	1.11%	6.32%	6.32%	0.63%	0.79%
3 AgServ For. Fish	0.11%	0.79%	1.58%	2.21%	6.32%	1.11%	6.32%	6.32%	0.63%	0.79%
4 Mining	3.89%	0.26%	0.53%	0.74%	2.11%	0.37%	2.11%	2.11%	0.21%	0.26%
5 Construction	5.52%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
6 Food Tobacco	2.41%	0.66%	1.32%	1.84%	5.26%	0.92%	5.26%	5.26%	0.53%	0.66%
7 Textile Goods	0.37%	0.53%	1.05%	1.47%	4.21%	0.74%	4.21%	4.21%	0.42%	0.53%
8 Misc Text. Prod.	0.73%	0.53%	1.05%	1.47%	4.21%	0.74%	4.21%	4.21%	0.42%	0.53%
9 Lumber & Wood	0.52%	0.53%	1.05%	1.47%	4.21%	0.74%	4.21%	4.21%	0.42%	0.53%
10 Furniture	0.34%	0.53%	1.05%	1.47%	4.21%	0.74%	4.21%	4.21%	0.42%	0.53%
11 Pulp & Paper	0.87%	1.05%	2.11%	2.95%	8.42%	1.47%	8.42%	8.42%	0.84%	1.05%
12 Print & Publish	1.31%	0.53%	1.05%	1.47%	4.21%	0.74%	4.21%	4.21%	0.42%	0.53%
13 Chemical & Drugs	1.40%	2.37%	4.74%	6.63%	18.95%	3.32%	18.95%	18.95%	1.89%	2.37%
14 Petrol. Refining	0.96%	1.32%	2.63%	3.68%	10.53%	1.84%	10.53%	10.53%	1.05%	1.32%
15 Rubber & Plastic	1.03%	1.32%	2.63%	3.68%	10.53%	1.84%	10.53%	10.53%	1.05%	1.32%
16 Leather Prods.	0.12%	0.53%	1.05%	1.47%	4.21%	0.74%	4.21%	4.21%	0.42%	0.53%
17 Glass Stone Clay	0.62%	1.32%	2.63%	3.68%	10.53%	1.84%	10.53%	10.53%	1.05%	1.32%
18 Prim. Metal Prod.	1.04%	1.32%	2.63%	3.68%	10.53%	1.84%	10.53%	10.53%	1.05%	1.32%
19 Fab. Metal Prod.	1.64%	1.32%	2.63%	3.68%	10.53%	1.84%	10.53%	10.53%	1.05%	1.32%
20 Mach. Exc. Elec.	1.56%	1.32%	2.63%	3.68%	10.53%	1.84%	10.53%	10.53%	1.05%	1.32%
21 Elec. & Electron	2.52%	1.32%	2.63%	3.68%	10.53%	1.84%	10.53%	10.53%	1.05%	1.32%
22 Transport Eq.	2.62%	1.32%	2.63%	3.68%	10.53%	1.84%	10.53%	10.53%	1.05%	1.32%
23 Instruments	0.68%	1.97%	3.95%	5.53%	15.79%	2.76%	15.79%	15.79%	1.58%	1.97%
24 Misc. Manufact.	0.69%	1.32%	2.63%	3.68%	10.53%	1.84%	10.53%	10.53%	1.05%	1.32%
25 Transp & Whse.	3.46%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
26 Utilities	5.89%	1.05%	2.11%	2.95%	8.42%	1.47%	8.42%	8.42%	0.84%	1.05%
27 Wholesale Trade	5.63%	0.26%	0.53%	0.74%	2.11%	0.37%	2.11%	2.11%	0.21%	0.26%
28 Retail Trade	5.63%	0.53%	1.05%	1.47%	4.21%	0.74%	4.21%	4.21%	0.42%	0.53%
29 F.I.R.E.	16.64%	0.53%	1.05%	1.47%	4.21%	0.74%	4.21%	4.21%	0.42%	0.53%
30 Pers./Prof Serv.	8.03%	0.53%	1.05%	1.47%	4.21%	0.74%	4.21%	4.21%	0.42%	0.53%
31 Eating Drinking	2.12%	1.05%	2.11%	2.95%	8.42%	1.47%	8.42%	8.42%	0.84%	1.05%
32 Auto Serv.	1.09%	0.13%	0.26%	0.37%	1.05%	0.18%	1.05%	1.05%	0.11%	0.13%
33 Amuse & Rec.	0.70%	1.05%	2.11%	2.95%	8.42%	1.47%	8.42%	8.42%	0.84%	1.05%
34 Health Ed. Soc.	6.30%	0.53%	1.05%	1.47%	4.21%	0.74%	4.21%	4.21%	0.42%	0.53%
35 Govt & Govt Ind.	11.79%	0.53%	1.05%	1.47%	4.21%	0.74%	4.21%	4.21%	0.42%	0.53%
36 Households	0.25%	0.92%	1.84%	2.58%	7.37%	1.29%	7.37%	7.37%	0.74%	0.92%

Table 6-9 Indirect Economic Loss due to Damage to the Railroad Lifeline (Percent Monthly GNP)

	U.S. Econ. Value Added (Percent)	*(M=8.0) New Madrid*	*Charleston*	*Cape Ann*	*Utah*	*Hayward*	*Fort Tejon*	*Seattle*	*(M7=.0) New Madrid*
1 Livestock	0.45%	4.21%	7.58%	7.58%	3.37%	5.47%	7.58%	7.58%	3.37%
2 Agr. Prod.	1.06%	4.21%	7.58%	7.58%	3.37%	5.47%	7.58%	7.58%	3.37%
3 AgServ For. Fish	0.11%	4.21%	7.58%	7.58%	3.37%	5.47%	7.58%	7.58%	3.37%
4 Mining	3.89%	3.68%	6.63%	6.63%	2.95%	4.79%	6.63%	6.63%	2.95%
5 Construction	5.52%	0.53%	0.95%	0.95%	0.42%	0.68%	0.95%	0.95%	0.42%
6 Food Tobacco	2.41%	2.11%	3.79%	3.79%	1.68%	2.74%	3.79%	3.79%	1.68%
7 Textile Goods	0.37%	2.11%	3.79%	3.79%	1.68%	2.74%	3.79%	3.79%	1.68%
8 Misc Text. Prod.	0.73%	2.11%	3.79%	3.79%	1.68%	2.74%	3.79%	3.79%	1.68%
9 Lumber & Wood	0.52%	4.21%	7.58%	7.58%	3.37%	5.47%	7.58%	7.58%	3.37%
10 Furniture	0.34%	2.11%	3.79%	3.79%	1.68%	2.74%	3.79%	3.79%	1.68%
11 Pulp & Paper	0.87%	4.74%	8.53%	8.53%	3.79%	6.16%	8.53%	8.53%	3.79%
12 Print & Publish	1.31%	2.11%	3.79%	3.79%	1.68%	2.74%	3.79%	3.79%	1.68%
13 Chemical & Drugs	1.40%	2.11%	3.79%	3.79%	1.68%	2.74%	3.79%	3.79%	1.68%
14 Petrol. Refining	0.96%	4.21%	7.58%	7.58%	3.37%	5.47%	7.58%	7.58%	3.37%
15 Rubber & Plastic	1.03%	2.11%	3.79%	3.79%	1.68%	2.74%	3.79%	3.79%	1.68%
16 Leather Prods.	0.12%	2.11%	3.79%	3.79%	1.68%	2.74%	3.79%	3.79%	1.68%
17 Glass Stone Clay	0.62%	2.11%	3.79%	3.79%	1.68%	2.74%	3.79%	3.79%	1.68%
18 Prim. Metal Prod.	1.04%	5.26%	9.47%	9.47%	4.21%	6.84%	9.47%	9.47%	4.21%
19 Fab. Metal Prod.	1.64%	4.74%	8.53%	8.53%	3.79%	6.16%	8.53%	8.53%	3.79%
20 Mach. Exc. Elec.	1.56%	4.74%	8.53%	8.53%	3.79%	6.16%	8.53%	8.53%	3.79%
21 Elec. & Electron	2.52%	2.11%	3.79%	3.79%	1.68%	2.74%	3.79%	3.79%	1.68%
22 Transport Eq.	2.62%	4.74%	8.53%	8.53%	3.79%	6.16%	8.53%	8.53%	3.79%
23 Instruments	0.68%	0.53%	0.95%	0.95%	0.42%	0.68%	0.95%	0.95%	0.42%
24 Misc. Manufact.	0.69%	2.11%	3.79%	3.79%	1.68%	2.74%	3.79%	3.79%	1.68%
25 Transp & Whse.	3.46%	3.16%	5.68%	5.68%	2.53%	4.11%	5.68%	5.68%	2.53%
26 Utilities	5.89%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
27 Wholesale Trade	5.63%	1.58%	2.84%	2.84%	1.26%	2.05%	2.84%	2.84%	1.26%
28 Retail Trade	5.63%	2.11%	3.79%	3.79%	1.68%	2.74%	3.79%	3.79%	1.68%
29 F.I.R.E.	16.64%	1.05%	1.89%	1.89%	0.84%	1.37%	1.89%	1.89%	0.84%
30 Pers./Prof Serv.	8.03%	1.05%	1.89%	1.89%	0.84%	1.37%	1.89%	1.89%	0.84%
31 Eating Drinking	2.12%	0.53%	0.95%	0.95%	0.42%	0.68%	0.95%	0.95%	0.42%
32 Auto Serv.	1.09%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
33 Amuse & Rec.	0.70%	0.53%	0.95%	0.95%	0.42%	0.68%	0.95%	0.95%	0.42%
34 Health Ed. Soc.	6.30%	0.53%	0.95%	0.95%	0.42%	0.68%	0.95%	0.95%	0.42%
35 Govt & Govt Ind.	11.79%	1.05%	1.89%	1.89%	0.84%	1.37%	1.89%	1.89%	0.84%
36 Households	0.25%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 6-10 Indirect Economic Loss due to Damage to the Electric System (Percent Monthly GNP)

			NEW MADRID (M=8.0)						CHARLESTON			CAPE ANN		
		U.S. Econ. Value Added (Percent)	Illinois	Missouri	Arkansas	Tennessee	Kentucky	Mississippi	South Carolina	North Carolina	Georgia	Massachusetts	Connecticut	Delaware
1	Livestock	0.45%	3.95%	6.58%	32.89%	13.16%	13.16%	44.74%	46.05%	7.89%	18.42%	44.74%	15.79%	10.53%
2	Agr. Prod.	1.06%	3.95%	6.58%	32.89%	13.16%	13.16%	44.74%	46.05%	7.89%	18.42%	44.74%	15.79%	10.53%
3	AgServ For. Fish	0.11%	3.95%	6.58%	32.89%	13.16%	13.16%	44.74%	46.05%	7.89%	18.42%	44.74%	15.79%	10.53%
4	Mining	3.89%	7.11%	11.84%	59.21%	23.68%	23.68%	80.53%	82.89%	14.21%	33.16%	80.53%	28.42%	18.95%
5	Construction	5.52%	3.16%	5.26%	26.32%	10.53%	10.53%	35.79%	36.84%	6.32%	14.74%	35.79%	12.63%	8.42%
6	Food Tobacco	2.41%	7.11%	11.84%	59.21%	23.68%	23.68%	80.53%	82.89%	14.21%	33.16%	80.53%	28.42%	18.95%
7	Textile Goods	0.37%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
8	Misc Text. Prod.	0.73%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
9	Lumber & Wood	0.52%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
10	Furniture	0.34%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
11	Pulp & Paper	0.87%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
12	Print & Publish	1.31%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
13	Chemical & Drugs	1.40%	7.11%	11.84%	59.21%	23.68%	23.68%	80.53%	82.89%	14.21%	33.16%	80.53%	28.42%	18.95%
14	Petrol. Refining	0.96%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
15	Rubber & Plastic	1.03%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
16	Leather Prods.	0.12%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
17	Glass Stone Clay	0.62%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
18	Prim. Metal Prod.	1.04%	7.11%	11.84%	59.21%	23.68%	23.68%	80.53%	82.89%	14.21%	33.16%	80.53%	28.42%	18.95%
19	Fab. Metal Prod.	1.64%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
20	Mach. Exc. Elec.	1.56%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
21	Elec. & Electron	2.52%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
22	Transport Eq.	2.62%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
23	Instruments	0.68%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
24	Misc. Manufact.	0.69%	7.89%	13.16%	65.79%	26.32%	26.32%	89.47%	92.11%	15.79%	36.84%	89.47%	31.58%	21.05%
25	Transp & Whse.	3.46%	2.37%	3.95%	19.74%	7.89%	7.89%	26.84%	27.63%	4.74%	11.05%	26.84%	9.47%	6.32%
26	Utilities	5.89%	6.32%	10.53%	52.63%	21.05%	21.05%	71.58%	73.68%	12.63%	29.47%	71.58%	25.26%	16.84%
27	Wholesale Trade	5.63%	7.11%	11.84%	59.21%	23.68%	23.68%	80.53%	82.89%	14.21%	33.16%	80.53%	28.42%	18.95%
28	Retail Trade	5.63%	7.11%	11.84%	59.21%	23.68%	23.68%	80.53%	82.89%	14.21%	33.16%	80.53%	28.42%	18.95%
29	F.I.R.E.	16.64%	7.11%	11.84%	59.21%	23.68%	23.68%	80.53%	82.89%	14.21%	33.16%	80.53%	28.42%	18.95%
30	Pers./Prof Serv.	8.03%	7.11%	11.84%	59.21%	23.68%	23.68%	80.53%	82.89%	14.21%	33.16%	80.53%	28.42%	18.95%
31	Eating Drinking	2.12%	6.32%	10.53%	52.63%	21.05%	21.05%	71.58%	73.68%	12.63%	29.47%	71.58%	25.26%	16.84%
32	Auto Serv.	1.09%	7.11%	11.84%	59.21%	23.68%	23.68%	80.53%	82.89%	14.21%	33.16%	80.53%	28.42%	18.95%
33	Amuse & Rec.	0.70%	6.32%	10.53%	52.63%	21.05%	21.05%	71.58%	73.68%	12.63%	29.47%	71.58%	25.26%	16.84%
34	Health Ed. Soc.	6.30%	6.32%	10.53%	52.63%	21.05%	21.05%	71.58%	73.68%	12.63%	29.47%	71.58%	25.26%	16.84%
35	Govt & Govt Ind.	11.79%	4.74%	7.89%	39.47%	15.79%	15.79%	53.68%	55.26%	9.47%	22.11%	53.68%	18.95%	12.63%
36	Households	0.25%	6.32%	10.53%	52.63%	21.05%	21.05%	71.58%	73.68%	12.63%	29.47%	71.58%	25.26%	16.84%

Table 6-10 Indirect Economic Loss due to Damage to the Electric System (Percent Monthly GNP) (Continued)

	U.S. Econ. Value Added (Percent)	CAPE ANN		WASATCH	CALIFORNIA		PUGET SOUND	NEW MADRID (M=7.0)			
		Rhode Island	New Hampshire	Utah	Hayward	Fort Tejon	Washington	Arkansas	Tennessee	Kentucky	Mississippi
1 Livestock	0.45%	42.11%	14.47%	35.53%	23.68%	13.16%	47.37%	23.68%	7.89%	3.95%	3.95%
2 Agr. Prod.	1.06%	42.11%	14.47%	35.53%	23.68%	13.16%	47.37%	23.68%	7.89%	3.95%	3.95%
3 AgServ For. Fish	0.11%	42.11%	14.47%	35.53%	23.68%	13.16%	47.37%	23.68%	7.89%	3.95%	3.95%
4 Mining	3.89%	75.79%	26.05%	63.95%	42.63%	23.68%	85.26%	42.63%	14.21%	7.11%	7.11%
5 Construction	5.52%	33.68%	11.58%	28.42%	18.95%	10.53%	37.89%	18.95%	6.32%	3.16%	3.16%
6 Food Tobacco	2.41%	75.79%	26.05%	63.95%	42.63%	23.68%	85.26%	42.63%	14.21%	7.11%	7.11%
7 Textile Goods	0.37%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
8 Misc Text. Prod.	0.73%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
9 Lumber & Wood	0.52%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
10 Furniture	0.34%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
11 Pulp & Paper	0.87%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
12 Print & Publish	1.31%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
13 Chemical & Drugs	1.40%	75.79%	26.05%	63.95%	42.63%	23.68%	85.26%	42.63%	14.21%	7.11%	7.11%
14 Petrol. Refining	0.96%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
15 Rubber & Plastic	1.03%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
16 Leather Prods.	0.12%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
17 Glass Stone Clay	0.62%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
18 Prim. Metal Prod.	1.04%	75.79%	26.05%	63.95%	42.63%	23.68%	85.26%	42.63%	14.21%	7.11%	7.11%
19 Fab. Metal Prod.	1.64%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
20 Mach. Exc. Elec.	1.56%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
21 Elec. & Electron	2.52%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
22 Transport Eq.	2.62%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
23 Instruments	0.68%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
24 Misc. Manufact.	0.69%	84.21%	28.95%	71.05%	47.37%	26.32%	94.74%	47.37%	15.79%	7.89%	7.89%
25 Transp & Whse.	3.46%	25.26%	8.68%	21.32%	14.21%	7.89%	28.42%	14.21%	4.74%	2.37%	2.37%
26 Utilities	5.89%	67.37%	23.16%	56.84%	37.89%	21.05%	75.79%	37.89%	12.63%	6.32%	6.32%
27 Wholesale Trade	5.63%	75.79%	26.05%	63.95%	42.63%	23.68%	85.26%	42.63%	14.21%	7.11%	7.11%
28 Retail Trade	5.63%	75.79%	26.05%	63.95%	42.63%	23.68%	85.26%	42.63%	14.21%	7.11%	7.11%
29 F.I.R.E.	16.64%	75.79%	26.05%	63.95%	42.63%	23.68%	85.26%	42.63%	14.21%	7.11%	7.11%
30 Pers./Prof Serv.	8.03%	75.79%	26.05%	63.95%	42.63%	23.68%	85.26%	42.63%	14.21%	7.11%	7.11%
31 Eating Drinking	2.12%	67.37%	23.16%	56.84%	37.89%	21.05%	75.79%	37.89%	12.63%	6.32%	6.32%
32 Auto Serv.	1.09%	75.79%	26.05%	63.95%	42.63%	23.68%	85.26%	42.63%	14.21%	7.11%	7.11%
33 Amuse & Rec.	0.70%	67.37%	23.16%	56.84%	37.89%	21.05%	75.79%	37.89%	12.63%	6.32%	6.32%
34 Health Ed. Soc.	6.30%	67.37%	23.16%	56.84%	37.89%	21.05%	75.79%	37.89%	12.63%	6.32%	6.32%
35 Govt & Govt Ind.	11.79%	50.53%	17.37%	42.63%	28.42%	15.79%	56.84%	28.42%	9.47%	4.74%	4.74%
36 Households	0.25%	67.37%	23.16%	56.84%	37.89%	21.05%	75.79%	37.89%	12.63%	6.32%	6.32%

Table 6-11 Indirect Economic Loss due to Damage to the Highway System (Percent Monthly GNP)

	U.S. Econ Value Added (Percent)	*New Madrid (M8.0)*	*Charleston*	*Cape Ann*	*Wasatch*	*Hayward*	*Fort Tejon*	*Puget Sound*	*New Madrid (M=7.0)*
1 Livestock	0.45%	85.53%	36.84%	78.95%	83.96%	42.11%	52.63%	60.53%	63.16%
2 Agr. Prod.	1.06%	136.84%	58.95%	126.32%	134.34%	67.37%	84.21%	96.84%	101.05%
3 AgServ For. Fish	0.11%	136.84%	58.95%	126.32%	134.34%	67.37%	84.21%	96.84%	101.05%
4 Mining	3.89%	59.87%	25.79%	55.26%	58.77%	29.47%	36.84%	42.37%	44.21%
5 Construction	5.52%	68.42%	29.47%	63.16%	67.17%	33.68%	42.11%	48.42%	50.53%
6 Food Tobacco	2.41%	136.84%	58.95%	126.32%	134.34%	67.37%	84.21%	96.84%	101.05%
7 Textile Goods	0.37%	128.29%	55.26%	118.42%	125.94%	63.16%	78.95%	90.79%	94.74%
8 Misc Text. Prod.	0.73%	128.29%	55.26%	118.42%	125.94%	63.16%	78.95%	90.79%	94.74%
9 Lumber & Wood	0.52%	153.95%	66.32%	142.11%	151.13%	75.79%	94.74%	108.95%	113.68%
10 Furniture	0.34%	128.29%	55.26%	118.42%	125.94%	63.16%	78.95%	90.79%	94.74%
11 Pulp & Paper	0.87%	136.84%	58.95%	126.32%	134.34%	67.37%	84.21%	96.84%	101.05%
12 Print & Publish	1.31%	128.29%	55.26%	118.42%	125.94%	63.16%	78.95%	90.79%	94.74%
13 Chemical & Drugs	1.40%	136.84%	58.95%	126.32%	134.34%	67.37%	84.21%	96.84%	101.05%
14 Petrol. Refining	0.96%	153.95%	66.32%	142.11%	151.13%	75.79%	94.74%	108.95%	113.68%
15 Rubber & Plastic	1.03%	128.29%	55.26%	118.42%	125.94%	63.16%	78.95%	90.79%	94.74%
16 Leather Prods.	0.12%	128.29%	55.26%	118.42%	125.94%	63.16%	78.95%	90.79%	94.74%
17 Glass Stone Clay	0.62%	128.29%	55.26%	118.42%	125.94%	63.16%	78.95%	90.79%	94.74%
18 Prim. Metal Prod.	1.04%	136.84%	58.95%	126.32%	134.34%	67.37%	84.21%	96.84%	101.05%
19 Fab. Metal Prod.	1.64%	136.84%	58.95%	126.32%	134.34%	67.37%	84.21%	96.84%	101.05%
20 Mach. Exc. Elec.	1.56%	136.84%	58.95%	126.32%	134.34%	67.37%	84.21%	96.84%	101.05%
21 Elec. & Electron	2.52%	128.29%	55.26%	118.42%	125.94%	63.16%	78.95%	90.79%	94.74%
22 Transport Eq.	2.62%	136.84%	58.95%	126.32%	134.34%	67.37%	84.21%	96.84%	101.05%
23 Instruments	0.68%	136.84%	58.95%	126.32%	134.34%	67.37%	84.21%	96.84%	101.05%
24 Misc. Manufact.	0.69%	128.29%	55.26%	118.42%	125.94%	63.16%	78.95%	90.79%	94.74%
25 Transp & Whse.	3.46%	136.84%	58.95%	126.32%	134.34%	67.37%	84.21%	96.84%	101.05%
26 Utilities	5.89%	68.42%	29.47%	63.16%	67.17%	33.68%	42.11%	48.42%	50.53%
27 Wholesale Trade	5.63%	119.74%	51.58%	110.53%	117.54%	58.95%	73.68%	84.74%	88.42%
28 Retail Trade	5.63%	94.08%	40.53%	86.84%	92.36%	46.32%	57.89%	66.58%	69.47%
29 F.I.R.E.	16.64%	76.97%	33.16%	71.05%	75.56%	37.89%	47.37%	54.47%	56.84%
30 Pers./Prof Serv.	8.03%	76.97%	33.16%	71.05%	75.56%	37.89%	47.37%	54.47%	56.84%
31 Eating Drinking	2.12%	85.53%	36.84%	78.95%	83.96%	42.11%	52.63%	60.53%	63.16%
32 Auto Serv.	1.09%	94.08%	40.53%	86.84%	92.36%	46.32%	57.89%	66.58%	69.47%
33 Amuse & Rec.	0.70%	85.53%	36.84%	78.95%	83.96%	42.11%	52.63%	60.53%	63.16%
34 Health Ed. Soc.	6.30%	94.08%	40.53%	86.84%	92.36%	46.32%	57.89%	66.58%	69.47%
35 Govt & Govt Ind.	11.79%	51.32%	22.11%	47.37%	50.38%	25.26%	31.58%	36.32%	37.89%
36 Households	0.25%	68.42%	29.47%	63.16%	67.17%	33.68%	42.11%	48.42%	50.53%

Table 6-12 Indirect Economic Losses Due to Damage to Lifeline Transmission Systems

Scenario Earthquakes	Natural Gas		Crude Oil		Refined Oil		Air Transportation		Railroads		Ports		Electric		Water		Highways	
	%	$ Bil	%	$ Bil	%	$ Bil	%	$ Bil	%	$ Bil	%	$ Bil	%	$ Bil	%	$ Bil	%	$ Bil
Cape Ann		$0.00		$0.00		$0.00	0.12	$0.49	0.01	$0.02	0.11	$0.45	2.20	$8.95	N/A	N/A	0.16	$0.65
Charleston		$0.00		$0.00		$0.00	0.11	$0.45	0.01	$0.02	1.21	$4.92	2.15	$8.75	N/A	N/A	0.08	$0.33
Fort Tejon	0.41	$1.67	1.07	$4.35		$0.00	0.35	$1.42	0.06	$0.25	0.61	$2.48	1.90	$7.73	1.2	$4.88	1.10	$4.47
Hayward	0.22	$0.89		$0.00		$0.00	0.10	$0.41	0.03	$0.11	0.33	$1.34	2.43	$9.88	1	$4.07	0.50	$2.03
Madrid, MO M=8	0.07	$0.28	0.10	$0.41	0.05	$0.20	0.2	$0.81	0.06	$0.25		$0.00	2.55	$10.37	N/A	N/A	2.30	$9.36
Madrid, MO M=7	0.04	$0.16	0.03	$0.11	0.04	$0.15	0.04	$0.16	0.01	$0.04		$0.00	0.81	$3.29	N/A	N/A	0.84	$3.42
Puget Sound	0.05	$0.20		$0.00		$0.00	0.10	$0.41	0.03	$0.11	0.13	$0.53	1.43	$5.82	0.19	$0.77	0.27	$1.10
Wasatch Front	0.01	$0.38		$0.00		$0.00	0.02	$0.08	0.01	$0.02		$0.00	0.40	$1.63	N/A	N/A	0.80	$3.25

Scenario Earthquakes	ESTIMATED TOTAL ECONOMIC LOSS/EVENT		
	Lower Bound	Upper Bound	Best Estimate
Cape Ann	$8.95	$10.56	$9.00
Charleston	$8.75	$14.46	$10.05
Fort Tejon	$7.73	$27.26	$11.56
Hayward	$9.88	$18.73	$11.01
Madrid, MO M=8	$10.37	$21.69	$14.00
Madrid, MO M=7	$3.42	$7.33	$4.76
Puget Sound	$5.82	$8.94	$6.01
Wasatch Front	$3.25	$5.02	$3.64

Table 6-13 Indirect Economic Losses Due to Damage to Lifeline Distribution Systems

	Electric		Water		Highways		
Scenario Earthquakes	%	$ Bil	%	$ Bil	%	$ Bil	SRSS
Cape Ann	0.32	$1.3	0.15	$.61	0.21	$0.86	$1.6
Charleston	0.27	$1.1	0.15	$.63	0.17	$0.71	$1.4
Fort Tejon	0.34	$1.4	0.11	$.47	0.08	$0.33	$1.5
Hayward	0.37	$1.5	0.10	$.41	0.09	$0.36	$1.6
New Madrid, M=8	0.76	$3.1	0.44	$1.8	0.49	$2.0	$4.1
New Madrid, M=7	0.23	$1.0	0.14	$.57	0.15	$0.63	$1.3
Puget Sound	0.22	$0.9	0.04	$.18	0.10	$0.40	$1.0
Wasatch Front	0.15	$0.6	0.06	$.27	0.09	$0.37	$1.25

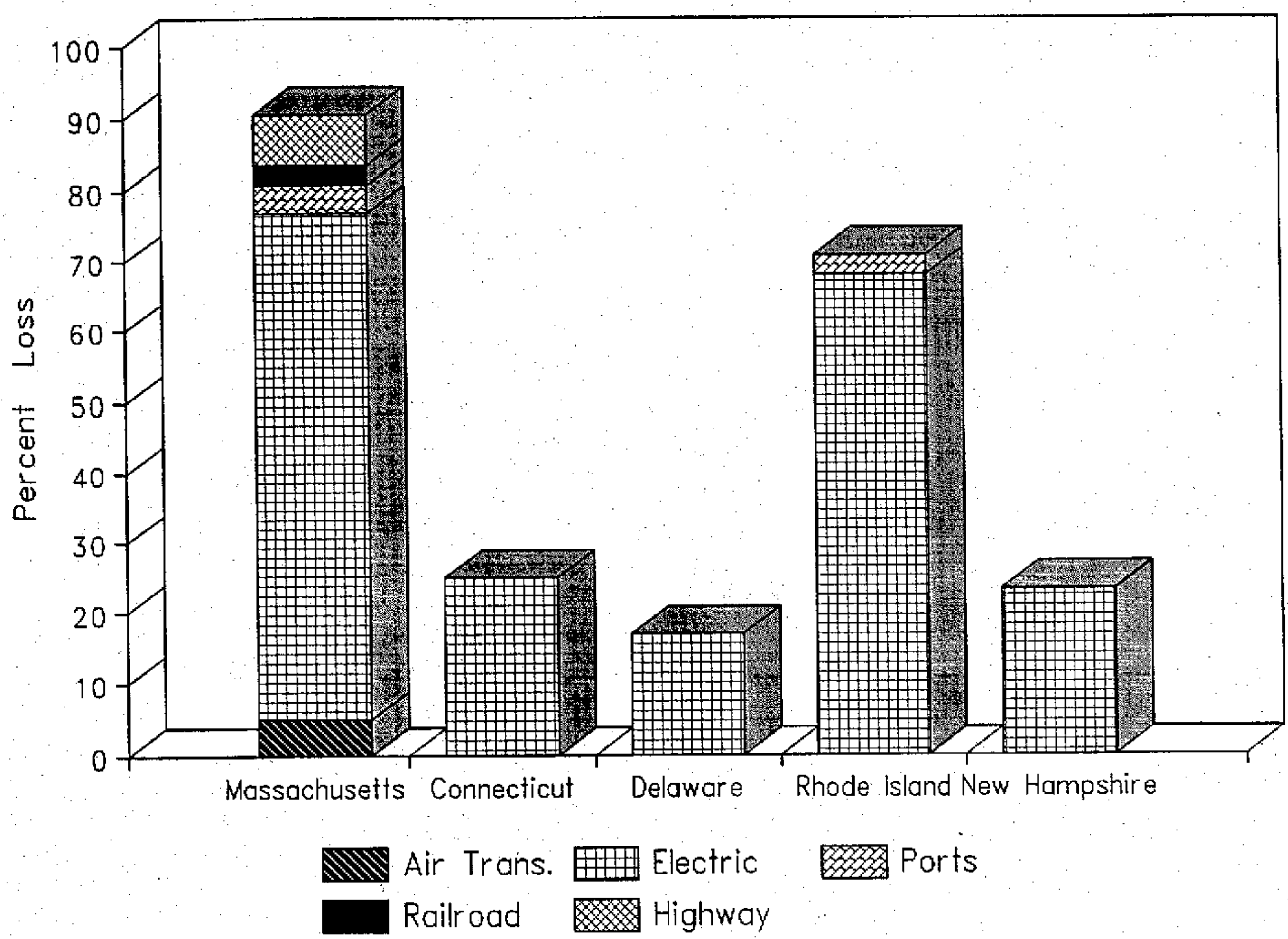


Figure 6-21 *Percent indirect economic loss by state (monthly GNP) resulting from damage to various lifelines, Cape Ann event (M=7.0).*

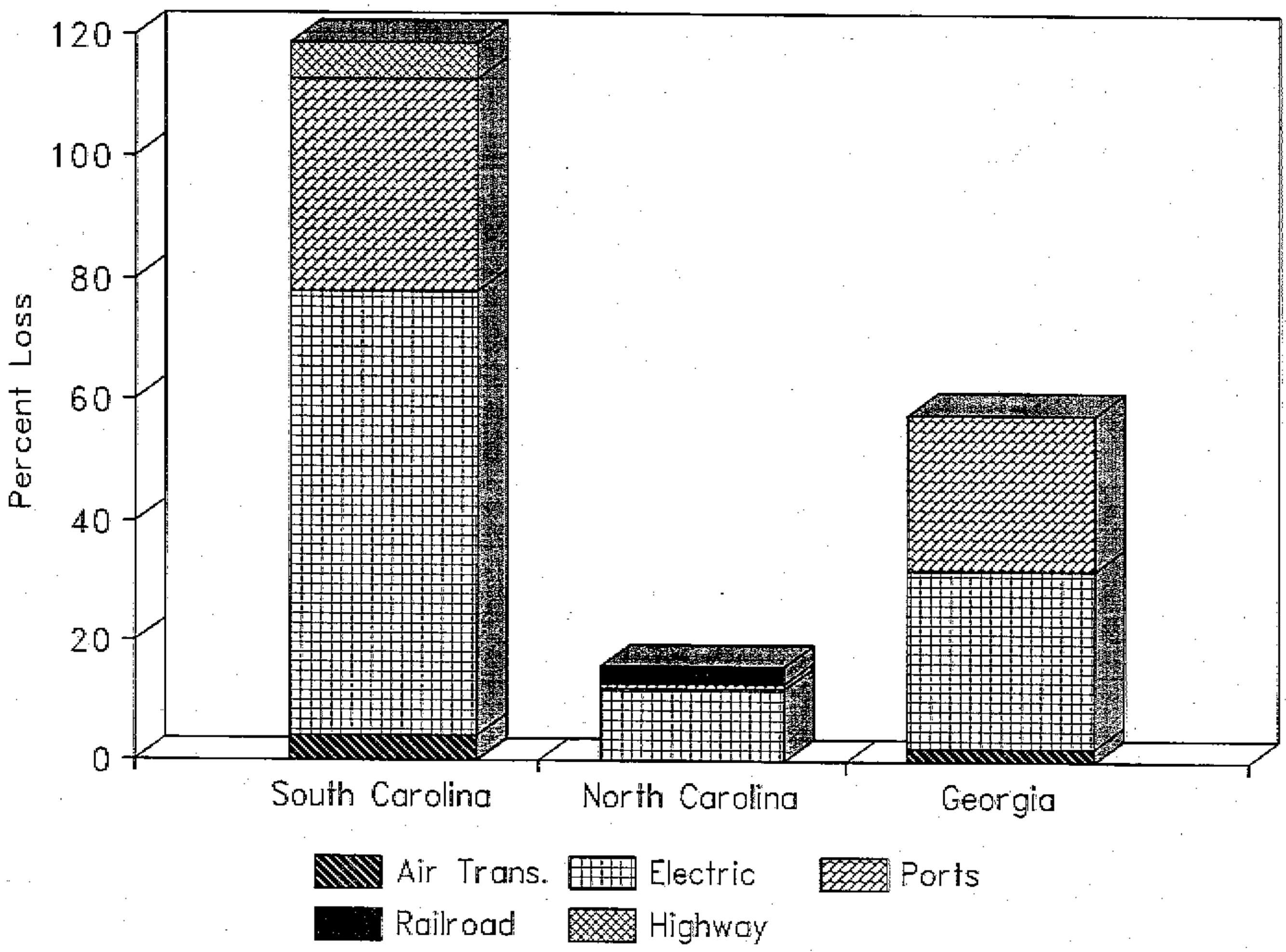


Figure 6-22. Percent indirect economic loss by state (monthly GNP) resulting from damage to various lifelines, Charleston event (M=7.5).

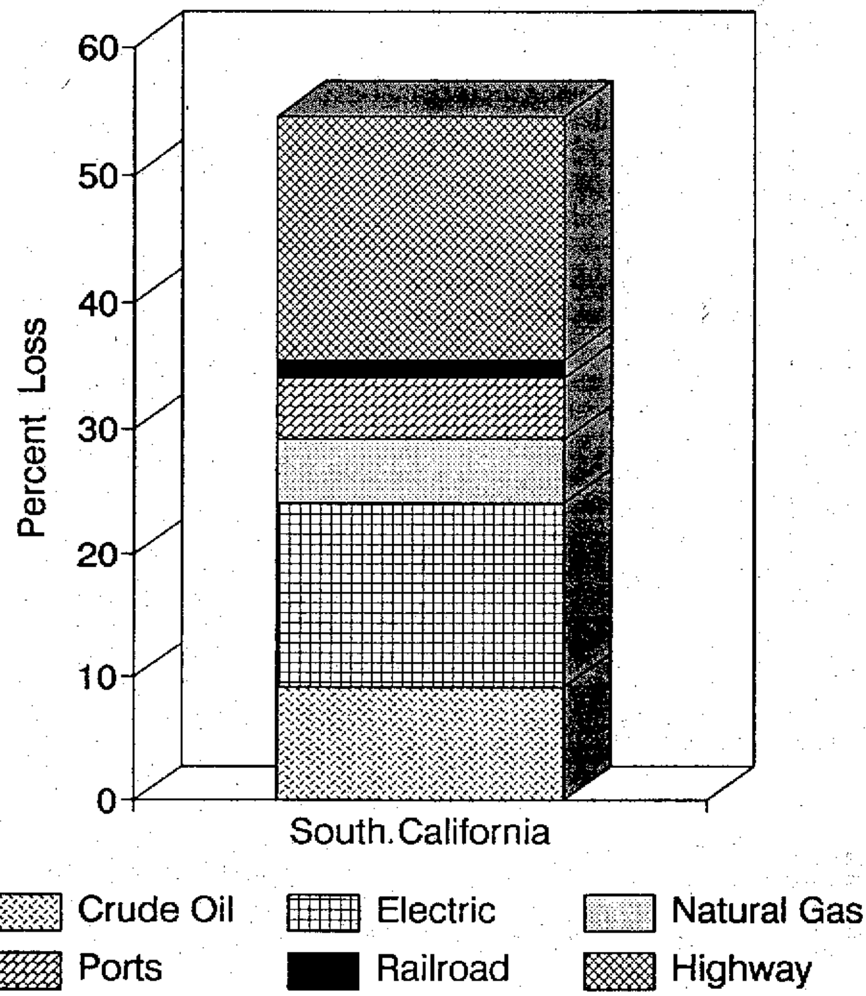


Figure 6-23 *Percent indirect economic loss in Southern California (monthly GNP) resulting from damage to various lifelines, Fort Tejon event (M=8.0).*

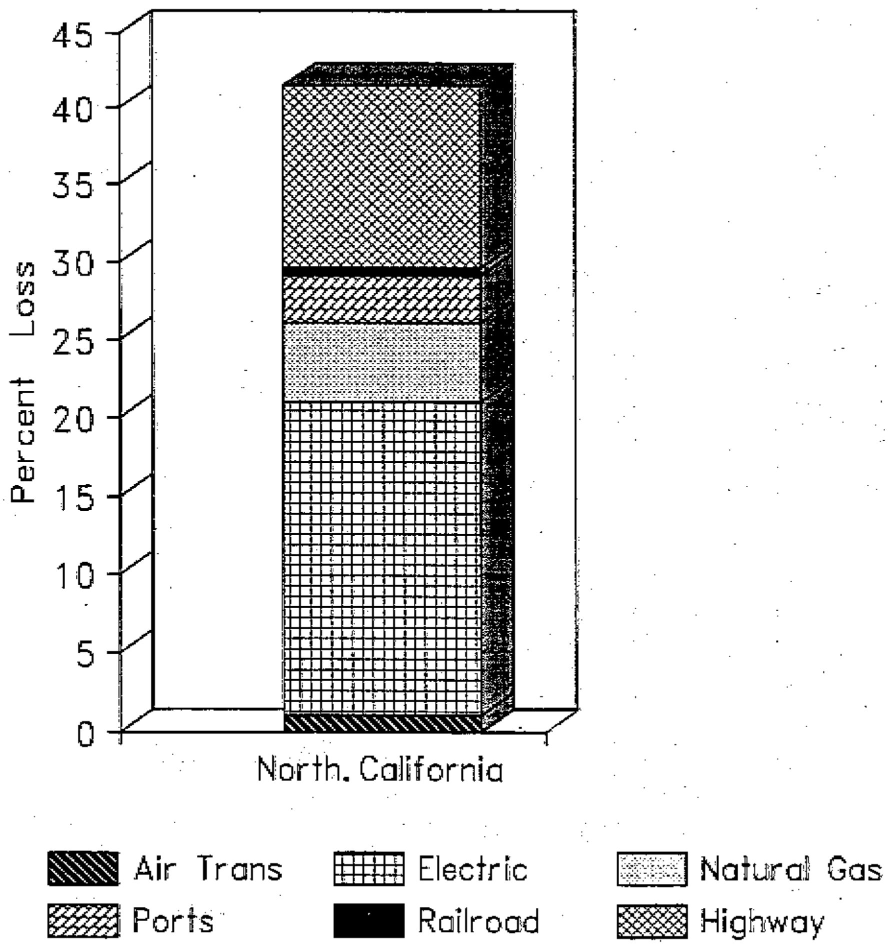


Figure 6-24 *Percent indirect economic loss in Northern California (monthly GNP) resulting from damage to various lifelines, Hayward event (M=7.5).*

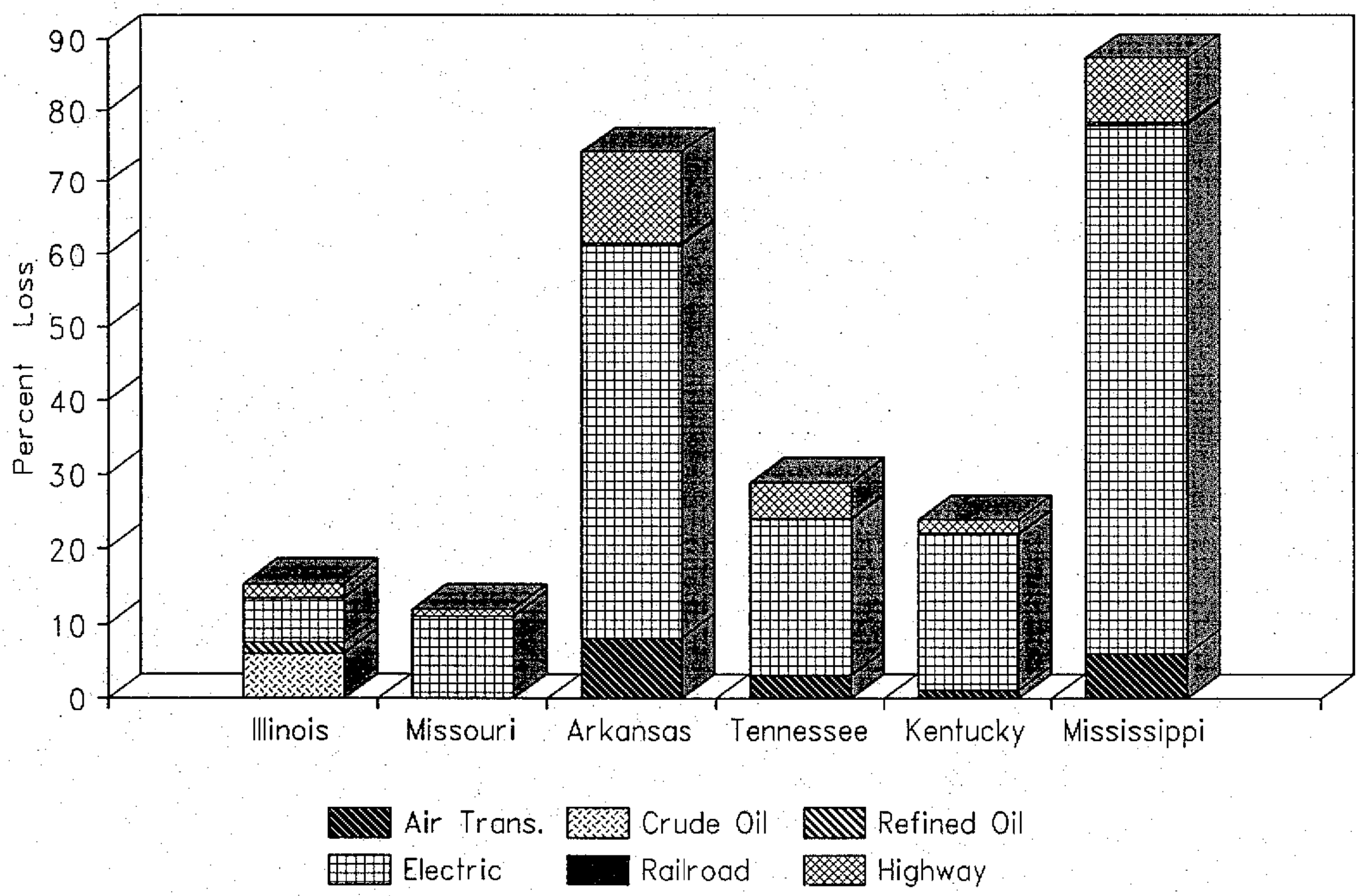


Figure 6-25 *Percent indirect economic loss by state (monthly GNP) resulting from damage to various lifelines, New Madrid event (M=8.0). Note that the relatively low losses for Missouri reflect the assumed location of the scenario earthquake source zone and the estimated distribution of intensity (see Figure 4-17).*

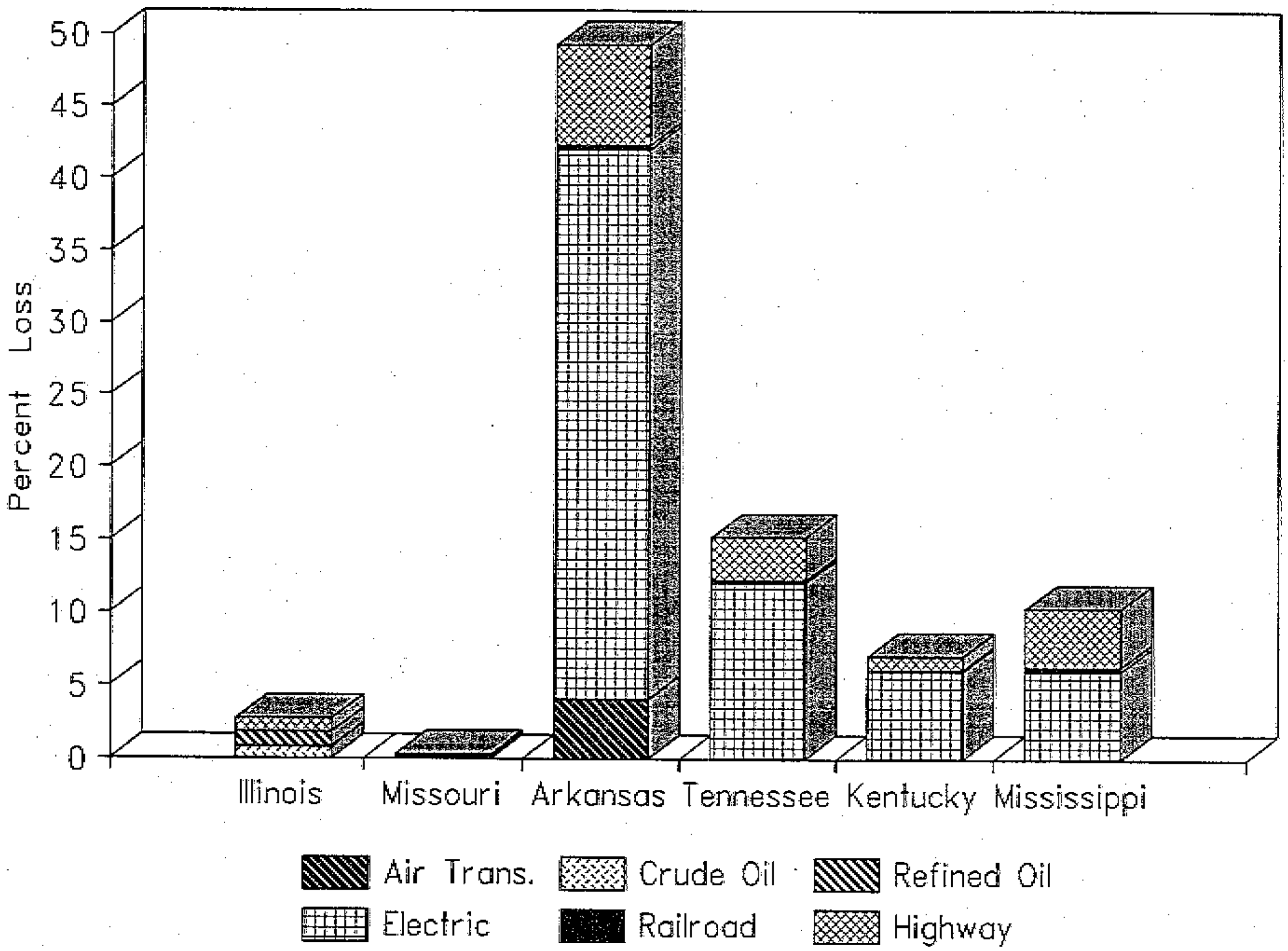


Figure 6-26 *Percent indirect economic loss by state (monthly GNP) resulting from damage to various lifelines, New Madrid event (M=7.0). Note that the relatively low losses for Missouri reflect the assumed location of the scenario earthquake source zone and the estimated distribution of intensity (see Figure 4-18).*

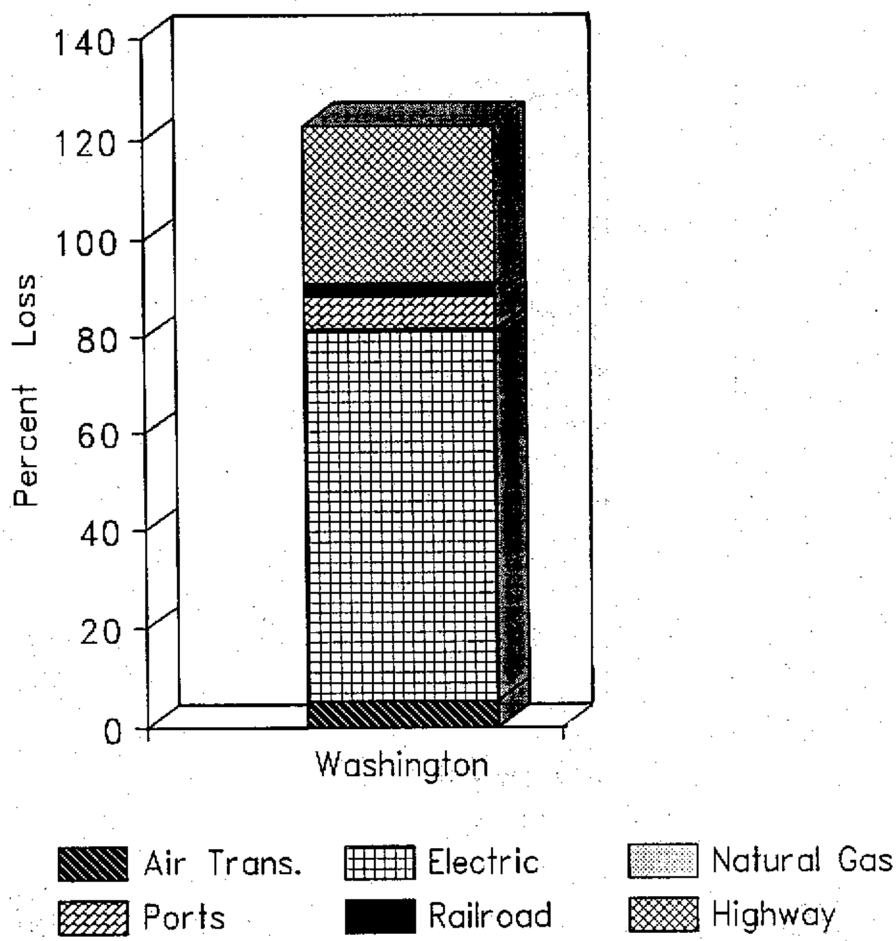


Figure 6-27 *Percent indirect economic loss in state of Washington (monthly GNP) resulting from damage to various lifelines, Puget Sound event (M=7.5).*

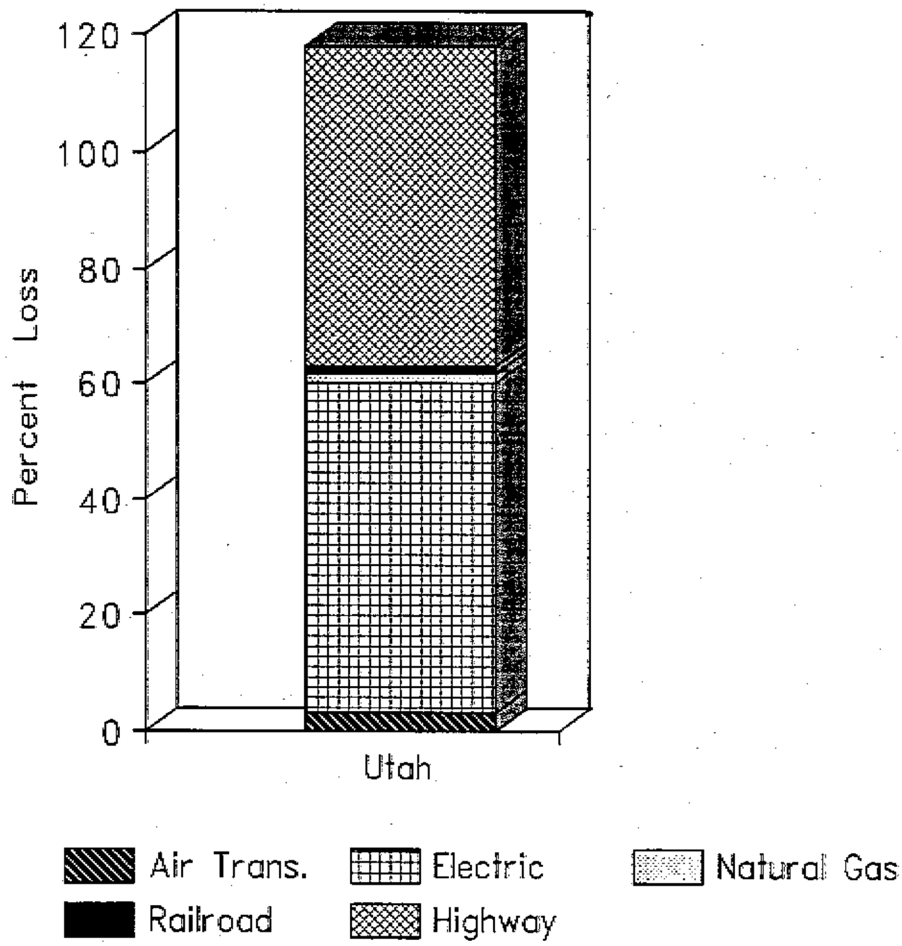


Figure 6-28 *Percent indirect economic loss in state of Utah (monthly GNP) resulting from damage to various lifelines, Wasatch Front event (M=7.5).*