

RISKS AND RECOVERIES FROM EXTREME DISRUPTIONS IN FREIGHT TRANSPORTATION SYSTEM IN A MEGACITY: CASE STUDY FOR THE GREATER LOS ANGELES AREA

FINAL REPORT

METRANS Project 09-29

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Abstract

Many megacities are exposed to natural hazards such as earthquakes, and, when located on coastal regions, are also vulnerable to hurricanes and tsunamis. The physical infrastructures of transportation systems in megacities have become so complicated that very few organizations can understand their response to extreme events such as earthquakes and can effectively mitigate subsequent economic downfalls. The technological advances made in recent years to support these complex systems have not grown as fast as the rapid demand on these systems burdened by population shift toward megacities.

The objective of this research is to examine the risks imposed on and recoveries of transportation systems in megacities as the result of extreme events such as earthquakes. It also addresses the economic impact due to earthquake scenarios locally as well as nationwide. REDARS software is used to estimate disruption level of earthquake on roadways and bridges. The integrated model consisting of a macroscopic terminal simulator, microscopic traffic simulator, and terminal cost model is developed to estimate the changes in traffic flows due to earthquake and evaluate the economic impact at the local level. Macroscopic terminal simulator is used to model trucks' movement inside container terminals. Road network adjacent to the container terminal are constructed by microscopic traffic flow simulator (VISSIM) and is connected to sea-ports. Also, terminal operational cost model is developed to evaluate additional terminal costs due to disruptions to traffic flows. All three models are integrated with each other, so that various disruption scenarios can be evaluated using the integrated model. NIEMO software is used to evaluate the economic impact of extreme events globally. Southern California is regarded as the region of study and results demonstrate the efficiency of the integrated model. The model can be used to evaluate any other disruptions to sea-ports such as terrorist attack or tsunami.

1 Introduction

Megacities have infrastructure systems that have become excessively complex in attempts to provide their residents with a healthy and safe place to live and work. Engineers face tremendous challenges with the increasing complexities of transportation systems in megacities, the unprecedented pressures of population growth, energy and environmental impacts, and risks from natural and manmade hazards. Cities function through complex interactions between people and social systems, infrastructure systems, business and industry, and the environment. Today these complex interdependencies are so poorly understood that urban transportation systems are likely to respond unpredictably to extreme events, such as the loss of a major transportation node through a major structural collapse or more widespread devastation stemming from a natural disaster. Many megacities are exposed to natural hazards such as earthquakes, and, when located on coastal regions, are also vulnerable to hurricanes and tsunamis. The physical infrastructures of transportation systems in megacities have become so complicated that very few organizations can understand their response to extreme events such as earthquakes and can effectively mitigate subsequent economic downfalls. The technological advances made in recent years to support these complex systems have not grown as fast as the rapid demand on these systems burdened by population shift toward megacities.

The objective of this research is to examine the risks imposed on and recoveries of transportation systems in megacities as the result of extreme events (EE) such as earthquakes. The research assesses risks not only in terms of physical damage to transportation infrastructure (e.g., bridges) and loss of system performance (e.g., decrease in transport capacity and traffic delays during recovery), but also in economic terms relevant to major stakeholders (e.g., freight transport to and from the Ports of Los Angeles and Long Beach) likely to experience the greatest economic losses. This economic perspective focuses on development of an integrated engineering-economic framework leading to meaningful financial incentives for various stakeholders and supporting broad financial support for infrastructure systems. This economic perspective is necessary to build private-public partnerships and pay for the maintenance, upgrade, and development of transportation infrastructure. The Los Angeles Region is an ideal laboratory for the exploration of this research. Los Angeles is the second largest city in the U.S., and its economy and way of life is highly dependent on its surface transportation, most notably automobiles and trucks. It contains the largest container port complex in the country, processing 40 percent of U.S. imports. Southern California is highly vulnerable to natural disasters such as earthquakes and man-made disasters such as terrorism. A disruption of its transportation systems would cripple its ports and freight mobility. Major damage to key portions

of its transportation network would isolate the port and render it dysfunctional. Failure to transportation systems will potentially cause cascading failures within the region and ripple throughout the U.S. Figure 1 represents general area of study and Ports of LA/LB. The main focus of this research is the area next to twin ports. The components and network connectivity are defined in REDARS2 (Werner et al., 2006) for the area under investigation.

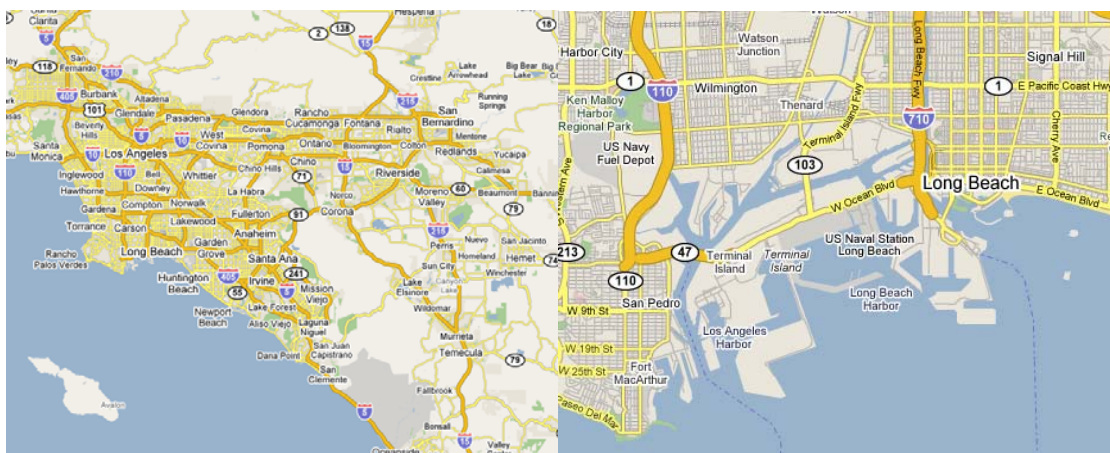


Figure 1: General area of study and area next to the Ports of LA/LB.

2 REDARS ANALYSIS OF HIGHWAY SYSTEM RISKS

This chapter provides initial estimates of risks and losses due to earthquake-induced damage to the highway system throughout the various Southern California counties considered in this project. These estimates are provided for three different scenario earthquakes -- a M_w 7.8 earthquake along the southern San Andreas Fault, a M_w 7.2 earthquake along the Newport-Inglewood Fault, and a M_w 7.0 earthquake along the Palos Verdes Fault. For each earthquake, system-wide ground motions have been estimated as described elsewhere in this report.

These estimates of highway system risks and losses have been evaluated using the REDARS methodology for deterministic seismic risk analysis (SRA) of highway systems. Within this METRANS project, the results from these REDARS analyses are intended to represent first level estimates of system-wide bridge damage, costs and times to restore system-wide traffic flows, and economic losses from disruption of passenger and freight traffic. The remainder of chapter contains four sections that summarize the REDARS methodology, assumptions of limitations of this analysis, and the analysis results for each earthquake, and then provide concluding comments.

2.1 REDARS OVERVIEW

Figure 2 shows the steps of the REDARS methodology for deterministic SRA of a highway system subjected to a specified earthquake. These steps are described in more detail elsewhere (e.g., Werner et al., 2006).

- **Seismic Hazards.** For the specified earthquake, seismic hazard models built into REDARS are used to compute the hazards at the site of each highway component (i.e., each bridge, tunnel, and roadway element). Alternatively, seismic hazards computed outside of REDARS can be directly input into REDARS.
- **Component Damage States.** Default fragility models are used to compute the damage state of each component throughout the highway system due to the above seismic hazards. REDARS currently uses the HAZUS fragility models as default models for this purpose in which, for deterministic applications, the median (50th percentile) damage state for the component is used. For bridges that have been retrofitted by column jacketing, capacity enhancement factors developed by Shinozuka (2004) are incorporated.
- **Post-Earthquake System States.** A default repair model is applied to each damaged component in order to estimate the cost and time for repair of the component, along with each component's traffic state (i.e., whether it is closed, partially open, or fully open to traffic as the repairs proceed). Then, each component's traffic state at various post-earthquake times is mapped into the highway system, in order to obtain overall system states that show which highway links are closed to traffic at each post-earthquake time.
- **Post-Earthquake Traffic Impacts.** Transportation analysis procedures are applied to each post-earthquake system state to estimate traffic congestion due to the links throughout the system that are fully or partially closed to traffic at that post-earthquake time. In addition, effects of this increased traffic congestion -- i.e., increases in travel times and reductions in traffic flows and trip demands on the system -- are also estimated.
- **Losses due to Earthquake-Induced Traffic Disruption.** The traffic disruptions estimated in the previous step are used to estimate corresponding losses. These can include economic losses (due to repair costs, increases in travel time, and reduced trip demands) as well as delays in travel time to/from key destinations or along key routes (e.g., transportation lifeline routes) that could impact emergency response and recovery.

and choice of route.

Another important factor when using economic loss results for decision-making is evaluation of impacts of the highway-system damage on stakeholders. Future development of economic models should include assessment of who gains (e.g., construction industry) and who loses (e.g., business sectors heavily dependent on trucking to distribute goods) in the event of such damage.

2.2.1 General Approach for Developing Default Loss Estimates

REDARS provides default parameters for estimating repair costs and losses due to travel-time delays and trips foregone. These parameters are based on construction practices, repair resources (i.e., materials, equipment, and labor), and earthquake-repair experience in California. Their selection as the REDARS default repair model was motivated by the extensive post-earthquake repair experience of the California Department of Transportation, which was viewed as a reasonable starting point for developing repair models for highway systems in other parts of the country.

2.2.2 Loss Sources

2.2.2.1 Repair Costs

REDARS expresses default repair costs as percentages of the estimated total replacement cost for the component. These percentages will depend on the component's earthquake-induced damage state. The replacement cost is computed as the product of a unit cost and an effective area of the component. The effective area, in turn, is represented as the product of the component's length and its effective width, which will depend on the component type.

2.2.2.2 Losses Due to Travel-Time Delays and Trips Foregone

The REDARS variable-demand network-analysis procedure represents how increased traffic congestion due to earthquake damage affects travel times throughout the system as well as trip demands on the system. That is, it accounts for possible increases in travel times and reductions in trip demands relative to the pre-earthquake conditions, as the level of traffic congestion increases. It also recognizes that different types of trips throughout the system (i.e., automobile trips and various types of freight trips) will have different economic values, and therefore estimates separate travel-time delays and trips foregone for each trip type.

Figure 3 shows how these losses are computed. In this figure, the highway systemic congestion due to earthquake damage affects travel times throughout the sS_1 , and the corresponding system-wide travel times and trip demands are represented by the parameters P_1 , and D_1 respectively. After the earthquake occurs, the system demands are represented by the parameter P_2 , its travel times increase to P_2' its travel times increase to P_{2k2} .

The economic losses due to travel-time increases and trip reductions are computed as the product of a unit loss and the area of the trapezoid in Figure 3 that is defined by P_1 and P_2' and D_1 and D_2 . Within this trapezoid, the losses due to travel-time increases are represented by the area of the rectangle that is defined by P_1 , P_2' , and D_2 . The corresponding losses due to trips foregone are represented by the area of the triangle defined by P_1 and P_2' and P_1 and D_2 multiplied by the unit loss.

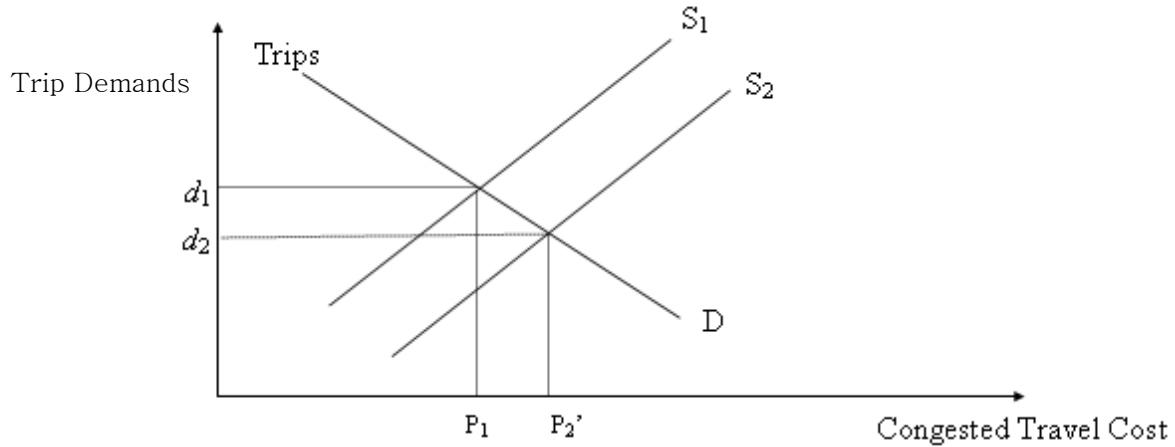


Figure 3: Variable Demand Model for Earthquake-Damaged Highway System

2.2.3 Unit Losses

In this approach, the unit loss represents the cost (in dollars per hour per passenger-car-unit) of the travel-time delays and trips foregone. These unit losses will depend on the type of trip (i.e., automobile vs. freight type 1, freight type 2, etc.) and will also vary for different regions of the United States. Werner et al. (2000) used a unit-cost estimation procedure that Caltrans applied to estimate economic losses due to disruption of the Los-Angeles area highway system by the 1994 Northridge Earthquake. This procedure applies user-specified estimates of such factors as vehicle occupancy rates, truck-trip dollar value, cost of excess fuel, etc. to develop these unit costs.

The default unit costs that are currently used in REDARS are based on data for the greater Los Angeles area that were based on traffic-congestion statistics developed by the Rand Corporation of California (and obtained from

their website, <http://ca.rand.org>). Based on these studies, REDARS uses default unit losses of \$13.45/(pcu-hour) for automobile trips and \$71.05/(pcu-hour) for commercial-vehicle (freight-transport) trips.

These unit costs will vary for different regions of the United States. Therefore, REDARS to regions outside of the greater Los Angeles area should not use the unit-cost values that are given here. Instead, it is important that these users obtain unit-cost values from data sources that are most appropriate for their particular region.

2.3 ASSUMPTIONS AND LIMITATIONS

This deterministic application of REDARS under this METTRANS project is based on the following assumptions that will affect the estimated bridge damage, repair costs, and downtimes, and the resulting losses due to traffic disruption. These assumptions should be kept in mind when reviewing the results of these analyses:

- **Seismic Hazards.** These analyses consider hazards from ground motions only. Liquefaction, surface fault rupture, and landside hazards are excluded from the analyses.
- **Component Fragility Models.** These analyses consider damage to bridges only. Damage to other highway components -- roadways, approach fills, and tunnels -- are excluded from the analyses. In addition, damage to all bridges throughout the highway system is estimated from the default bridge fragility models contained in REDARS, which are the HAZUS bridge models with modification to account for effects of column jacketing retrofit as summarized in Section 2.1. User-specified models for individual highway components have not been developed under this project. The HAZUS model characterizes bridge damage in terms of the damage state definitions shown in Table 1.
- **Bridge Retrofit Data.** Identification of those bridges throughout the Los Angeles highway system that have been column jacketed is based on data provided by Caltrans in 2005. Since that time, other bridges throughout the system have also been column jacketed. These additional retrofits are not considered in these analyses. Also, this data indicates column jacket retrofit has been carried out at only a surprisingly small number of older bridges within the dense highway network in the central to western areas of Los Angeles. Effects of any other type of seismic upgrade of these bridges that may have been carried out are not considered in these analyses. This should be reviewed with Caltrans.
- **Bridge Downtimes.** Damaged bridge repair costs and downtimes are estimated from the REDARS default bridge repair model for California bridges that was established in close collaboration with Caltrans bridge maintenance engineers in 2005 (Table 2). These downtimes do not account for the time needed to mobilize

repair resources (materials, equipment, and labor) at the sites of the various damaged bridges. That is, it is assumed that repair resources can be immediately mobilized at the sites of all damaged components following an earthquake. This assumption will under-estimate the damaged bridge downtimes, particularly for earthquakes that damage many bridges throughout the highway system. This under-estimation of these downtimes will result in an under-estimation of the losses due to post-earthquake traffic disruption.

- **Assessment of Results.** These REDARS analyses have been carried out under a limited budget that has constrained interpretation of certain input data, model assumptions, and analysis results that warrant further assessment in our opinion. This is further discussed later in this chapter.

Table 1: Assumed Repair Consequences and Strategies for Each Bridge Damage State

Damage State	Repair Consequences and Strategies
1 (None)	No repair costs or interruption of traffic.
2 (Slight)	Minor repair costs but no shoring is needed. No interruption of traffic.
3 (Moderate)	Bridge damage is repairable, but shoring will be needed before repairs proceed. Shoring must be sufficient to totally support all dead loads and full traffic loads during repairs. Any jacking/ramping needed at locations of moderate settlement and offset will be done while shoring is proceeding. Bridge will be fully closed to traffic during shoring, and then fully reopened to traffic while repairs proceed. Moderate repair costs will be incurred.
4 (Extensive)	Some bridge elements are irreparably damaged and must be replaced. However, replacement of these elements can occur without replacing entire bridge. Bridge will first be extensively shored so that all dead loads and full pre-earthquake traffic loads are completely supported during replacement of damaged elements. Any jacking or ramping needed at locations of significant offset or settlement will be done while shoring is proceeding. Bridge will be fully closed to traffic during shoring, and then fully reopened to traffic during replacement of damaged elements. Major costs for replacement of damaged elements will be incurred. The shoring requirements for extensively damaged bridges will be more extensive than the shoring for moderately damaged bridges.
5 (Irreparable)	Damage is irreparable and requires replacement of entire bridge.

Table 2: Default Bridge Repair Model used in REDARS (Werner et al., 2006)

Damage State	Number of Bridge Spans	Traffic State	
		Time after Earthquake	Percent of Pre-EQ Traffic Carrying Capacity
1 or 2 (None or Slight)	--	--	--

3 (Moderate)	--	0-4 days	0%
		> 4 days	100%
4 (Extensive)	--	0-12 days	0%
		> 12 days	100%
5 (Irreparable)	3 spans	0-140 days	0%
		> 140 days	100%
	4 spans	0-180 days	0%
		> 180 days	100%
	5 span	0-220 days	0%
		> 220 days	100%

2.4 RESULTS

2.4.1 Overview

The REDARS analyses for each of the three scenario earthquakes for this project used a model of the Southern California highway-roadway system that extends through Los Angeles, Orange, Riverside, San Bernadino, Ventura, Imperial, and San Diego counties. The model contains 156,708 directional links, 52,262 nodes, 4,185 traffic analysis zones (TAZs), and 6,353 bridges. The 4,185 TAZs consist of 4,109 zones within the first six counties listed above, plus external zones outside of these counties. Results from each application of the model include:

- **Ground Motions.** The spatial distribution of the intensity of the ground shaking throughout the surrounding region is mapped. In these displays, the ground shaking intensity is represented in terms of the spectral acceleration at a period of 1.0 sec. termed $S_a(1.0)$, which is the ground motion parameter used by the HAZUS model to estimate bridge damage.
- **Bridge Damage.** Damage to the bridges throughout the highway system is displayed. The HAZUS model defines bridge damage in terms of the following five damage states that are defined in Table 1. Tabulations of the number of bridges in each of these damage states due to each earthquake scenario are also provided.
- **System States.** Post-earthquake system states are displayed at times of 3 days, 4-12 days, and 13-49 days after the earthquake. According to the bridge repair model used in this analysis, the longest closure duration that will be experienced by any link in the system will be 221 days (which will occur if the link contains a long-span bridge that suffers complete (i.e., irreparable) damage).
- **Traffic Flows.** Post-earthquake traffic flows, in terms of passenger-car-units/hour, will be displayed at each of the above post-earthquake times for which system states are displayed.

- **Economic Losses.** Economic losses due to travel time delays and trips foregone are tabulated.

2.4.2 *M_w 7.2 Scenario Earthquake along Newport-Inglewood Fault*

The fault rupture for this scenario earthquake extends through a populated region of central Los Angeles, Long Beach and Orange County where the highway-roadway system is dense. Therefore, many roadways and bridges are located in close proximity to this fault rupture, where the ground shaking is severe.

2.4.2.1 *Ground Motions*

Figure 4a maps the intensity of the ground shaking from this earthquake. This figure shows that the ground shaking is very strong, with $S_a(1.0)$ values at many bridge sites that exceed 0.8 g..

2.4.2.2 *Bridge Damage States*

Figure 4b displays the estimated bridge damage states due to these earthquake ground motions. These results show an extremely large number of irreparably damaged bridges (with Damage State 5), all of which are within about 10 miles of the fault rupture. It turns out that all of these bridges are non-seismically designed bridges (defined in the HAZUS model as bridges constructed before 1973) that also have not been column jacketed. In addition, Table 3 shows that all of these bridges were also subjected to very severe levels of ground shaking.

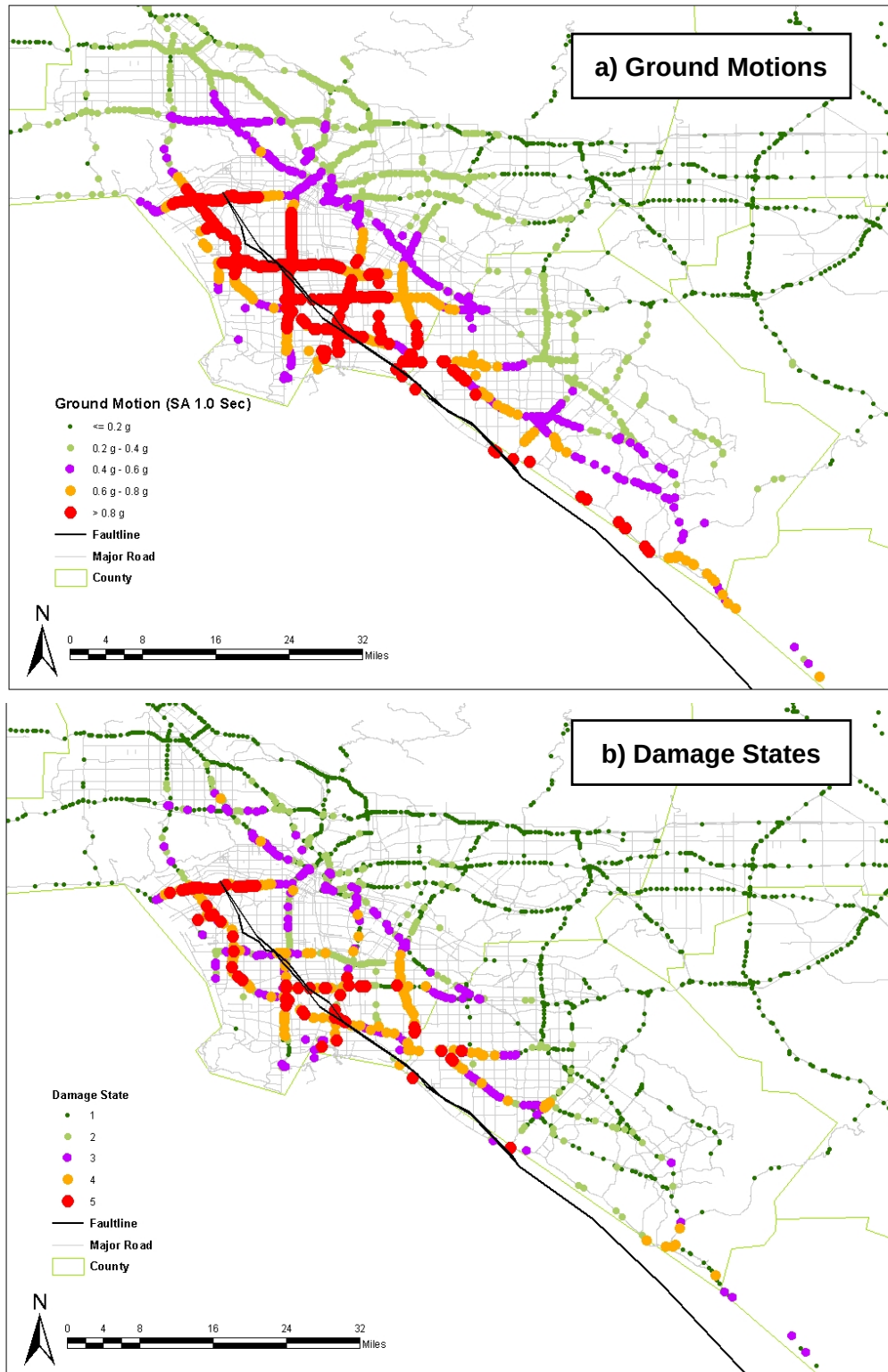


Figure 4: Scenario Earthquake on Newport-Inglewood Fault: Ground Motions and Bridge Damage States

Table 3: Estimated Bridge Damage States due to Scenario Earthquake on Newport-Inglewood Fault

Ground Shaking $S_a(1.0)$, g	Bridge Damage States					Total No. of Bridges
	Damage State 1 (No damage)	Damage State 2 (Slight damage)	Damage State 3 (Moderate damage)	Damage State 4 (Extensive damage)	Damage State 5 (Irreparable damage)	
< 0.20 g	2,903					2,903
0.21 g – 0.40 g	1,238	185	9			1,432
0.41 g – 0.60 g	401	201	231	41		874
0.61 g – 0.80 g	165	111	44	189	14	523
> 0.80 g	18	192	64	250	97	621
Total No. of Bridges	4,725	689	64	480	111	6,353

In view of these factors, one may conclude that it is not surprising that the bridges would be predicted to be severely damaged. However, it is important to recognize that the California Department of Transportation (Caltrans) has over the past few decades been carrying out an extensive seismic retrofit program for bridges throughout California. In view of this, it seems unlikely that this retrofit program would have overlooked the seismic vulnerability of this many non-seismically designed bridges without column jacketing that are in close proximity to the Newport-Inglewood Fault whose potential for a major earthquake is well recognized. Therefore, there may be various aspects of the bridge attributes and input data and HAZUS bridge model limitations that could have affected these bridge damage predictions. These aspects, which should be carefully examined in collaboration with Caltrans engineers, could include:

- Are there structural features of the bridges that cannot be considered by the HAZUS bridge model which could improve their structural performance under severe ground shaking? For example, have there been past seismic retrofits of the pre-1973 bridges other than column jacketing that could have improved their seismic performance?
- Is the input data for these bridges current? For example, over the years since the column jacketing information used in this analysis was obtained from a 2005-vintage Caltrans data base, have any of the bridges been column jacketed since then, which would not be included in this data base?

- Has the seismic response of any of these bridges been evaluated using more detailed and complete analysis procedures than the procedures used in the HAZUS model?

2.4.2.3 System States

Figure 5 shows system states in terms of roadway link closures at post-earthquake times of 3 days, 12 days, 49 days, and 140 days. The rates at which the closed links reopen over time after the earthquake depend on the REDARS default bridge repair model that is shown in Table 2. Figure 5 shows that: (a) all of the closed links are located within 10 miles of the fault rupture; (b) at 12 days after the earthquake, the links along the Golden State Freeway that were closed at 3 days after the earthquake are now reopened, which is because of the lower levels of bridge damage along this freeway that is shown in Figure 5b; (c) at 49 days (and 140 days) after the earthquake, all but a few of the closed links along the bridge are now reopened.

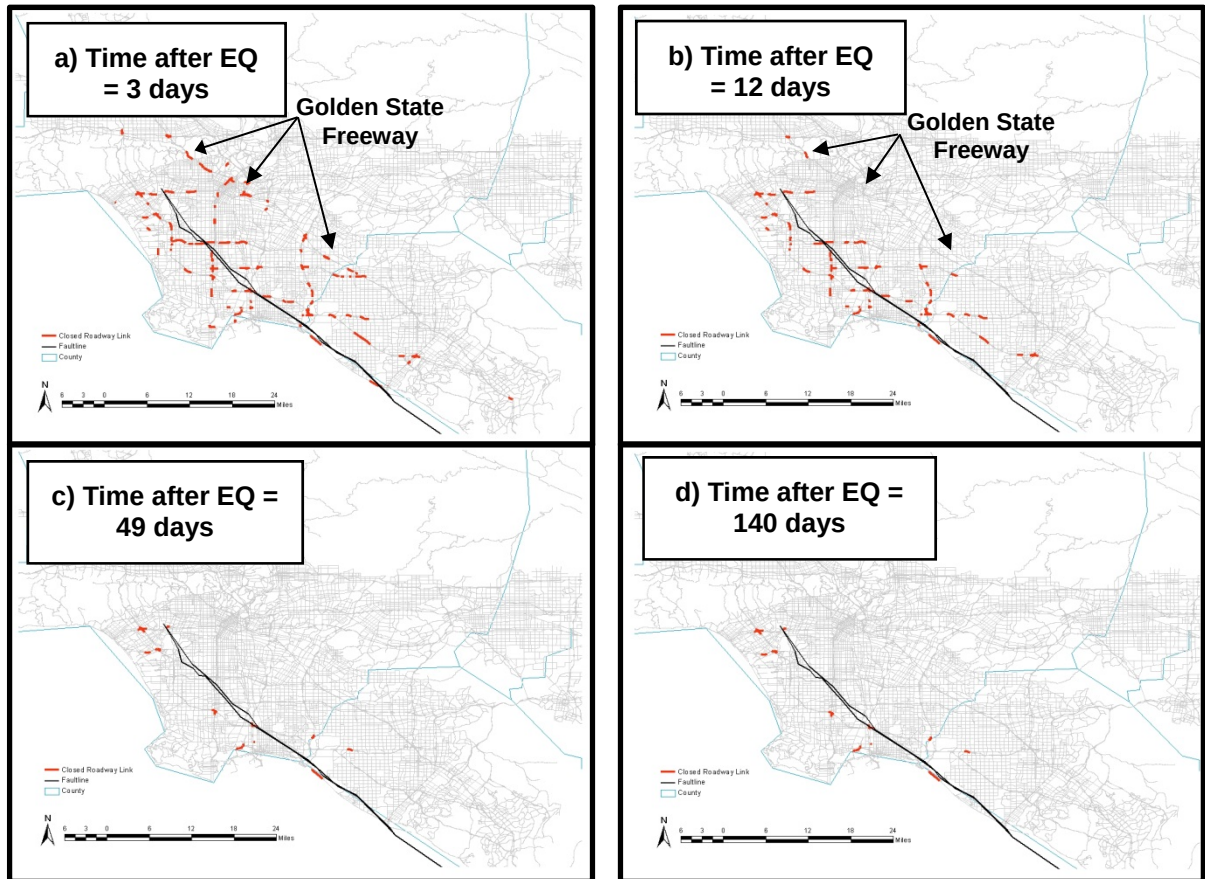


Figure 5: Scenario Earthquake on Newport-Inglewood Fault: Roadway Closures at Various Post-Earthquake Times

2.4.2.4 Traffic Volumes

Figure 6 shows the changes in traffic volumes throughout the highway system due to the earthquake-induced bridge damage and roadway link closures. As expected, the largest traffic volume reductions occur along the roadway segments with closures along their length. It is seen that many roadways throughout the system experience an increase in traffic volume because they are accommodating the trips that would ordinarily be traveling along the damaged roadways. This is a benefit of the significant redundancy in the highway-roadway system throughout the greater Los Angeles area.

2.4.2.5 Economic Losses

Table 4 shows the economic losses due to the travel time delays and trips foregone that are a consequence of the earthquake damage to the highway system. This table shows an estimated total economic loss of about \$22.4 billion, most of which is due to travel time delays experienced by passenger and freight traffic. This very high economic loss estimate is due to the very large number of irreparably damaged bridges estimated from this analysis, which we believe to be unlikely for reasons noted in Section 2.4.2.2. If further evaluations show that the estimated number of irreparably damaged bridges should be reduced, these estimated economic losses would likewise be reduced.

Table 4: Scenario Earthquake on Newport-Inglewood Fault: Economic Losses over Time after Earthquake due to Travel Time Delays and Trips Foregone for Passenger and Freight Trips

Post-EQ Time Segment	Economic Losses during Each Post-EQ Time Segment, millions of dollars				
	Passenger		Freight		Total
	Forgone Trips	Travel Time Delay	Forgone Trips	Travel Time Delay	
0-3 days	\$5.3	\$582.3	\$19.7	\$752.0	\$1,359.3
4-12 days	\$12.5	\$1,674.2	\$52.3	\$2,109.1	\$3,848.1
13-49 days	\$19.5	\$3,725.7	\$98.5	\$4,494.0	\$8,337.8
50-140 days	\$1.4	\$2,134.0	\$23.8	\$2,267.5	\$4,426.7
141-220 days	\$1.4	\$2,122.3	\$23.7	\$2,255.0	\$4,402.4
Total	\$40.1	\$10,238.5	\$218.0	\$11,877.7	\$22,374.3

Figures 7a and 7b provide graphical displays of the losses from travel time delays and trips foregone and how they accumulate over time after the earthquake. These figures show that, as expected, the largest rate of increase of these

losses occurs within the first 49 days, before a most of the damaged roadways are repaired and reopened to traffic. They also show, as does Table 4, that the losses due to foregone trips are largest for freight traffic whereas the losses due to travel time delays are largest for the passenger traffic.

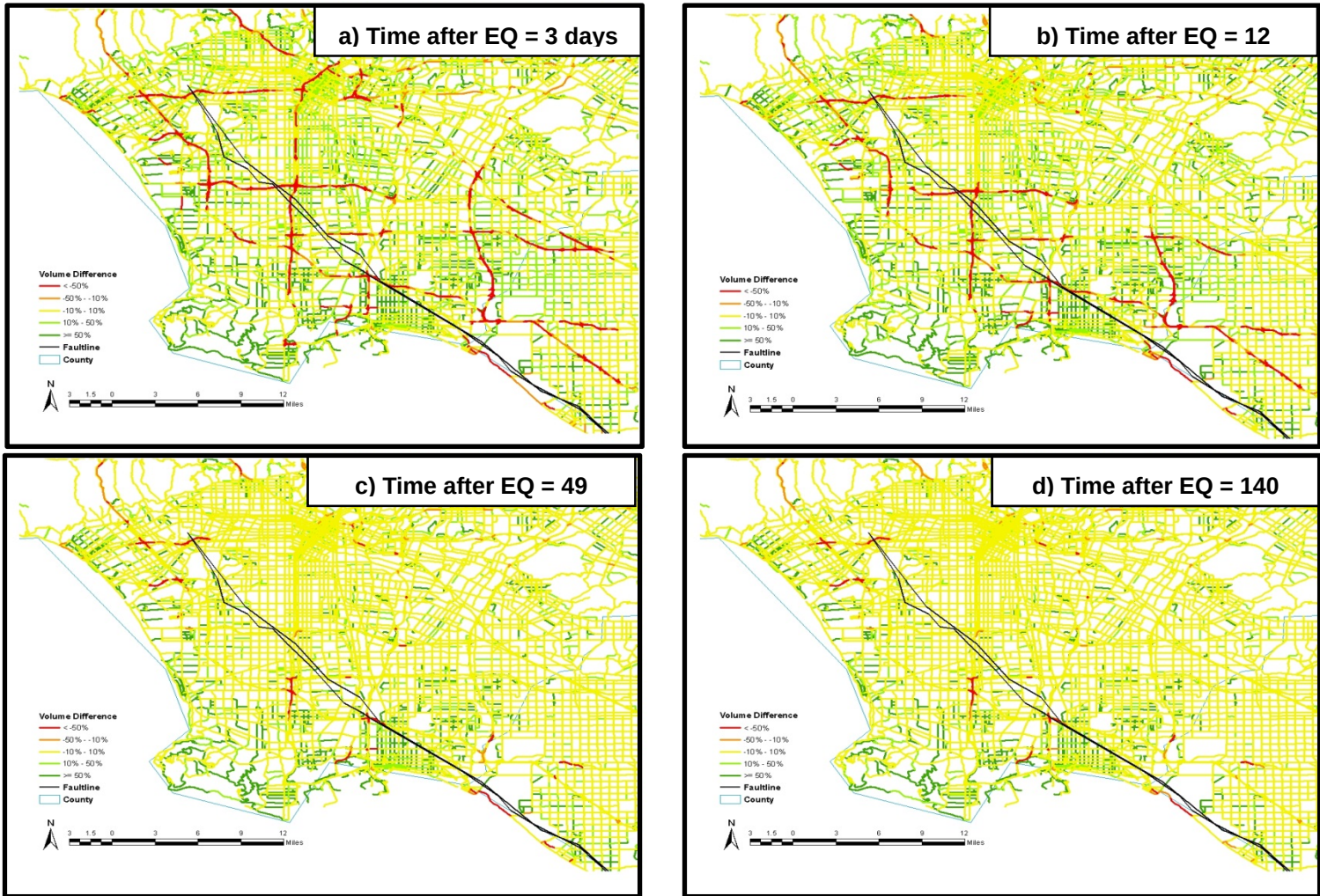
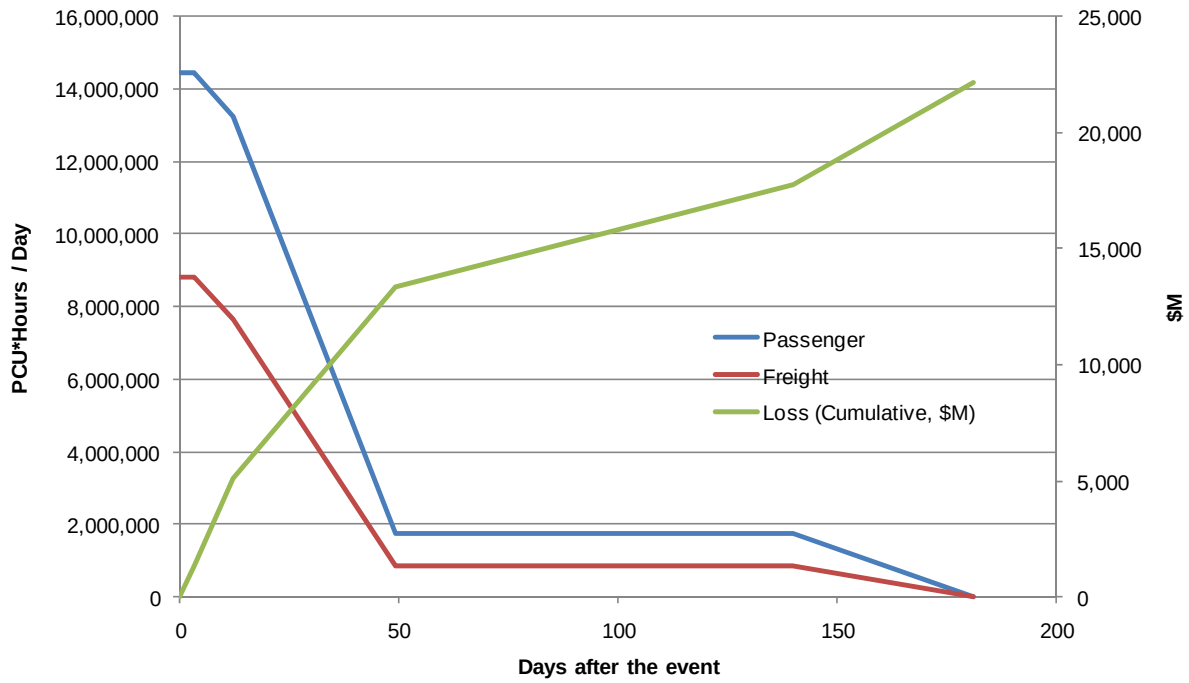
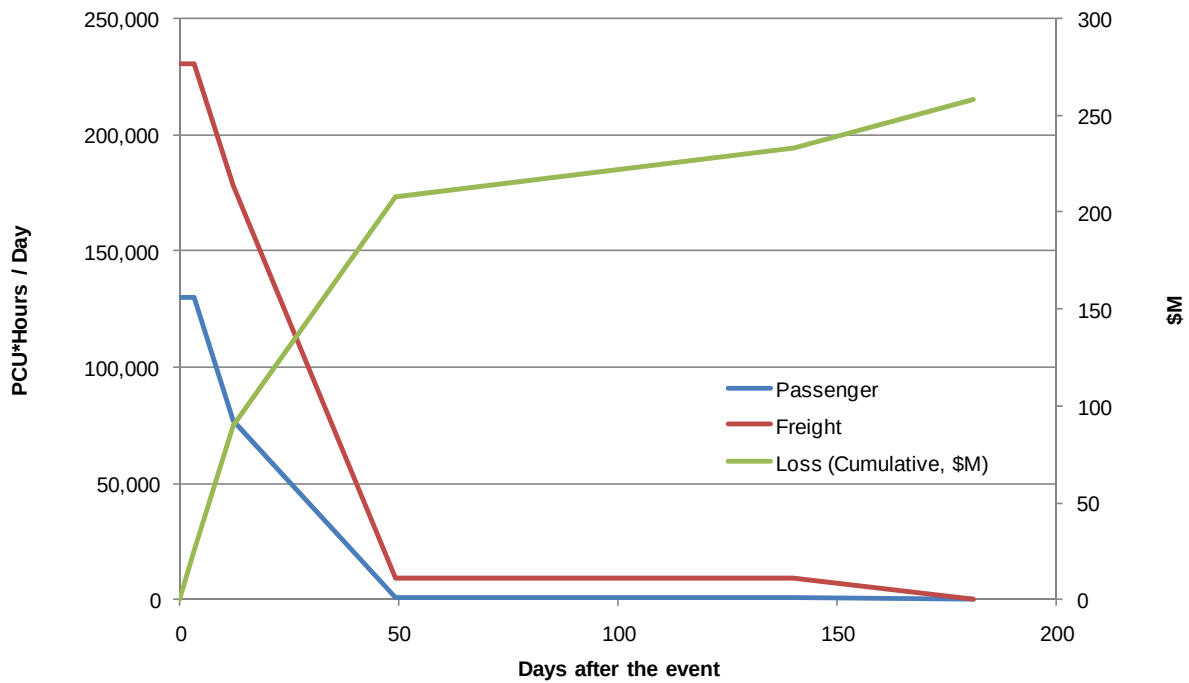


Figure 6: Scenario Earthquake on Newport-Inglewood Fault: Traffic Volumes at Various Post-Earthquake Times



a) Losses due to Travel Time Delays



b) Losses due to Trips Foregone

Figure 7: Scenario Earthquake on Newport-Inglewood Fault: Economic Losses

2.4.3 $M_w 7.0$ Scenario Earthquake along Palos Verdes Fault

The fault rupture for this scenario earthquake passes through the Palos Verdes Peninsula at a location close to the Port of Los Angeles (POLA) and the Port of Long Beach (POLB).

2.4.3.1 Ground Motions

Figure 8a maps the intensity of the ground motions from this earthquake. This figure shows very strong motions in the vicinity of POLA and POLB, where $S_a(1.0)$ values exceed 0.8 g at several bridge sites. The ground motions along the southern segments of the Harbor Freeway and Long Beach Freeway that are closest to POLA and POLB are less intense but still strong, with $S_a(1.0)$ values at several bridge sites that range from 0.6 g to 0.8 g.

2.4.3.2 Bridge Damage States

Figure 8b show the estimated damage states of the bridges throughout the highway system due to these earthquake ground motions. These results indicate irreparable damage to three bridges (none of which are seismically designed or column jacketed according to our input data. One of these bridges is very near POLA, one is adjacent to POLB, and one is near the southern terminus of the Harbor Freeway. In addition, extensive damage is estimated to occur at another bridge near POLA, another bridge near POLB, and several bridges along the southern segments of the Harbor and Long Beach Freeways where the strongest ground motion are estimated. Table 5 shows the number of bridges and the ranges of ground shaking levels for the bridges in each damage state.

Table 5: Scenario Earthquake on Palos Verdes Fault: Bridge Damage States

Ground Shaking $S_a(1.0)$, g	Bridge Damage States					Total No. of Bridges
	Damage State 1 (No damage)	Damage State 2 (Slight damage)	Damage State 3 (Moderate damage)	Damage State 4 (Extensive damage)	Damage State 5 (Irreparable damage)	
< 0.20 g	5,029					5,029
0.21 g – 0.40 g	786	54	1			841
0.41 g – 0.60 g	227	45	78	40		390
0.61 g – 0.80 g	34	8	4	24	1	71
> 0.80 g	2	10	1	7	1	22
Total No. of Bridges	6,078	117	84	71	3	6,353

2.4.3.3 System States

Figure 9 shows system states in terms of roadway link closures at post-earthquake times of 3 days, 12 days, 49 days, and 140 days. As previously noted, the rates at which the closed links reopen over time after the earthquake depend on the REDARS default bridge repair model that is shown in Table 3. Figure 9 shows that: (a) several links in the vicinity of POLA and POLB and also along the Harbor, Long Beach, and San Diego Freeways are closed at post-earthquake times of 3 days and 12 days; and (b) most of these closed links are reopened at 49 days after the earthquake.

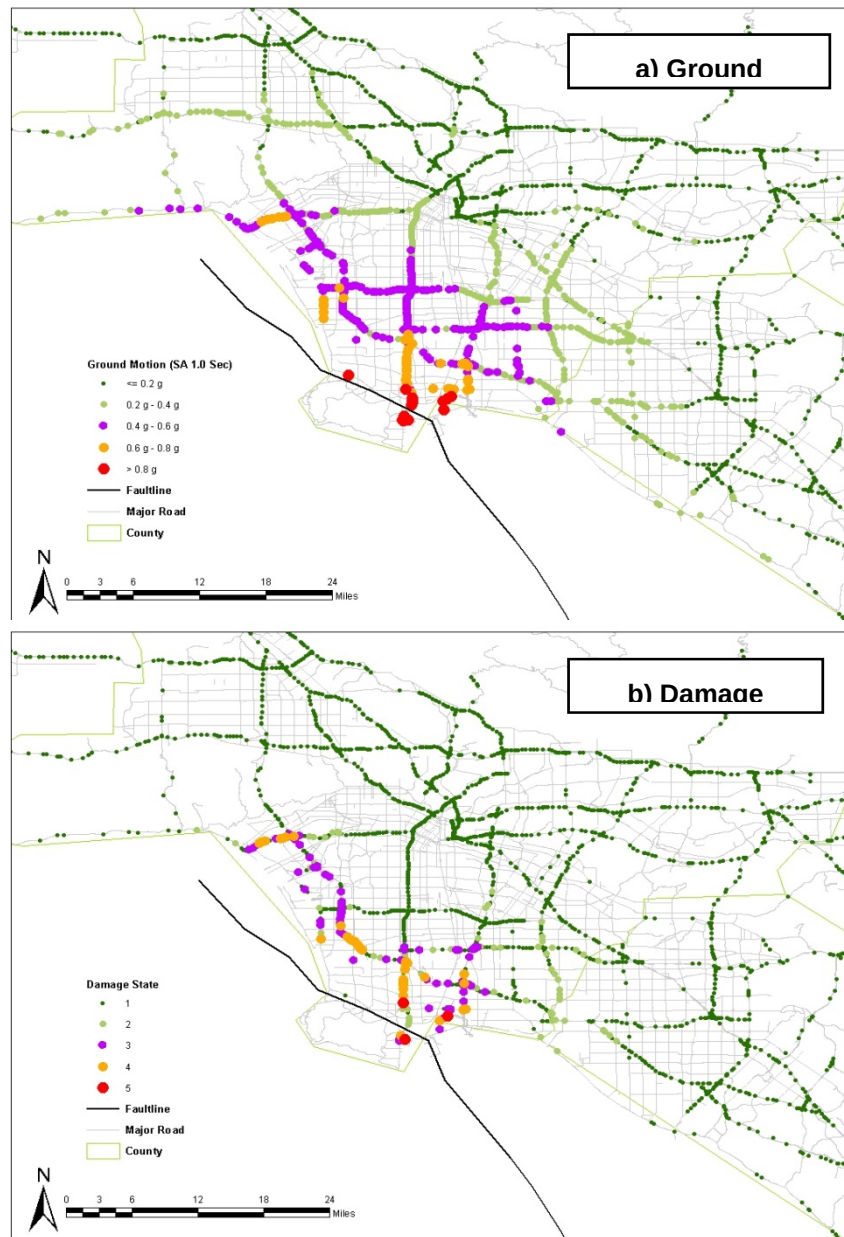


Figure 8: Scenario Earthquake on Palos Verdes Fault: Ground Motions and Damage State

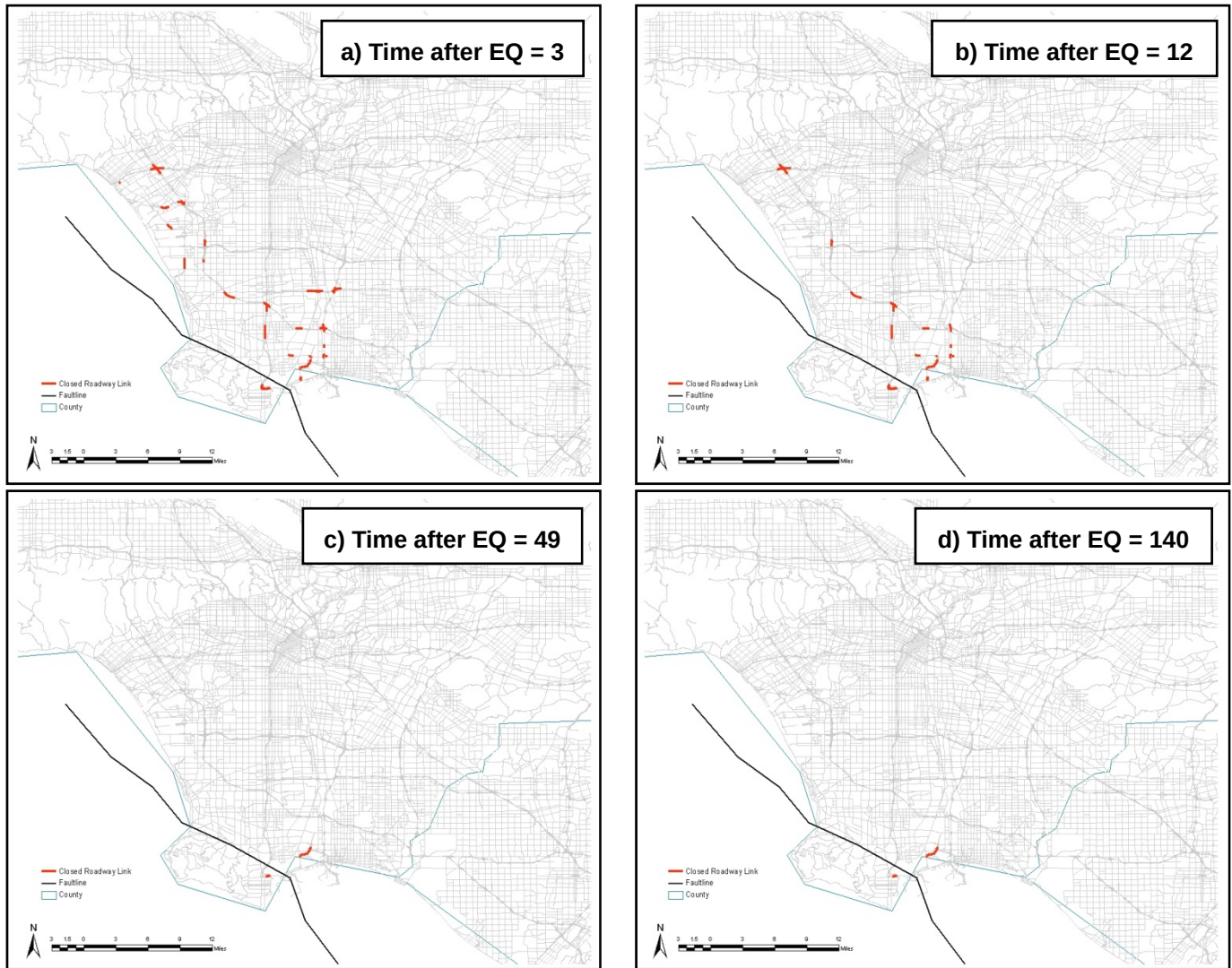


Figure 9: Scenario Earthquake on Palos Verdes Fault: Roadway Closures at Various Post-Earthquake Times

2.4.3.4 Traffic Volumes

Figure 10 shows the changes in traffic volumes throughout the highway system due to the earthquake-induced bridge damage and roadway link closures. As expected, the largest reductions in traffic volume occur along the roadway segments with the link closures. It is seen that many roadway links throughout the system experience an increase in traffic volume because they are accommodating the trips that would ordinarily be traveling along the damaged roadways. This is a benefit of the significant redundancy in the highway-roadway system throughout the greater Los Angeles area.

2.4.3.5 Economic Losses

Table 6 shows the economic losses due to the travel time delays and trips foregone that are a consequence of the earthquake damage to the highway system. This table shows an estimated total economic loss of about \$5.8 billion, most of which is a result of travel time delays experienced by passenger and freight traffic.

Table 6: Scenario Earthquake on Palos Verdes Fault: Economic Losses over Time after Earthquake due to Travel Time Delays and Trips Foregone for Passenger and Freight Trips

Post-EQ Time Segment	Economic Losses during Each Post-EQ Time Segment, millions of dollars				
	Passenger		Freight		Total
	Forgone Trips	Travel Time Delay	Forgone Trips	Travel Time Delay	
0-3 days	\$0.2	\$103.4	\$0.8	\$111.4	\$215.7
4-12 days	\$0.4	\$249.7	\$1.6	\$263.9	\$515.6
13-49 days	\$0.4	\$593.3	\$1.8	\$589.6	\$1,185.1
50-140 days	\$0.2	\$1,004.3	\$1.2	\$941.0	\$1,946.7
141-220 days	\$0.2	\$998.8	\$1.2	\$935.8	\$1,936.0
Total	\$1.3	\$2,949.5	\$6.7	\$2,841.6	\$5,799.1

Figures 11a and 11b provide graphical displays of the losses from travel time delays and trips foregone and how they accumulate over time after the earthquake. These figures show that, as expected, the largest rate of increase of these losses occurs within the first 49 days, before a most of the damaged roadway links are repaired and reopened to traffic. They also show, as does Table 6, that the losses due to foregone trips are largest for freight traffic whereas the losses due to travel time delays are largest for the passenger traffic.

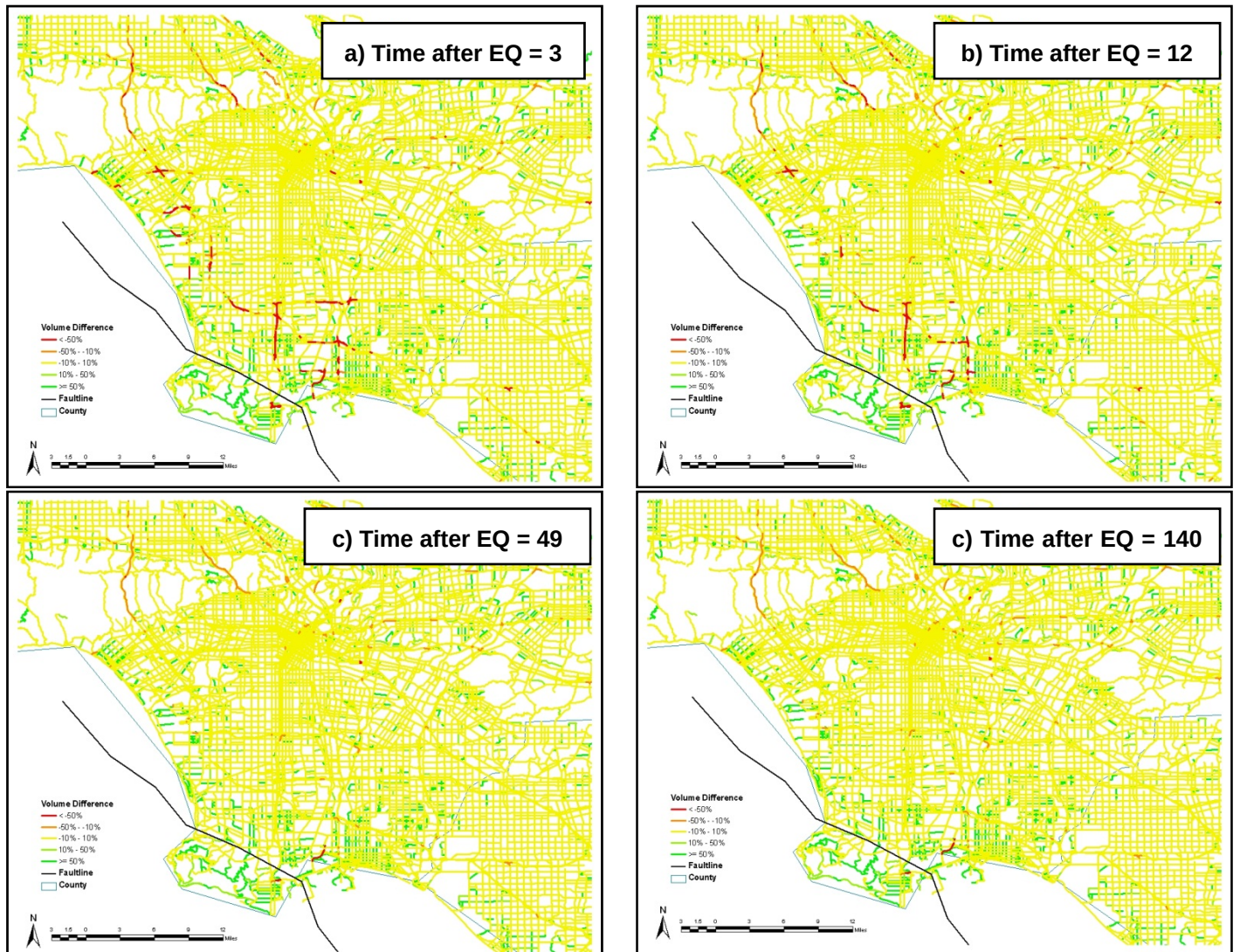
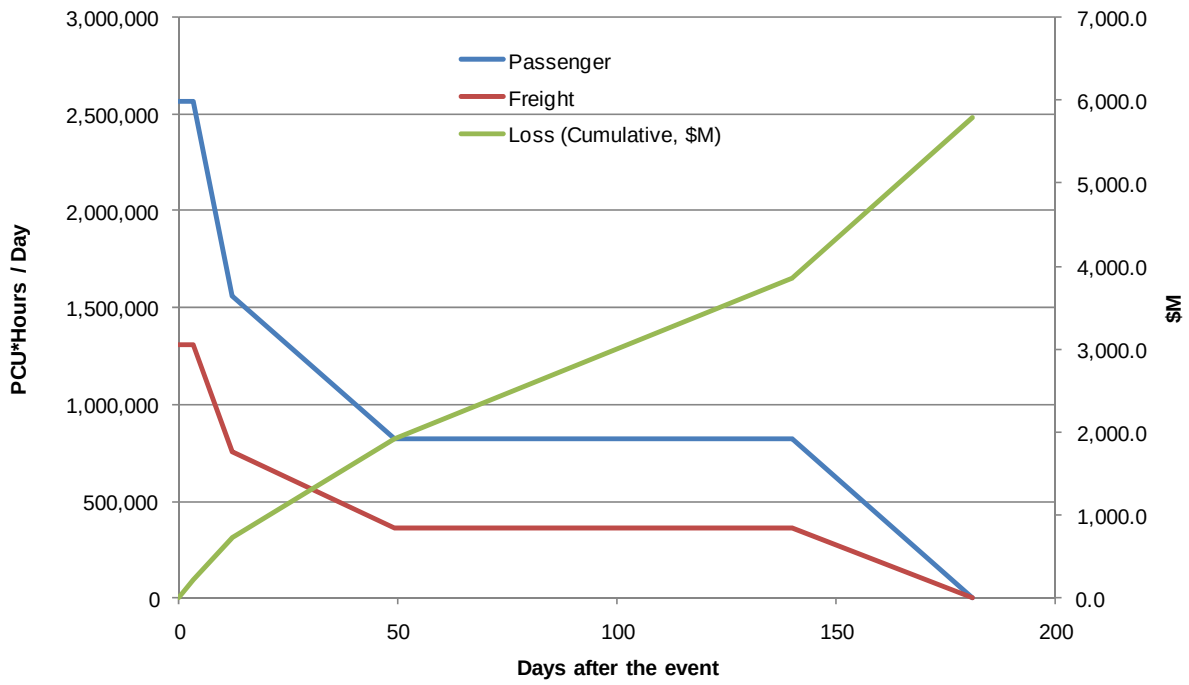
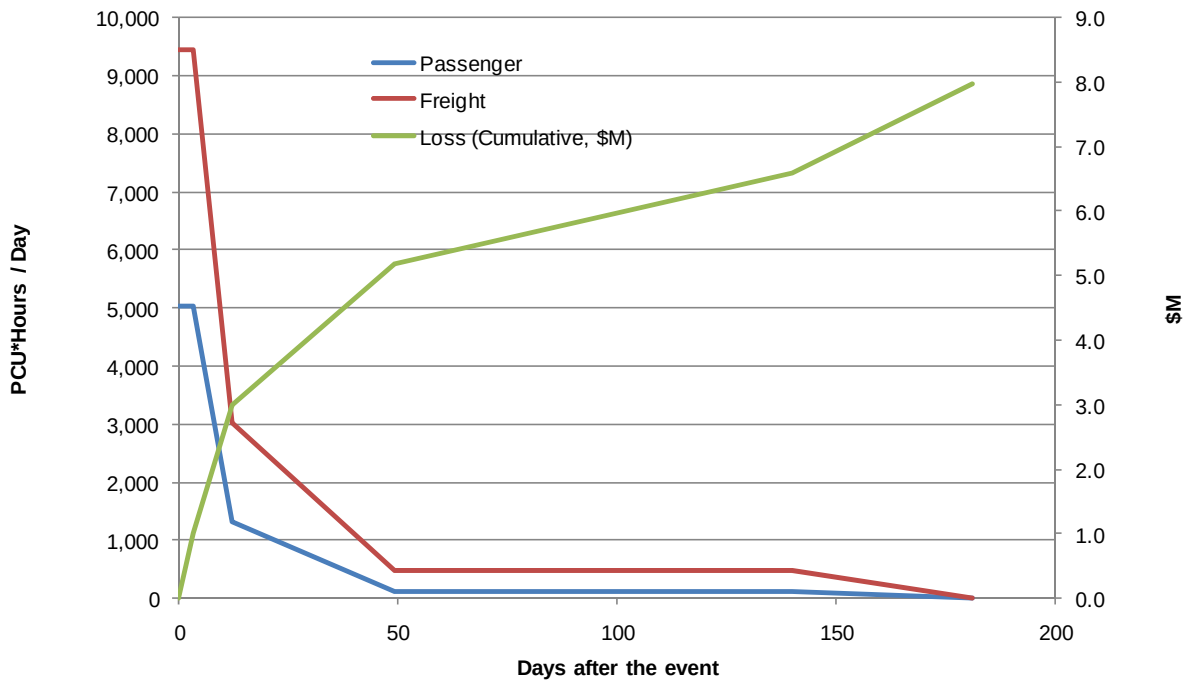


Figure 10: Scenario Earthquake on Palos Verdes Fault: Traffic Volumes at Various Post-Earthquake Times



a) Losses due to Travel Time Delays



b) Losses due to Trips Foregone

Figure 11: Scenario Earthquake on Palos Verdes Fault: Economic Losses

2.4.4 $M_w7.8$ Scenario Earthquake along San Andreas Fault

Because of the large magnitude of this earthquake, its fault rupture is long. The most heavily populated areas (with the largest number of roadways and bridges) in the vicinity of the fault rupture are the cities of San Bernardino and Palm Springs. Most of the remaining segments of this rupture extend through sparsely populated areas with fewer roadways. The closest distance from the fault rupture to POLA and POLB is roughly 50 miles.

2.4.4.1 Ground Motions

Figure 12a maps the intensity of the ground shaking from this earthquake. This figure shows that the intensity of the shaking is very strong within a distance of about 10 miles from the fault rupture, and then decays to more moderate levels of shaking. However, for this very large magnitude earthquake, the intensity is not the only feature of the ground motions that could cause bridge damage. In addition, the duration of the shaking will be very long for earthquakes of this magnitude and this could also lead to damage to bridges and other structures, even if the intensity of the shaking is moderate. Effects of the duration of the shaking are not considered in the HAZUS bridge model that is currently used in REDARS to estimate the seismic performance of bridges.

2.4.4.2 Bridge Damage States

Figure 12b shows the estimated damage states of the bridges throughout the region due to these ground motions. A large number of the bridges is estimated to experience irreparable damage (Damage State 5), all of which: (a) are within a close proximity of the fault rupture where the estimated levels of ground shaking are very strong (Table 7); and (b) are shown by the input data for these bridges to have not been seismically designed or column jacketed. However, as previously noted in our discussion of the bridge damage due to the scenario earthquake along the Newport-Inglewood Fault, we believe that the actual structural attributes and the availability of more detailed analyses of these bridges should be further examined in collaboration with Caltrans engineers. This may well result in fewer estimates of irreparably damaged bridges.

Table 7: Scenario Earthquake on San Andreas Fault: Bridge Damage States

Ground Shaking $S_a(1.0)$, g	Bridge Damage States					Total No. of Bridges
	Damage State 1 (No damage)	Damage State 2 (Slight damage)	Damage State 3 (Moderate damage)	Damage State 4 Extensive damage)	Damage State 5 (Irreparable damage)	
< 0.20 g	4,511	3				4,514

0.21 g – 0.40 g	1,139	28				1,167
0.41 g – 0.60 g	152	28	47	31		258
0.61 g – 0.80 g	88	14	10	45	4	161
> 0.80 g	12	103	30	74	34	253
Total No. of Bridges	5,902	175	87	150	38	6,353

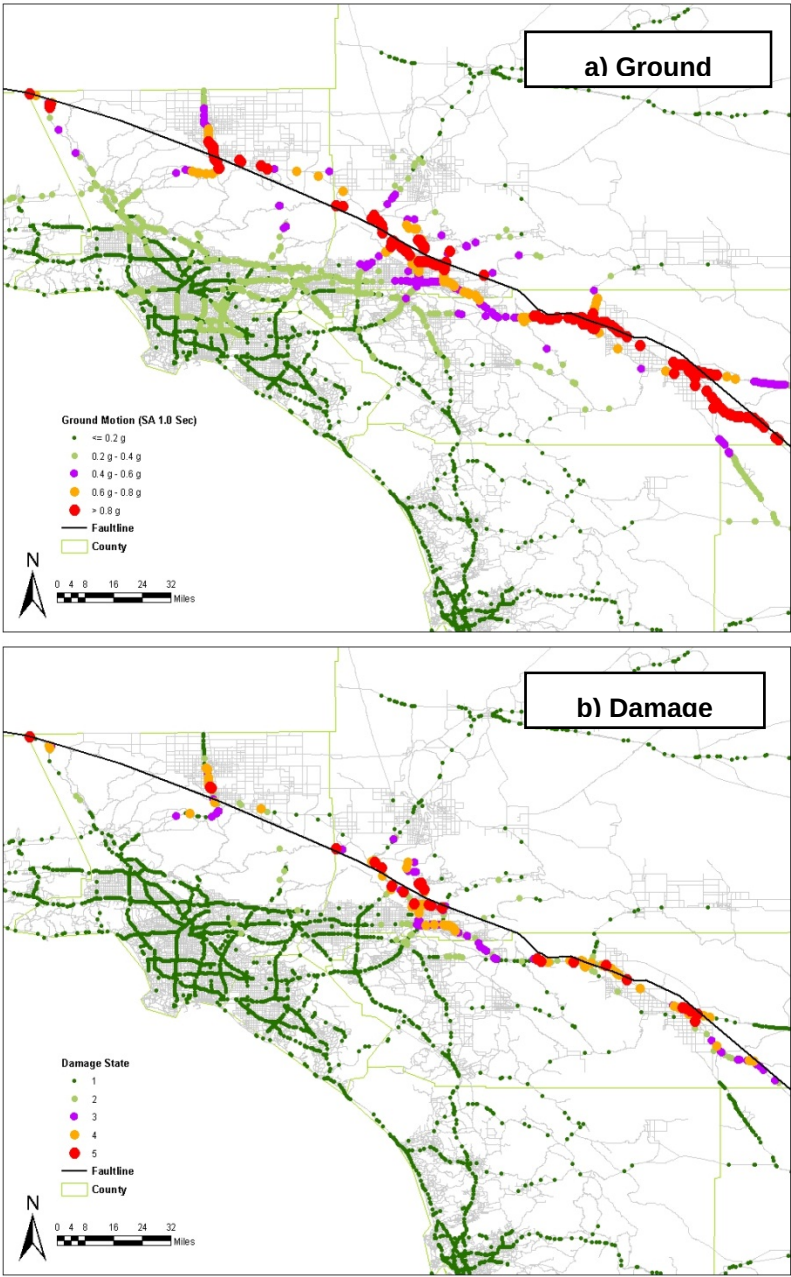


Figure 12: Scenario Earthquake on San Andreas Fault: Ground Motions and Damage State

2.4.4.3 System States

Figure 13 shows system states in terms of link closures at post-earthquake times of 3 days, 12 days, 49 days, and 140 days. As previously noted, the rates at which the closed links reopen over time after the earthquake depend on the REDARS default bridge repair model that is shown in Table 2. Figure 13 shows that all of the closed roadway links are located close to the fault rupture where the most severe bridge damage is estimated to occur.

2.4.4.4 Traffic Volumes

Figures 14 shows the changes in traffic volumes throughout the highway system due to the earthquake-induced bridge damage and roadway link closures. As expected, the largest traffic volume reductions occur along the roadway segments in the vicinity of the fault rupture where bridges were severely damaged and roadway links were closed. This figure also shows some isolated locations with large traffic volume reductions within the Los Angeles area well to the west of the fault rupture. These appear to occur along some on-ramps and off-ramps that have very small baseline (pre-earthquake) traffic volumes. Therefore, we interpret these particular results as being analogous to “noise” in the results with little consequence regarding the seismic performance of the overall highway system.

2.4.4.5 Economic Losses

Table 6 shows the economic losses due to the travel time delays and trips foregone that are a result of the earthquake damage to the highway system. This table shows an estimated total economic loss of about \$8.8 billion, most of which is due to travel time delays experienced by passenger and by freight traffic.

Table 8: Scenario Earthquake on Palos Verdes Fault: Economic Losses over Time after Earthquake due to Travel Time Delays and Trips Foregone for Passenger and Freight Trips

Post-EQ Time Segment	Economic Losses during Each Post-EQ Time Segment, millions of dollars				
	Passenger		Freight		Total
	Forgone Trips	Travel Time Delay	Forgone Trips	Travel Time Delay	
0-3 days	\$0.9	\$84.6	\$5.6	\$76.9	\$168.0
4-12 days	\$2.5	\$244.8	\$16.4	\$224.5	\$488.2
13-49 days	\$8.0	\$809.9	\$56.5	\$763.1	\$1,637.6
50-140 days	\$14.6	\$1,599.8	\$114.8	\$1,548.6	\$3,277.8

141–220 days	\$14.5	\$1,591.0	\$114.2	\$1,540.1	\$3,259.8
Total	\$40.6	\$4,330.2	\$307.5	\$4,153.2	\$8,831.4

Figures 15a and 15b provide graphical displays of economic losses from travel time delays and trips foregone and how they accumulate over time after the earthquake. These figures show that: (a) as expected, the largest rate of increase of these losses occurs within the first 49 days, before most of the damaged roadway links are repaired and reopened to traffic; and (b) the losses due to foregone trips are largest for freight traffic whereas the losses due to travel time delays are largest for the passenger traffic (also shown by Table 6).

2.4.5 CONCLUDING COMMENTS

This chapter has described results of REDARS analyses of seismic risks to the highway system in Los Angeles and surrounding counties due to ground motion hazards caused by scenario earthquakes along the Newport-Inglewood fault, Palos Verdes fault, and San Andreas fault. For each earthquake, these analyses represent first level estimates of bridge damage throughout the highway system, costs and times to restore traffic flows throughout the system, and economic losses due to earthquake-induced disruption of region-wide freight and passenger traffic.

The REDARS analyses have met this objective by providing graphical and tabular displays of the following types of results from the analyses for each earthquake: (a) ground motion intensities and their spatial distribution throughout the highway system; (b) estimated damage states for every bridge in the highway system; (c) system states at various post-earthquake time that showed location of roadway links throughout the system that were closed due to earthquake-induced bridge damage and the rate at which the links reopened to traffic as repairs of the damaged bridges proceeded; (d) how traffic volumes along each roadway throughout the system were affected by the link closures, including how the traffic that would ordinarily travel along the closed routes was accommodated by other roadways throughout this highly redundant highway system throughout the greater Los Angeles area; and (e) economic losses due to earthquake-induced travel time delays and trips foregone.

Of the three scenario earthquakes considered in this project, the earthquake along the Newport-Inglewood fault caused by far the largest impacts on the highway system and losses due to earthquake damage. This is because the fault rupture from this earthquake extends through a very dense segment of the Los Angeles highway network. In addition, the bridge attribute data that we used as input to the REDARS analysis shows a large number of bridges in close proximity to the Newport-Inglewood fault (where the estimated ground motions were particularly strong) that were neither seismically designed or column jacketed. Because of this, an extremely large number of bridges near the fault rupture were estimated to undergo irreparable damage (Damage State 5) due to this earthquake. In fact, all

of the bridges that experienced irreparable damage due to this earthquake and also due to the other two scenario earthquakes were bridges with no seismic design or column jacket retrofit according to our input data. In this report, we have suggested that this may not be realistic, and that bridge damage may have been overestimated because our input data for these bridges either may not be current or may not reflect certain features of the bridges that could improve their seismic performance but could not be accommodated by the simplified HAZUS bridge fragility modeling procedure that is currently used in REDARS¹. Because of budget constraints, these issues could not be investigated under this project. However, we strongly recommend that these issues and how they might affect bridge earthquake damage estimates should be thoroughly evaluated in collaboration with Caltrans engineers.

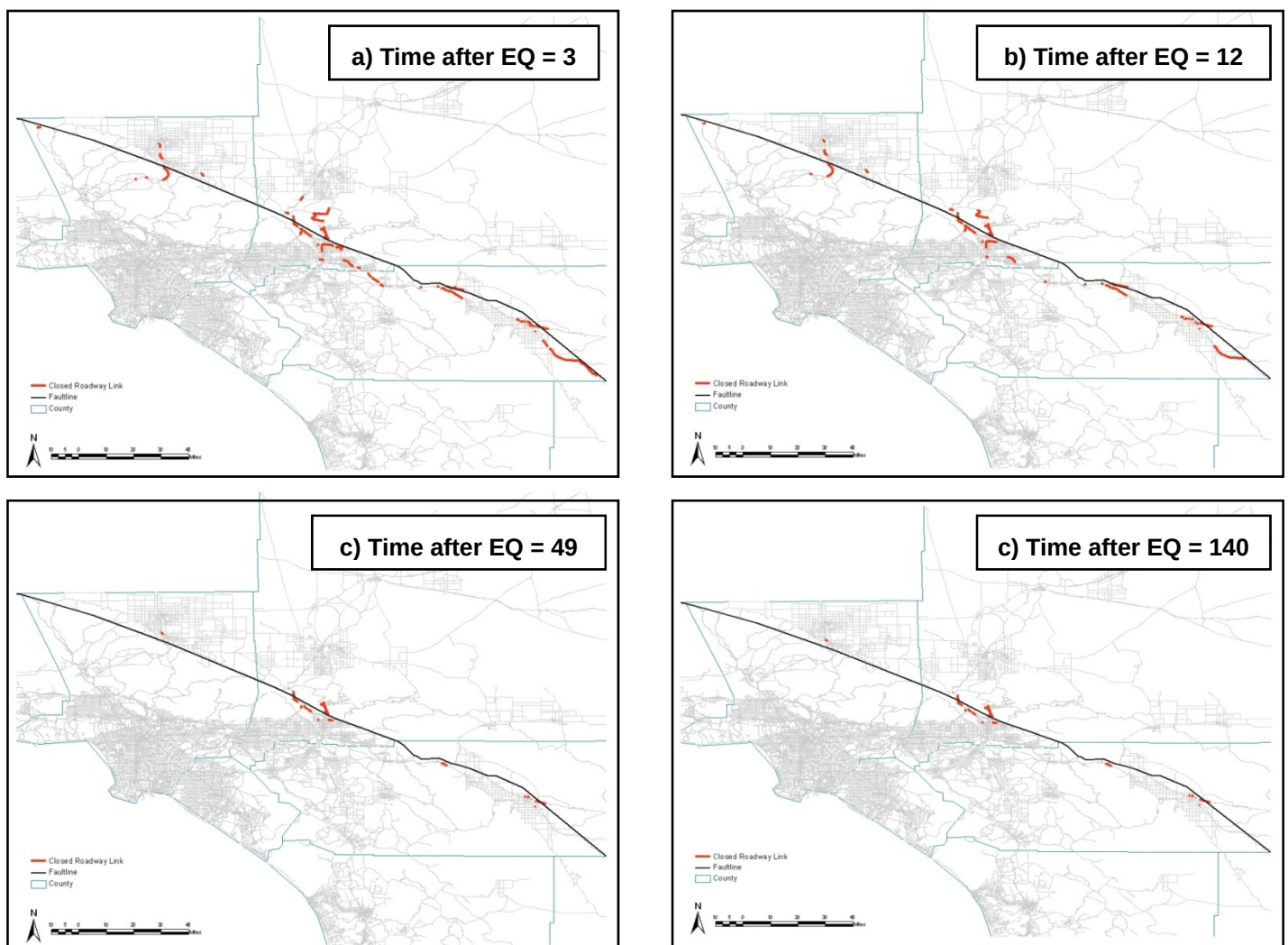


Figure 13: Scenario Earthquake on San Andreas Fault: Roadway Closures at Various Post-Earthquake Times

¹ For example, such features of the bridges could include whether they were seismically retrofitted by other methods besides column jacketing.

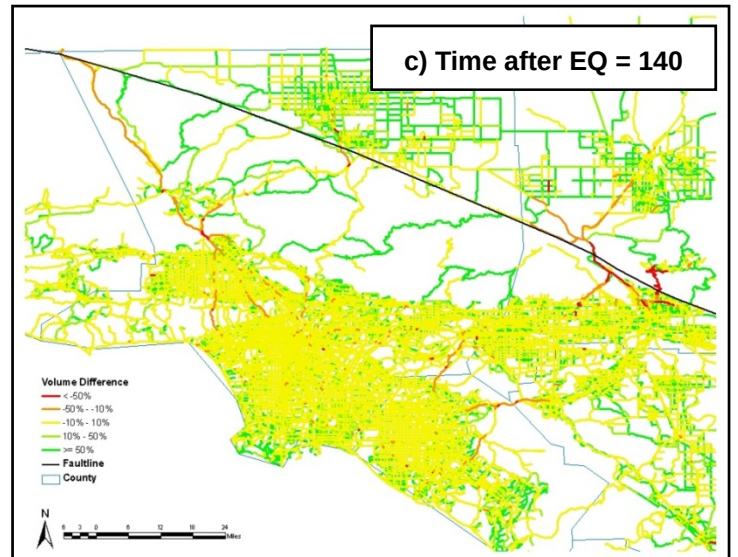
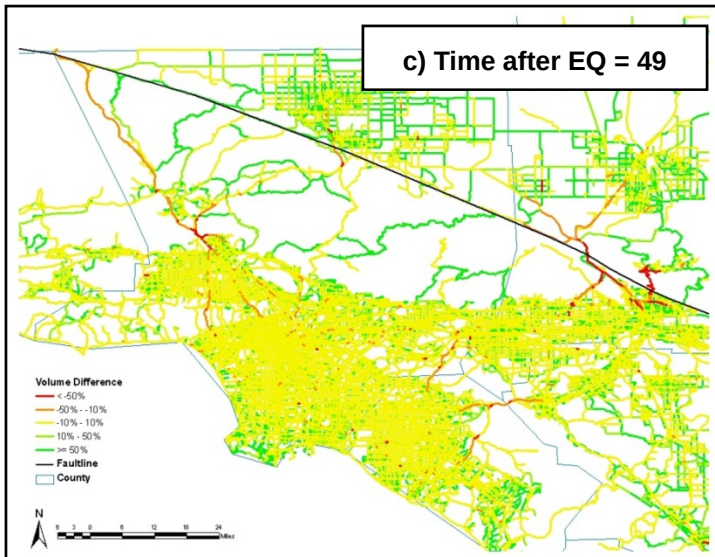
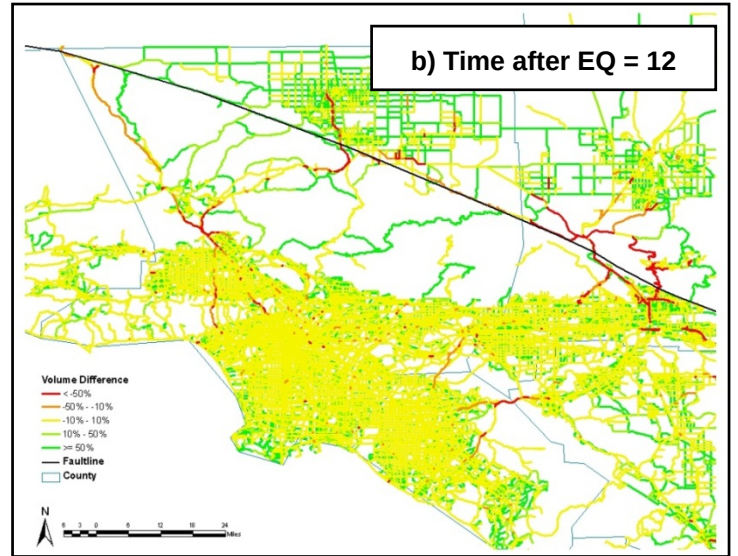
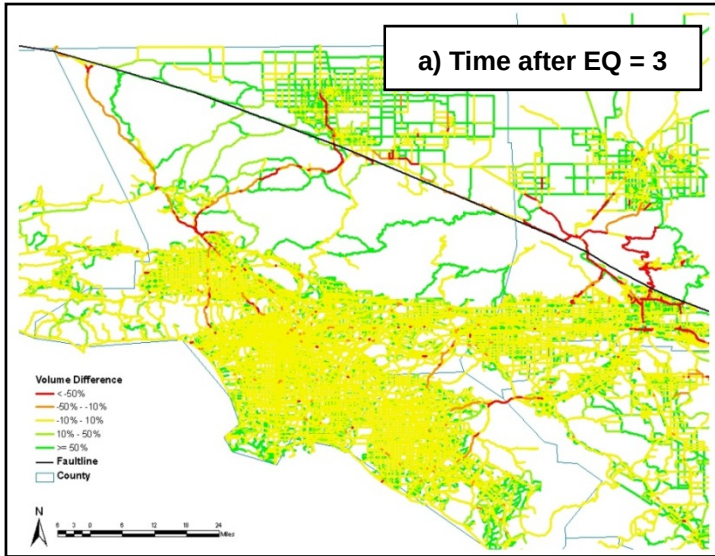
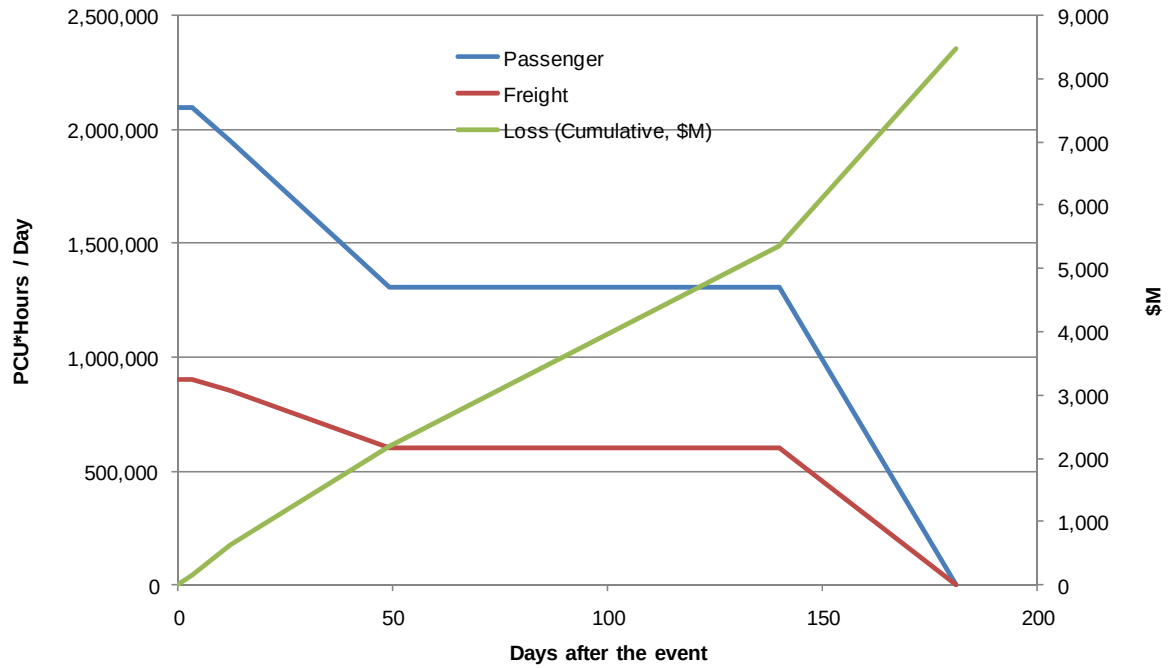
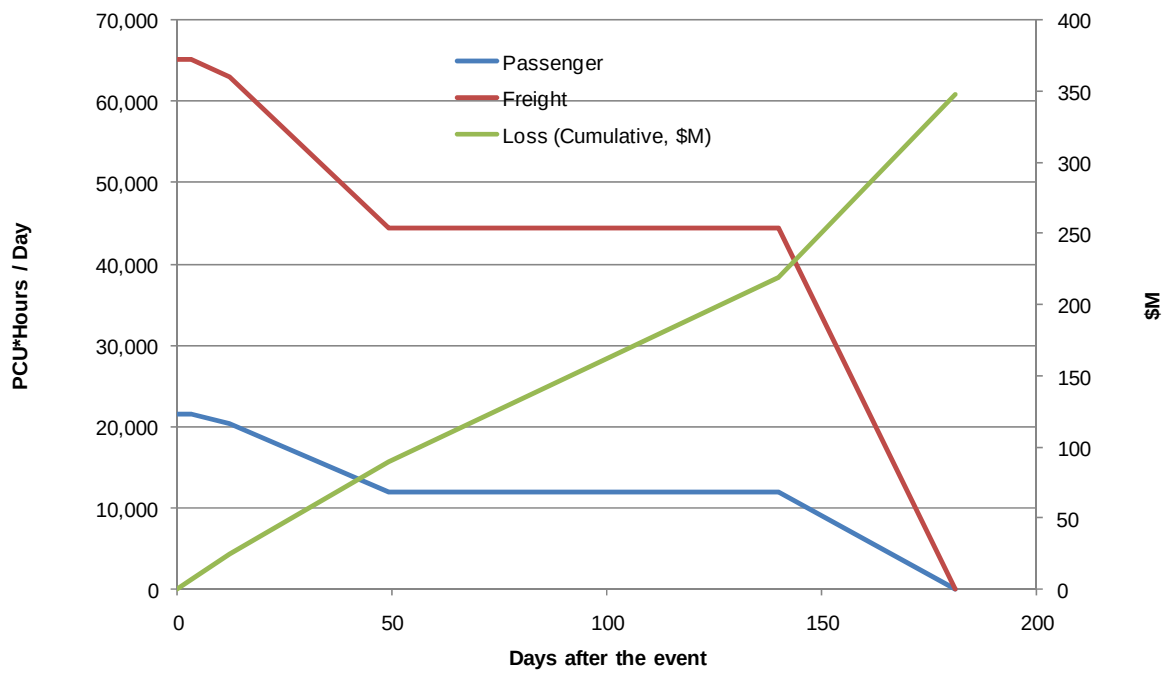


Figure 14: Scenario Earthquake on San Andreas Fault: Traffic Volumes at Various Post-Earthquake Times



a) Losses due to Travel Time Delays



b) Losses due to Trips Foregone

Figure 15: Scenario Earthquake on San Andreas Fault: Economic Losses

3 Impact analysis of the worst case scenario using Microscopic traffic flow simulator

Various traffic flow simulators have been developed to generate traffic flow on constructed road network. VISSIM, Corsim, Paramics are some of developed traffic flow software. Bloomberg and Dale, 2000, Tian et al., 2002, Panawi and Dia, 2002 introduce the comparisons among the developed versions of traffic flow software. In this section, we use VISSIM to simulate defined scenarios in LA/LB port complex as illustrated in Figure 16. VISSIM is integrated with the developed macroscopic terminal simulation model to generate containers movements in and out of terminals. Our developed macroscopic terminal simulator is explained in details in the impact analysis for port operations section. Microscopic traffic flow simulators can be applied on different road configurations, where the real experiments are costly or even impossible.

Road network adjacent to the port complex is constructed in microscopic traffic flow simulator (VISUM) constituting three interstate highways (I-710, I-405, I-110) and two state highways (CA-47 S, CA-103 S). The layout of our constructed model is presented in Figure 16. We implemented some detectors in the constructed model to collect simulation data. The level of traffic flow rates that are used as inputs to VISUM network are measured exploiting historical traffic data from the Performance Measurement System (PeMS). Locations of loop data on the surface streets are indicated with white arrows in the following Figure.

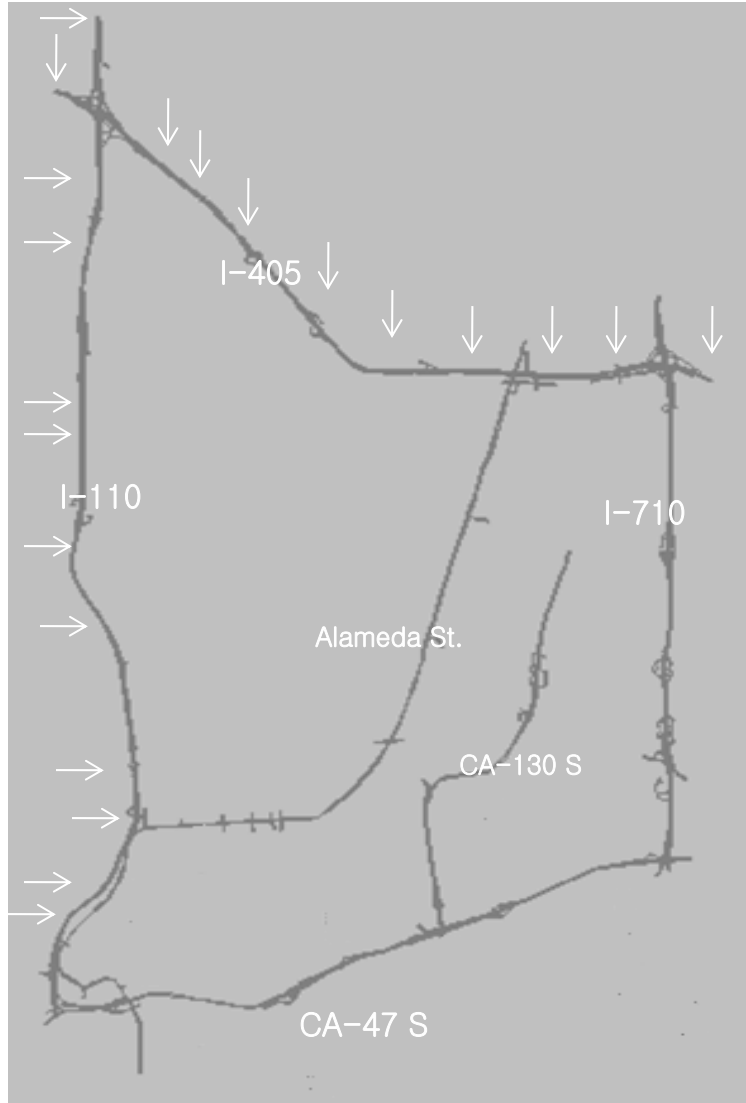


Figure 16: Layout of the twin ports and adjacent freeways

In this chapter, the economic loss of three different hypothetical earthquakes (Newport-Inglewood, Palos-Verdes and San Andreas) in the designated region is demonstrated in details. Delays due to disruption to the steady flow impose the additional cost to vehicles. This loss depends on the type of trip (car, freight). The default unit costs are based on data studied by the Rand Corporation of California (Gordon et al., 2009). In the following subsections, the economic losses of three different earthquakes are investigated in details. The baseline of bridge damages and link closures due to earthquake are provided by REDAES2 methodology and software (Werner et al., 2006).

3.1 Newport-Inglewood earthquake

REDARS 2 provides various data to set the baseline for microscopic traffic simulator (VISSIM) in order to run and

evaluate the economic consequences of each earthquake scenario as the result of delays to the steady flow on the road network.

The following Figures illustrate bridge damage estimation and link closure after 3, 12 and 49 days for the Newport-Inglewood earthquake scenario in the designated region provided by REDARS 2.

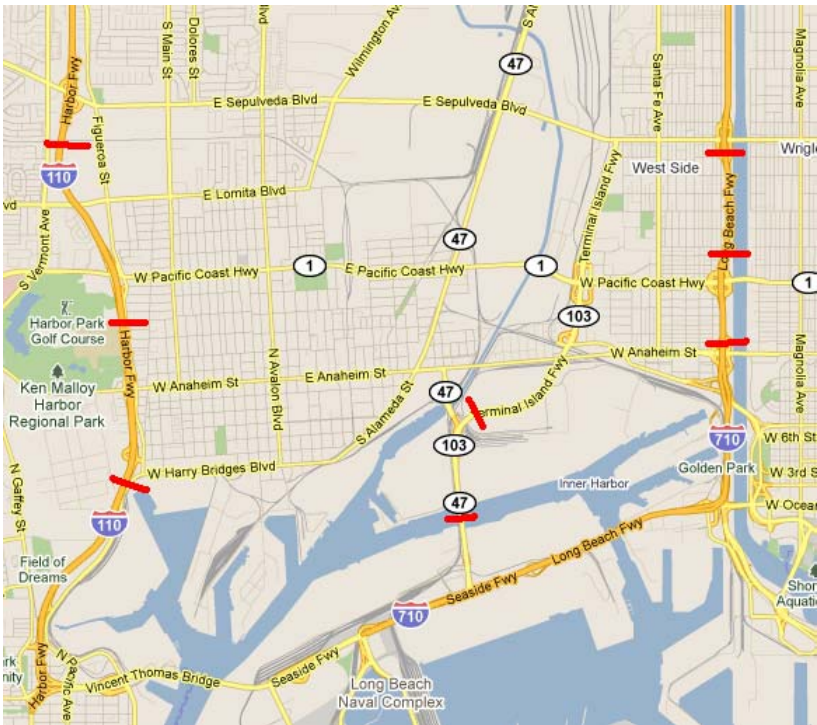


Figure 17: Bridge damage estimation in Newport-Inglewood earthquake

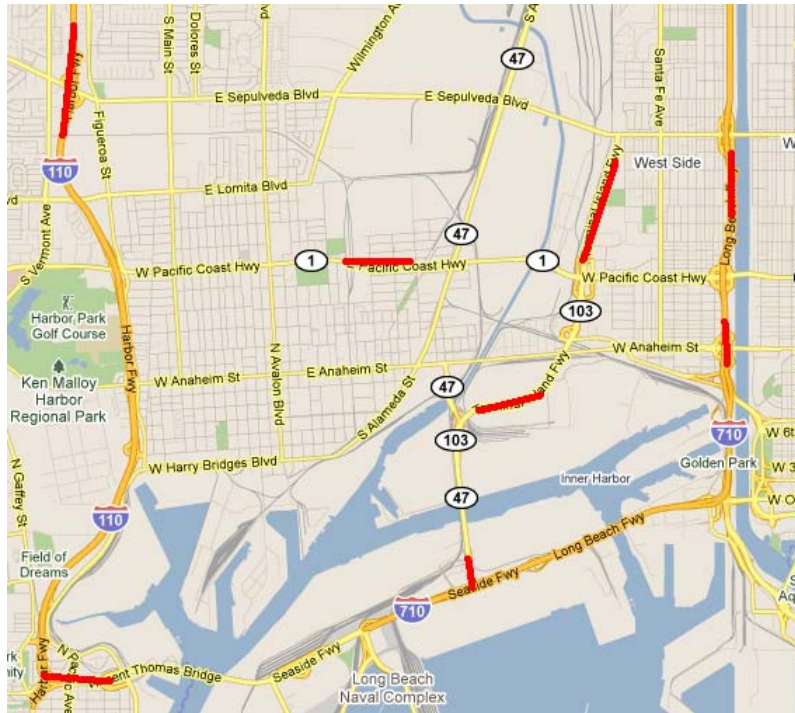


Figure 18: Link Closure 3 days after Newport-Inglewood earthquake

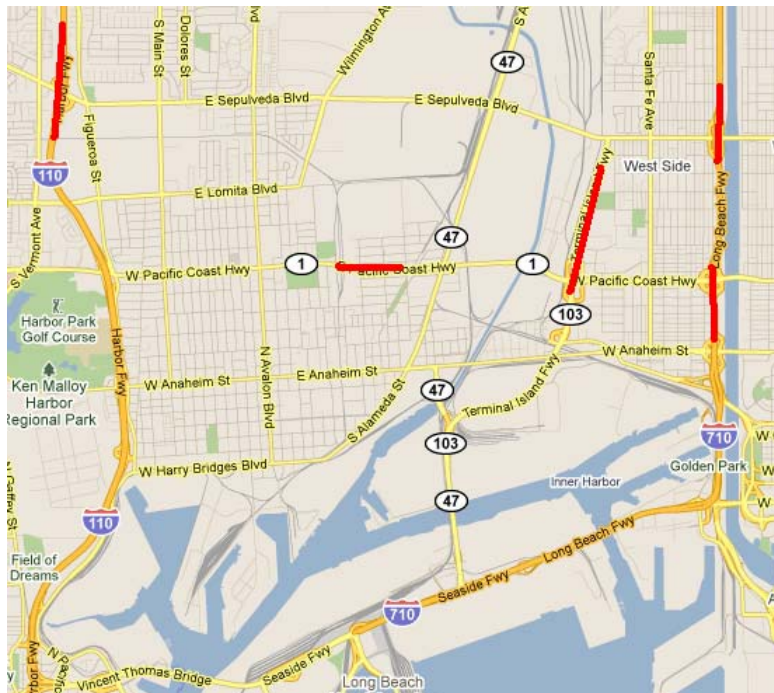


Figure 19: Link Closure 12 days after Newport-Inglewood earthquake

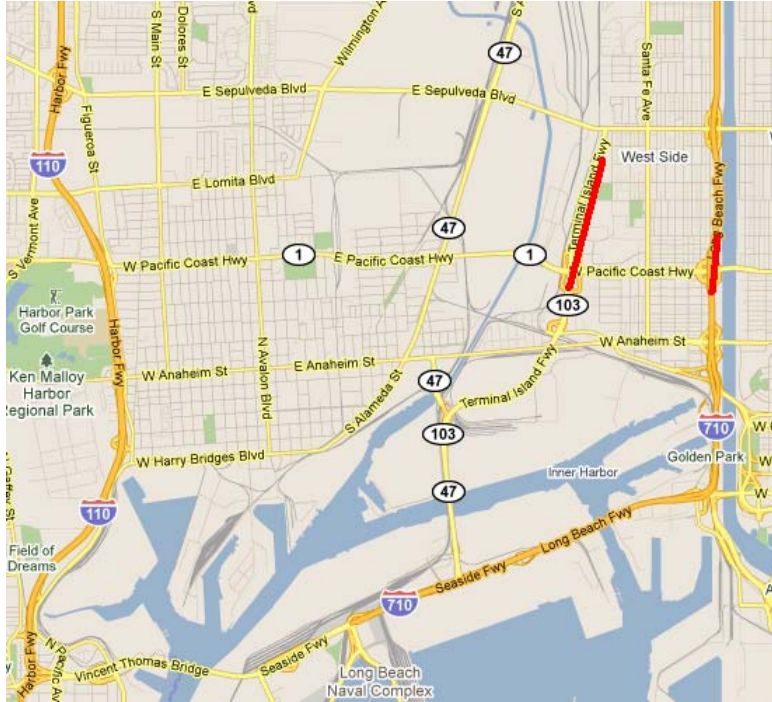


Figure 20: Link Closure 49 days after Newport-Inglewood earthquake

We use default unit losses of \$13.45 PCU-hour delay for automobile trips and \$28.42 PCU-hour delay for commercial-vehicle (freight-transport) trips. PCU stands for Passenger Car Unit. Table 9 and Figure 21 demonstrate our evaluated economic loss using traffic simulator (VISSIM) based on the Passenger Car Unit delay cost.

Table 9: Economic loss due to vehicle delay in Newport-Inglewood earthquake

Days	Passenger (PCU-hour Delay)	Freight (PCU-hour Delay)	Loss(Cumulative, \$M)
0	301227	234241	0
3	301227	234241	31.836
12	261653	210136	151.944
49	59180	27456	420.658
140	59180	27456	639.353
181	0	0	780.723

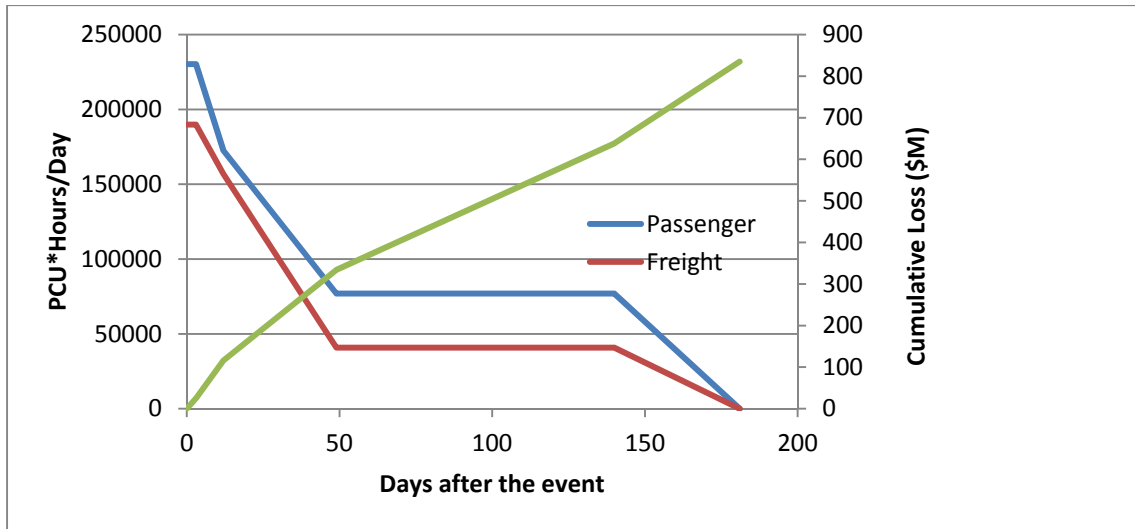


Figure 21: Economic loss due to vehicle delay in Newport-Inglewood earthquake

3.2 Palos-Verdes earthquake

The following Figures illustrate the bridge damage estimation and link closure due to the Palos-Verdes earthquake scenario in the port complex area provided by REDARS 2. Figures 23, 24, and 25 demonstrate link closure in the port complex region 3, 12, and 49 days after the earthquake respectively.

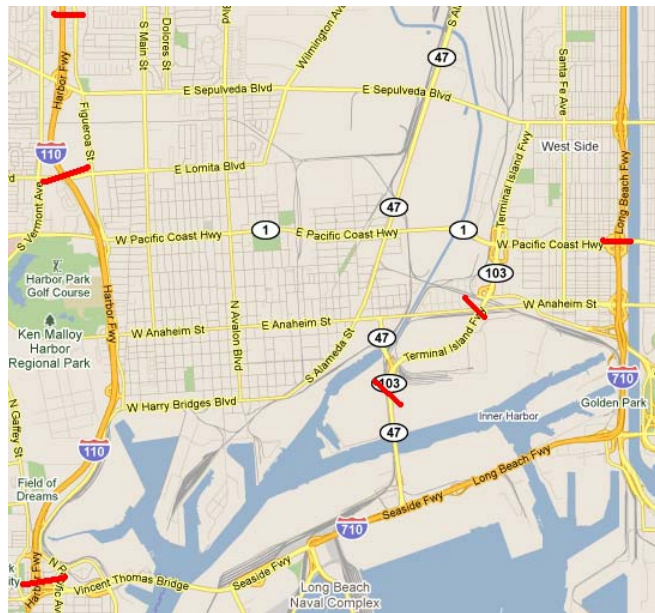


Figure 22: Bridge damage estimation in Palos-Verdes earthquake

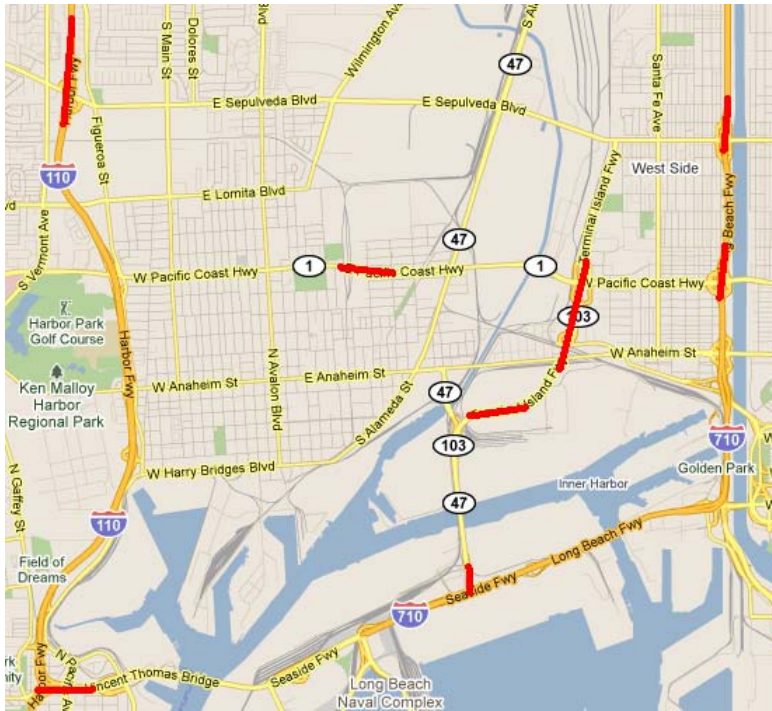


Figure 23: Link Closure 3 days after Palos-Verdes earthquake

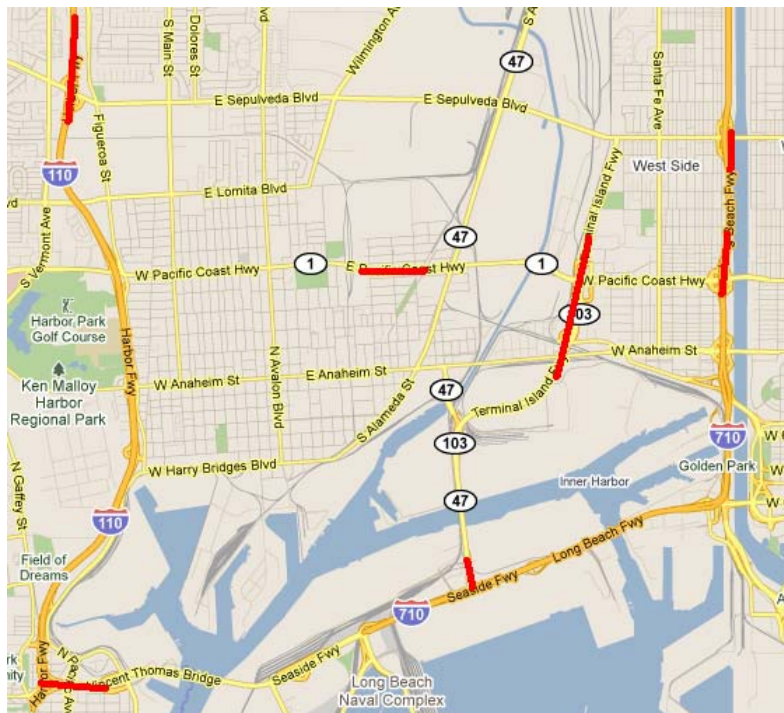


Figure 24: Link Closure 12 days after Palos-Verdes earthquake

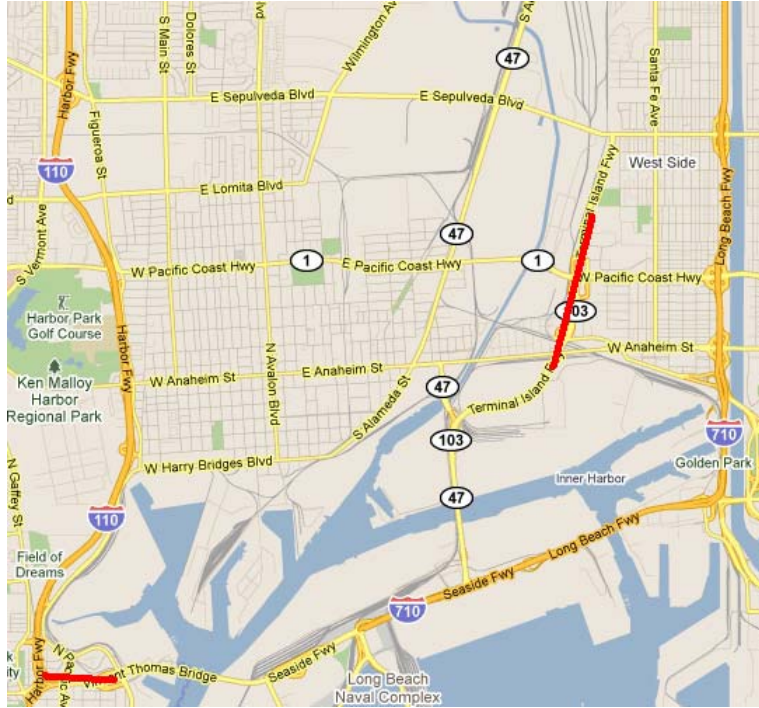


Figure 25: Link Closure 49 days after Palos-Verdes earthquake

We use the same assumptions for losses, where \$13.45 PCU-hour delay for automobile trips and \$28.42 PCU-hour delay for commercial-vehicle (freight-transport) trips. Table 10 and Figure 26 illustrate the simulation results.

Table 10: Economic loss due to vehicle delay in Palos-Verdes earthquake

Days	Passenger (PCU-hour Delay)	Freight (PCU-hour Delay)	Loss(Cumulative, \$M)
0	100810	82996	0
3	100810	82996	11.043
12	74187	52764	47.98
49	49870	8786	130.963
140	49870	8786	258.669
181	0	0	341.221

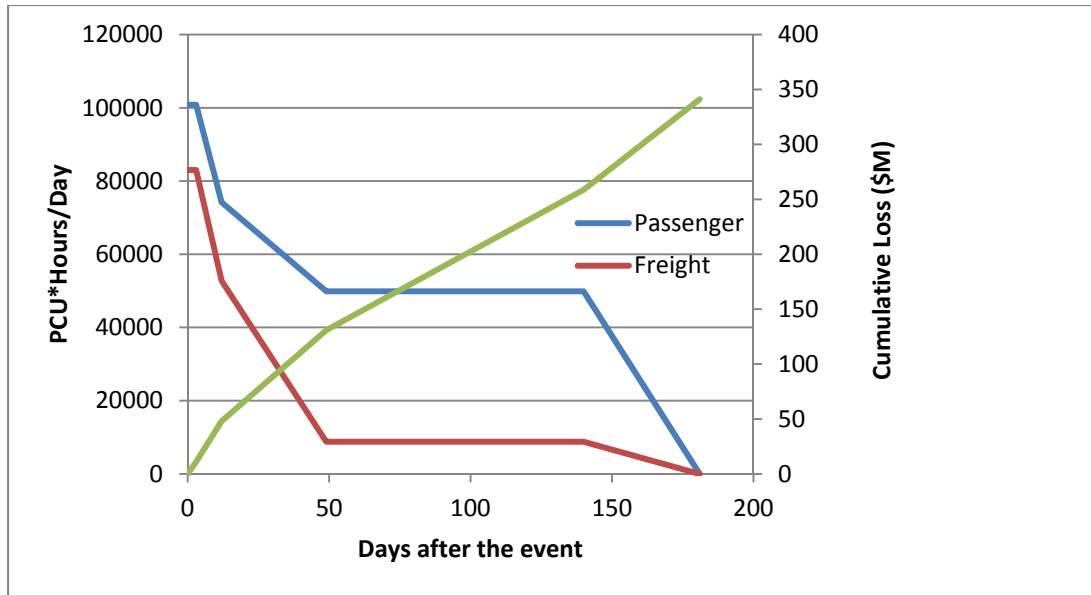


Figure 26: Economic loss due to vehicle delay in Palos-Verdes earthquake

3.3 San-Andreas earthquake

San-Andreas earthquake does not have a direct impact on the port complex region. It has indirect impact on the steady traffic flow in the port complex region and the results are demonstrated in the Table 11 and Figure 27.

Table 11: Economic loss due to vehicle delay in San-Andreas earthquake

Days	Passenger (PCU-hour Delay)	Freight (PCU-hour Delay)	Loss(Cumulative, \$M)
0	91925	75515	0
3	91925	75515	10.056
12	78752	47774	44.539
49	40688	12685	125.262
140	40688	12685	251.204
181	0	0	332.616

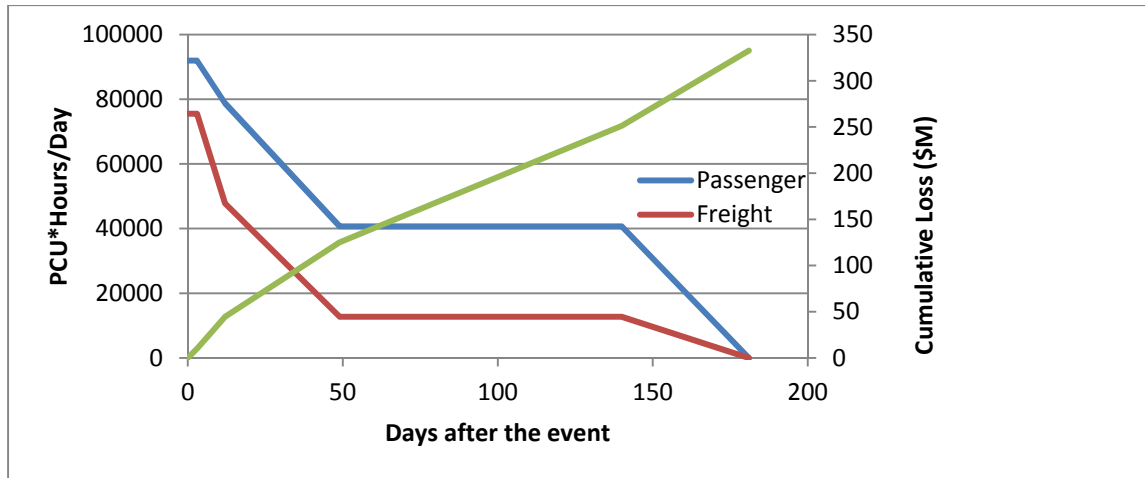


Figure 27: Economic loss due to vehicle delay in San-Andreas earthquake

4 Impact analysis for Port Operations

Damage to the roadway system feeding the terminals will have a negative impact on the port operation processes. Under this task we plan to use our terminal models we developed under METRANS as well as a cost model to evaluate the impact of any incident on the port operations.

4.1 Macroscopic Terminal Simulator

We developed Terminal Simulator that is a macroscopic model and focuses on the flows of containers in and out of terminals rather than individual pieces of equipment. The Terminal Simulator is used to simulate all the 15 container terminals of Los Angeles and Long Beach port simultaneously. The simulator takes inputs from the roadway network as well as trains, ships and generates output flows to the road network, ships, and trains.

The simulation executive is comprised of container terminal object and three other objects used to generate trucks, ships and trains. Other major components such as import and export yards, train and ship cranes, and inbound and outbound gates are contained within the terminal object. The Terminal Simulator model emulates the actual operation of shipping terminal. The exact processes in container terminal are controlled by parameters set by the user.

The Macroscopic Terminal Simulator Model could be modified to create a new Terminal Simulator package which would be able to track individual trucks and containers as they enter the inbound gate and follow them through the yard. This process enables the user to record wait and cycle times at different junctions in the terminal, obtain useful statistics, and create more sophisticated and complex scenarios. Figure 28 presents the inter-component

connections of a container terminal in Terminal Simulation Model.

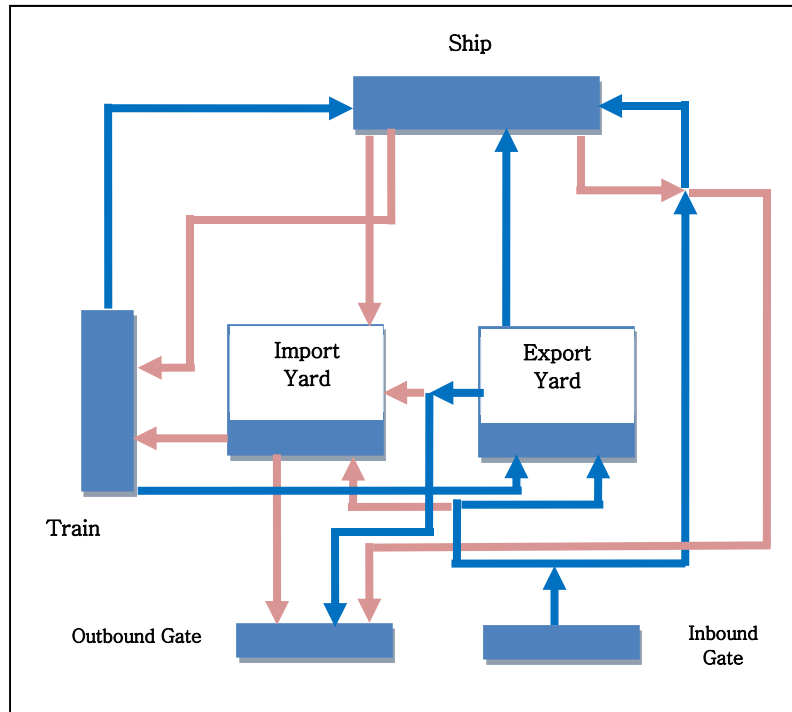


Figure 28: Seaport container terminal model

The constructed VISSIM transportation network of the adjacent streets to the twin ports has to be integrated with the macroscopic terminal model in order to generate the volumes of trucks entering and leaving the twin ports. Component Object Model (COM) interface allows VISSIM to work as an automation server to import and export data. COM interface collects data from traffic simulation model and generates input for the terminal simulation model. On the other hand, it provides input for the traffic simulation model from the output of the terminal simulation model. COM interface generates inputs for both terminal and urban traffic simulation model in each clock event.

Link closures and bridge damages are applied to the integrated model consisting of macroscopic terminal simulator and transportation network (VISSIM). Terminal operational cost model is used to calculate additional terminal operational costs in the LA/LB port complex. Terminal operational cost model and formulation is described in detail in section 4.2.

4.2 Terminal Operational Cost Model

One useful measure that is often used for economic evaluation of container terminal operations is the Average Cost per Container (ACC). ACC is the average cost to move a container through a terminal. It is calculated as the ratio of

the total yearly expenses of a terminal to the number of containers processed at that terminal in a year. Terminal operational cost unit can be derived from ACC. The following elements contribute to the total cost calculation.

- Cost of activities
- Cost of land
- Cost of equipment
- Cost of labors

4.2.1 Cost of activities

Container terminals contain several operation divisions in order to handle containers including gates, berths, storage yards, maintenance areas, and a central controller. Initial investment is required to build the structures in the terminal area; that investment is expressed as a fixed cost. There exist some variable costs with respect to daily operations. For instance, electricity cost associated with the activities inside container terminals is considered as part of variable cost of activities. Total cost of activities (TCA) is defined as the sum of variable and fixed costs. Fixed cost of activities (FCA) is calculated by the following formula:

$$FCA = \frac{II}{AL} + II * (PIT + PIS + PRE) \quad (1)$$

Annual ratio of capital investment is calculated by dividing initial investment to accounting life. In the above formula, II represents initial investment and AL is accounting life. Every facility in a container terminal has costs relating to insurance, interest and maintenance repairs. PIT, PIS, and PRE are percentages of insurance, interest and repair respectively.

4.2.2 Cost of land

Container terminals are usually operated by private sector. Terminal buildings are constructed on large acreages that require significant the capital investments. The price of land depends on the location of land. It is calculated by multiplying the area of the land (in acres) with land cost per acre and taking into account inflation rate. Annual cost of land is calculated as follows:

$$A = P * R * \left(\frac{(1+R)^n}{(1+R)^n - 1} \right) \quad (2)$$

where A is the annual land cost, R is the inflation rate, P is the initial land investment, and n represents the accounting life. Therefore, total annual land cost (TALC) can be expressed:

$$TALC = P*IR+A \quad (3)$$

where IR represents lost investment opportunity that is the average (over 25 years) annual interest rate.

4.2.3 Cost of equipment

The number of vehicles, quay cranes, yard cranes, management infrastructure and other equipment of a container terminal are accounted in the equipment cost calculation. Two main costs are engaged in the equipment cost calculation.

1. Variable cost
2. Fixed cost

Energy consumption of equipment is variable depending on working hours (WH) and utilization factor, the percentage of equipment employed at a given time (UF). Hence, equipment variable cost (EVC) can be presented as (4).

$$EVC = WH * PPH * UF * n \quad (4)$$

PPH indicates price of energy per hour and n is number of pieces equipment. The equipment fixed cost (EFC) is calculated the same way as activities fixed cost, i.e.

$$EFC = \frac{II}{AL} + II * (PIT + PIS + PRE) \quad (5)$$

Total cost of equipment (TCE) is expressed by adding up the variable and fixed costs for equipment in a container terminal.

$$TCE = EVC + EFC \quad (6)$$

4.2.4 Cost of labor

Overtime working hour cost (OWH) is 1.5 times higher than regular hourly wages. Adding regular working hour (RWH) and overtime costs yield total cost of labor. Therefore, total labor cost (TLC) is determined by (7).

$$TLC = RWH + OWH \quad (7)$$

Let ANC corresponds to the annual number of containers that are handled in a container terminal; thus, ACC is defined as annual total terminal operational cost divided by ANC .

$$ACC = \frac{TCA + TACL + TEC + TLC}{ANC} \quad (8)$$

4.2.5 Economic impact on the container terminals

Container terminals operate under tight constraints due to pressures for performance due to rising demand, pressure for lower cost in order to meet competition. Any event that disturbs the normal operations of the terminals could lead to high cost and disruption of the transportation chain that can be felt all over the world. Following Tables illustrate additional operational costs of the integrated model including macroscopic terminal simulator, VISSIM as well as terminal operational cost model due to three hypothetical earthquakes. Note, the inputs of the integrated model are provided by REDARS2 methodology and software.

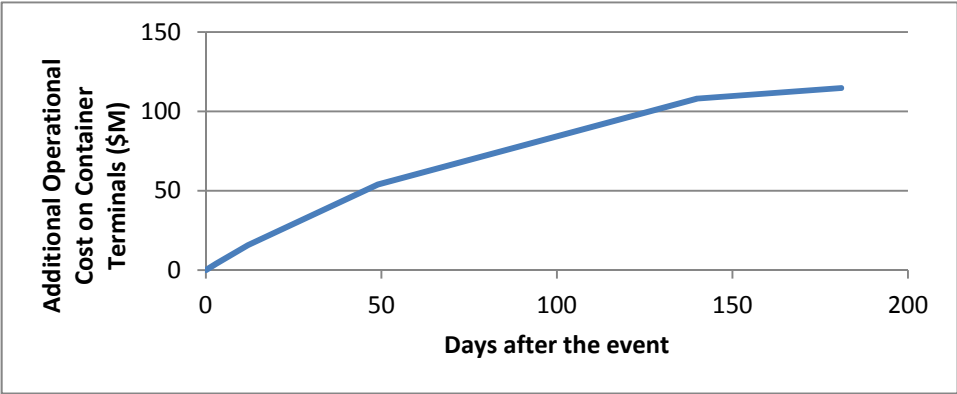


Figure 29: Additional terminal cost due to vehicles delay in Newport-Inglewood earthquake

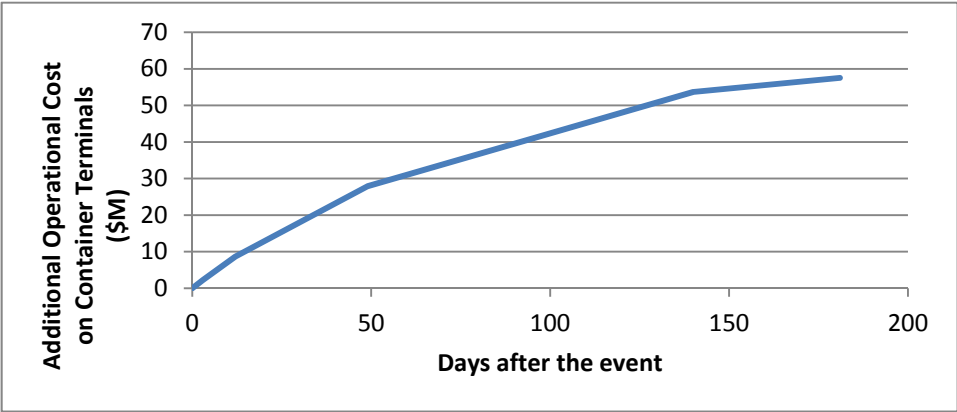


Figure 30: Additional terminal cost due to vehicles delay in Palos-Verdes earthquake

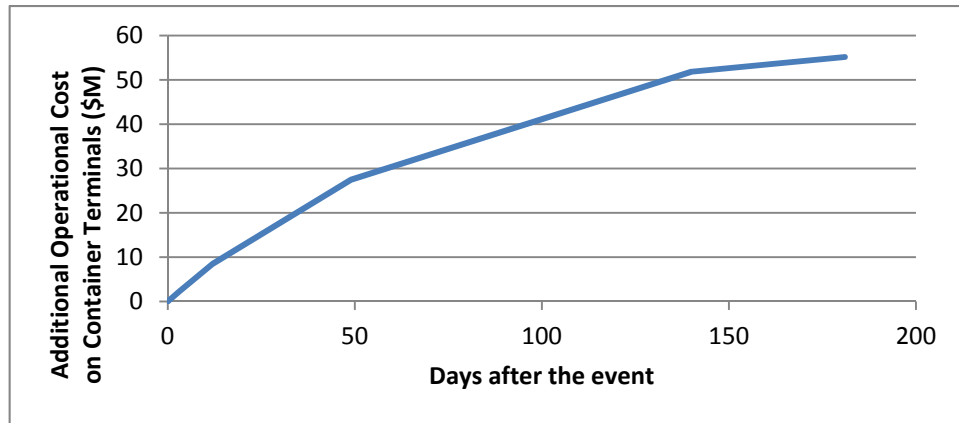


Figure 31: Additional terminal cost due to vehicles delay in San-Andreas earthquake

The additional terminal cost can be decreased by reducing demands at container terminals. The assumption is that demands at the port of LA/LB complex are reduced in the first three days for each earthquake scenario. The results are demonstrated in the following Figures.

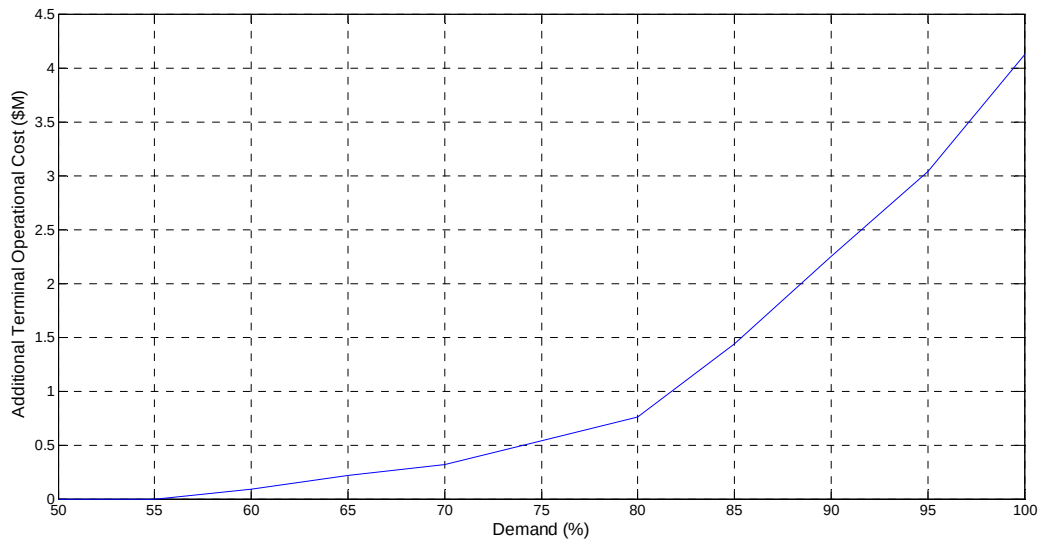


Figure 32: Decreasing additional terminal cost in Newport-Inglewood earthquake

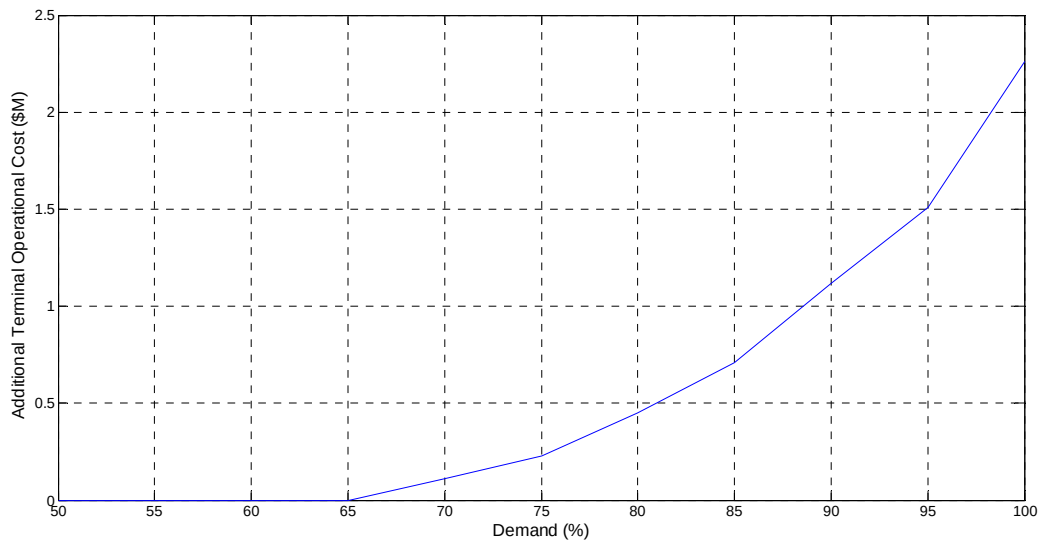


Figure 33: Decreasing additional terminal cost in Palos-Verdes earthquake

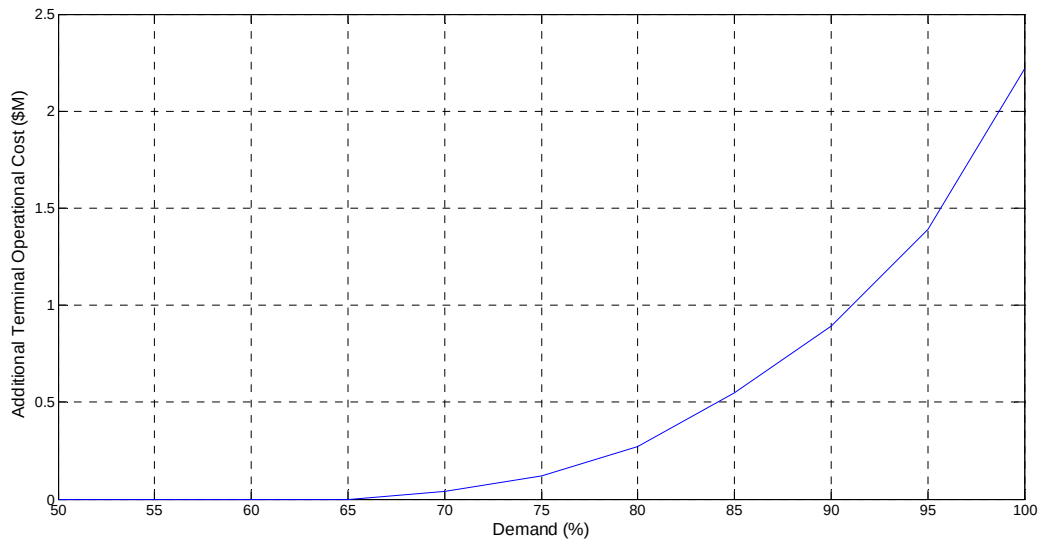


Figure 34: Decreasing additional terminal cost in San-Andreas earthquake

5 Direct Impacts

Tables 12 to 14 show direct losses by each case. These tables were available from the research outcomes conducted by the USC team.

Table 12: Newport/Inglewood Direct Percent Losses on Los Angeles and Long Beach ports (\$M)

Days After Earthquake	0	3	12	49	140	181
PCT Reduced	0	7.7201448	5.548854	3.136309	3.1363088	0

Table 13: Palos/Verdes Direct Percent Losses on Los Angeles and Long Beach ports (\$M)

Days After Earthquake	0	3	12	49	140	181
PCT Reduced	0	5.910736	3.860072	2.171291	2.171291	0

Table 14: South San Andreas Direct Percent Losses on Los Angeles and Long Beach ports (\$M)

Days After Earthquake	0	3	12	49	140	181
PCT Reduced	0	5.428227	4.101327	1.809409	1.809409	0

5.1 Scenarios

The dollar losses were calculated based on the trade flows of Los Angeles and Long Beach dual ports. Tables 15 and 16 suggest the domestic and foreign exports and imports, respectively, for 180 days in 2001 by the USC Sector, referring to Park (2008)'s study. Based on the Tables 15 and 16, the direct losses stemming from the scenario-based earthquake damages were suggested in Table 17. Based on the effects, the three scenarios were run with the NIEMO to estimate the total economic impacts. Tables 18 to 20 provide the estimated total losses by trade type and by state. Further, to figure out per capita losses, total population data of each state were collected and the last two columns suggest per capita economic losses of exports and imports. Demand-driven NIEMO for export losses and supply-driven NIEMO for import losses were applied.

Table 15: Domestic and foreign exports for 180 days in 2001 by the USC Sector (unit: \$ millions)

USC Sectors	2001 WISERT	2001 WCUS	SUM	FD LOSS
EXPORT	FOREIGN	DOMESTIC	ONE YEAR TOTAL	180 DAYS TOTAL
USC 1	1,267	61	1,327	655
USC 2	1,842	72	1,914	944
USC 3	1,948	57	2,005	989
USC 4	104	14	118	58
USC 5	932	69	1,002	494
USC 6	116	100	215	106
USC 7	342	1	342	169
USC 8	143	5	147	73
USC 9	66	0	66	33

USC 10	669	4,669	5,338	2,632
USC 11	2,562	44	2,607	1,286
USC 12	490	21	511	252
USC 13	26	0	26	13
USC 14	2,091	762	2,853	1,407
USC 15	3,445	19	3,464	1,708
USC 16	191	715	906	447
USC 17	576	28	604	298
USC 18	225	553	778	384
USC 19	1,223	440	1,663	820
USC 20	508	2,070	2,578	1,271
USC 21	493	77	569	281
USC 22	657	480	1,138	561
USC 23	5,078	179	5,257	2,593
USC 24	3,161	794	3,955	1,950
USC 25	1,434	1,048	2,481	1,224
USC 26	791	540	1,331	657
USC 27	821	1,500	2,321	1,145
USC 28	307	420	726	358
USC 29	1,714	1,416	3,131	1,544
Total	33,222	16,154	49,376	24,350
Use only 29 USC commodity sectors	Convert SITC to USC sectors, and then, use WISERT data directly	First, Convert WCUS to SITC in Short Tons. Second, Convert Tons to Dollars from WISERTrade Foreign data. Finally, convert SITC to USC sectors.	WISERT+WCUS	FD LOSS = SUM*(180/365)

Table 16: Domestic and foreign imports for 180 days in 2001 by the USC Sector (unit: \$ millions)

USC Sectors	2001 WISERT	2001 WCUS	SUM	FD LOSS
IMPORT	FOREIGN	DOMESTIC	ONE YEAR TOTAL	180 DAYS TOTAL
USC 1	3,462	3	3,465	1,709
USC 2	798	44	842	415
USC 3	306	5	311	153
USC 4	216	2	218	107
USC 5	1,026	107	1,132	558
USC 6	586	2	588	290
USC 7	65	1	66	33
USC 8	37	4	41	20
USC 9	9	0	9	4
USC 10	3,108	3,104	6,212	3,063
USC 11	2,260	468	2,728	1,345
USC 12	153	3	157	77
USC 13	4	0	4	2
USC 14	1,433	1,078	2,510	1,238
USC 15	6,639	8	6,647	3,278
USC 16	1,598	213	1,811	893
USC 17	889	4	893	440
USC 18	1,017	26	1,043	514
USC 19	34,786	63	34,849	17,186
USC 20	2,568	29	2,597	1,281
USC 21	1,741	3	1,744	860
USC 22	6,421	43	6,463	3,187
USC 23	12,597	58	12,655	6,241
USC 24	41,181	76	41,257	20,346
USC 25	17,588	465	18,054	8,903
USC 26	539	56	595	293
USC 27	4,018	144	4,162	2,053
USC 28	7,910	18	7,928	3,910
USC 29	11,623	56	11,679	5,760
Total	164,577	6,082	170,659	84,161
Use only 29 USC commodity sectors	Convert SITC to USC sectors, and then, use WISERT data directly	First, Convert WCUS to SITC in Short Tons. Second, Convert Tons to Dollars from WISERTrade Foreign data. Finally, convert SITC to USC sectors.	WISERT+WCUS	FD LOSS = SUM*(180/365)

Table 17: Direct losses by each earthquake scenario by the USC Sector (unit: \$ millions)

FD LOSS BY USC SECTOR FROM THE EARTHQUAKE SCENARIOS	EXPORTS			IMPORTS		
	Newport / Inglewood	Palos / Verdes	South San Andreas	Newport / Inglewood	Palos / Verdes	South San Andreas
USC 1	12,793	9,239	8,608	33,393	24,117	22,468
USC 2	18,448	13,324	12,413	8,114	5,860	5,460
USC 3	19,323	13,955	13,001	2,998	2,165	2,017
USC 4	1,134	819	763	2,100	1,516	1,413
USC 5	9,653	6,972	6,495	10,911	7,880	7,341
USC 6	2,077	1,500	1,397	5,666	4,092	3,812
USC 7	3,300	2,383	2,220	635	459	428
USC 8	1,420	1,026	956	395	285	266
USC 9	640	462	431	83	60	56
USC 10	51,440	37,151	34,611	59,862	43,233	40,277
USC 11	25,121	18,143	16,902	26,293	18,989	17,691
USC 12	4,924	3,556	3,313	1,510	1,091	1,016
USC 13	255	184	172	37	27	25
USC 14	27,494	19,857	18,499	24,193	17,473	16,278
USC 15	33,385	24,111	22,463	64,053	46,261	43,098
USC 16	8,733	6,307	5,876	17,450	12,603	11,741
USC 17	5,822	4,205	3,917	8,605	6,215	5,790
USC 18	7,495	5,413	5,043	10,054	7,261	6,765
USC 19	16,026	11,574	10,783	335,835	242,547	225,963
USC 20	24,844	17,943	16,716	25,028	18,075	16,840
USC 21	5,487	3,963	3,692	16,804	12,136	11,306
USC 22	10,963	7,918	7,376	62,286	44,984	41,908
USC 23	50,665	36,592	34,090	121,954	88,078	82,055
USC 24	38,111	27,525	25,643	397,596	287,153	267,518
USC 25	23,912	17,270	16,089	173,982	125,654	117,062
USC 26	12,830	9,266	8,632	5,735	4,142	3,859
USC 27	22,368	16,154	15,050	40,110	28,968	26,988
USC 28	7,001	5,056	4,710	76,402	55,180	51,407
USC 29	30,171	21,790	20,300	112,553	81,288	75,730
TOTAL	475,834	343,658	320,160	1,644,636	1,187,793	1,106,576

NOTE: FD LOSS BY EARTHQUAKE = (Loss Percent available in Tables 12 to 14)* (FD LOSS available in Tables 16 and 17)

Table 18: Sum of intra- and inter-state effects of Los Angeles and Long Beach ports disruption for 180 days: a Newport/Inglewood case

State	Export Losses (\$M.)		Import Losses (\$M.)		2000 Total Population (Unit: 1,000)	Per Capita Export Losses	Per Capita Import Losses
	Direct Impacts	Indirect Impacts	Direct Impacts	Indirect Impacts			
AL	0.00	31.61	0.00	57.14	4,447	7.11	12.85
AK	0.00	3.62	0.00	47.85	627	5.77	76.32
AZ	0.00	62.95	0.00	425.59	5,131	12.27	82.95
AR	0.00	29.92	0.00	75.51	2,673	11.19	28.25
CA	4,824.43	3,096.84	16,674.78	9,949.10	33,872	233.86	786.02
CO	0.00	36.82	0.00	119.64	4,301	8.56	27.82
CT	0.00	18.81	0.00	33.35	3,406	5.52	9.79
DE	0.00	5.95	0.00	11.17	784	7.60	14.26
DC	0.00	0.73	0.00	11.75	572	1.28	20.53
FL	0.00	36.61	0.00	161.60	15,982	2.29	10.11
GA	0.00	30.39	0.00	74.99	8,186	3.71	9.16
HI	0.00	6.33	0.00	53.55	1,212	5.23	44.20
ID	0.00	14.44	0.00	30.68	1,294	11.16	23.71
IL	0.00	83.06	0.00	129.97	12,419	6.69	10.46
IN	0.00	62.34	0.00	64.04	6,080	10.25	10.53
IA	0.00	42.28	0.00	31.91	2,926	14.45	10.90
KS	0.00	37.51	0.00	45.43	2,688	13.95	16.90
KY	0.00	34.19	0.00	48.41	4,042	8.46	11.98
LA	0.00	91.40	0.00	97.32	4,469	20.45	21.78
ME	0.00	6.32	0.00	13.25	1,275	4.95	10.40
MD	0.00	13.40	0.00	60.82	5,296	2.53	11.48
MA	0.00	25.56	0.00	95.06	6,349	4.03	14.97
MI	0.00	64.48	0.00	132.46	9,938	6.49	13.33
MN	0.00	39.63	0.00	70.03	4,919	8.06	14.24
MS	0.00	17.21	0.00	19.97	2,845	6.05	7.02
MO	0.00	42.12	0.00	62.58	5,595	7.53	11.18
MT	0.00	19.08	0.00	24.12	902	21.15	26.73
NE	0.00	29.69	0.00	64.37	1,711	17.35	37.61
NV	0.00	15.34	0.00	109.55	1,998	7.67	54.82
NH	0.00	8.47	0.00	20.37	1,236	6.85	16.49
NJ	0.00	49.63	0.00	82.91	8,414	5.90	9.85
NM	0.00	7.76	0.00	24.94	1,819	4.26	13.71
NY	0.00	64.31	0.00	170.96	18,976	3.39	9.01

NC	0.00	38.86	0.00	72.73	8,049	4.83	9.04
ND	0.00	5.71	0.00	5.76	642	8.90	8.97
OH	0.00	90.11	0.00	96.16	11,353	7.94	8.47
OK	0.00	31.64	0.00	45.57	3,451	9.17	13.21
OR	0.00	59.08	0.00	106.15	3,421	17.27	31.03
PA	0.00	72.46	0.00	107.68	12,281	5.90	8.77
RI	0.00	5.69	0.00	11.52	1,048	5.43	10.99
SC	0.00	19.65	0.00	25.12	4,012	4.90	6.26
SD	0.00	7.88	0.00	11.21	755	10.44	14.85
TN	0.00	39.50	0.00	42.02	5,689	6.94	7.39
TX	0.00	459.58	0.00	356.29	20,852	22.04	17.09
UT	0.00	37.24	0.00	58.35	2,233	16.68	26.13
VM	0.00	2.83	0.00	5.95	609	4.64	9.77
VA	0.00	19.91	0.00	65.80	7,079	2.81	9.30
WA	0.00	93.21	0.00	289.61	5,894	15.81	49.14
WV	0.00	12.41	0.00	17.33	1,808	6.86	9.58
WI	0.00	61.87	0.00	75.12	5,364	11.53	14.00
WY	0.00	7.64	0.00	6.06	494	15.47	12.26
US Total	4,824.43	5,194.07	16,674.78	13,818.80	281,422	35.60	59.25
Rest of World	0.00	576.90	0.00	1,052.61			
World Total	4,824.43	5,770.96	16,674.78	14,871.41			

Note: 2000 population by state were collected from Census 2000 available at www.census.gov.

Table 19: Sum of intra- and inter-state effects of Los Angeles and Long Beach ports disruption for 180 days: a Palos/Verdes case

State	Export Losses (\$M.)		Import Losses(\$M.)		2000 Total Population (Unit: 1,000)	Per Capita Export Losses	Per Capita Import Losses
	Direct Impacts	Indirect Impacts	Direct Impacts	Indirect Impacts			
AL	0.00	22.83	0.00	41.26	4,447	5.13	9.28
AK	0.00	2.61	0.00	34.56	627	4.17	55.12
AZ	0.00	45.47	0.00	307.37	5,131	8.86	59.91
AR	0.00	21.61	0.00	54.54	2,673	8.08	20.40
CA	3,484.31	2,236.61	12,042.90	7,185.46	33,872	168.90	567.68
CO	0.00	26.59	0.00	86.41	4,301	6.18	20.09
CT	0.00	13.58	0.00	24.09	3,406	3.99	7.07
DE	0.00	4.30	0.00	8.07	784	5.49	10.30
DC	0.00	0.53	0.00	8.48	572	0.93	14.83
FL	0.00	26.44	0.00	116.71	15,982	1.65	7.30
GA	0.00	21.95	0.00	54.16	8,186	2.68	6.62
HI	0.00	4.57	0.00	38.67	1,212	3.78	31.92
ID	0.00	10.43	0.00	22.16	1,294	8.06	17.12
IL	0.00	59.99	0.00	93.86	12,419	4.83	7.56
IN	0.00	45.02	0.00	46.25	6,080	7.40	7.61
IA	0.00	30.53	0.00	23.05	2,926	10.43	7.88
KS	0.00	27.09	0.00	32.81	2,688	10.08	12.20
KY	0.00	24.69	0.00	34.96	4,042	6.11	8.65
LA	0.00	66.01	0.00	70.29	4,469	14.77	15.73
ME	0.00	4.56	0.00	9.57	1,275	3.58	7.51
MD	0.00	9.68	0.00	43.92	5,296	1.83	8.29
MA	0.00	18.46	0.00	68.66	6,349	2.91	10.81
MI	0.00	46.57	0.00	95.66	9,938	4.69	9.63
MN	0.00	28.62	0.00	50.58	4,919	5.82	10.28
MS	0.00	12.43	0.00	14.42	2,845	4.37	5.07
MO	0.00	30.42	0.00	45.20	5,595	5.44	8.08
MT	0.00	13.78	0.00	17.42	902	15.28	19.31
NE	0.00	21.44	0.00	46.49	1,711	12.53	27.17
NV	0.00	11.08	0.00	79.12	1,998	5.54	39.59
NH	0.00	6.11	0.00	14.72	1,236	4.95	11.91
NJ	0.00	35.85	0.00	59.88	8,414	4.26	7.12
NM	0.00	5.60	0.00	18.01	1,819	3.08	9.90
NY	0.00	46.45	0.00	123.47	18,976	2.45	6.51
NC	0.00	28.07	0.00	52.53	8,049	3.49	6.53

ND	0.00	4.13	0.00	4.16	642	6.42	6.48
OH	0.00	65.08	0.00	69.45	11,353	5.73	6.12
OK	0.00	22.85	0.00	32.91	3,451	6.62	9.54
OR	0.00	42.67	0.00	76.67	3,421	12.47	22.41
PA	0.00	52.33	0.00	77.77	12,281	4.26	6.33
RI	0.00	4.11	0.00	8.32	1,048	3.92	7.94
SC	0.00	14.19	0.00	18.14	4,012	3.54	4.52
SD	0.00	5.69	0.00	8.09	755	7.54	10.72
TN	0.00	28.53	0.00	30.35	5,689	5.01	5.33
TX	0.00	331.92	0.00	257.32	20,852	15.92	12.34
UT	0.00	26.90	0.00	42.14	2,233	12.04	18.87
VM	0.00	2.04	0.00	4.30	609	3.35	7.06
VA	0.00	14.38	0.00	47.52	7,079	2.03	6.71
WA	0.00	67.32	0.00	209.16	5,894	11.42	35.49
WV	0.00	8.96	0.00	12.51	1,808	4.96	6.92
WI	0.00	44.68	0.00	54.25	5,364	8.33	10.11
WY	0.00	5.52	0.00	4.37	494	11.17	8.86
US Total	3,484.31	3,751.27	12,042.90	9,980.24	281,422	12.91	21.48
Rest of World	0.00	416.65	0.00	760.22			
World Total	3,484.31	4,167.92	12,042.90	10,740.46			

Note: 2000 population by state were collected from Census 2000 available at www.census.gov.

Table 20: Sum of intra- and inter-state effects of Los Angeles and Long Beach ports disruption for 180 days: a South San Andreas case

State	Export Losses (\$M.)		Import Losses(\$M.)		2000 Total Population (Unit: 1,000)	Per Capita Export Losses	Per Capita Import Losses
	Direct Impacts	Indirect Impacts	Direct Impacts	Indirect Impacts			
AL	0.00	21.27	0.00	38.44	4,447	4.78	8.64
AK	0.00	2.43	0.00	32.19	627	3.88	51.35
AZ	0.00	42.36	0.00	286.35	5,131	8.26	55.81
AR	0.00	20.13	0.00	50.81	2,673	7.53	19.01
CA	3,246.07	2,083.68	11,219.45	6,694.15	33,872	157.35	528.87
CO	0.00	24.77	0.00	80.50	4,301	5.76	18.72
CT	0.00	12.65	0.00	22.44	3,406	3.72	6.59
DE	0.00	4.01	0.00	7.52	784	5.11	9.60
DC	0.00	0.49	0.00	7.90	572	0.86	13.82
FL	0.00	24.63	0.00	108.73	15,982	1.54	6.80
GA	0.00	20.45	0.00	50.46	8,186	2.50	6.16
HI	0.00	4.26	0.00	36.03	1,212	3.52	29.74
ID	0.00	9.71	0.00	20.64	1,294	7.51	15.95
IL	0.00	55.88	0.00	87.45	12,419	4.50	7.04
IN	0.00	41.94	0.00	43.09	6,080	6.90	7.09
IA	0.00	28.44	0.00	21.47	2,926	9.72	7.34
KS	0.00	25.24	0.00	30.56	2,688	9.39	11.37
KY	0.00	23.01	0.00	32.57	4,042	5.69	8.06
LA	0.00	61.50	0.00	65.48	4,469	13.76	14.65
ME	0.00	4.25	0.00	8.92	1,275	3.33	6.99
MD	0.00	9.02	0.00	40.92	5,296	1.70	7.73
MA	0.00	17.20	0.00	63.96	6,349	2.71	10.07
MI	0.00	43.38	0.00	89.12	9,938	4.37	8.97
MN	0.00	26.66	0.00	47.12	4,919	5.42	9.58
MS	0.00	11.58	0.00	13.44	2,845	4.07	4.72
MO	0.00	28.34	0.00	42.11	5,595	5.06	7.53
MT	0.00	12.84	0.00	16.23	902	14.23	17.99
NE	0.00	19.98	0.00	43.31	1,711	11.67	25.31
NV	0.00	10.32	0.00	73.71	1,998	5.16	36.89
NH	0.00	5.70	0.00	13.71	1,236	4.61	11.09
NJ	0.00	33.39	0.00	55.78	8,414	3.97	6.63
NM	0.00	5.22	0.00	16.78	1,819	2.87	9.22
NY	0.00	43.27	0.00	115.03	18,976	2.28	6.06

NC	0.00	26.15	0.00	48.93	8,049	3.25	6.08
ND	0.00	3.84	0.00	3.88	642	5.98	6.03
OH	0.00	60.63	0.00	64.70	11,353	5.34	5.70
OK	0.00	21.29	0.00	30.66	3,451	6.17	8.89
OR	0.00	39.75	0.00	71.42	3,421	11.62	20.88
PA	0.00	48.75	0.00	72.45	12,281	3.97	5.90
RI	0.00	3.83	0.00	7.75	1,048	3.65	7.40
SC	0.00	13.22	0.00	16.90	4,012	3.30	4.21
SD	0.00	5.30	0.00	7.54	755	7.03	9.99
TN	0.00	26.58	0.00	28.27	5,689	4.67	4.97
TX	0.00	309.22	0.00	239.73	20,852	14.83	11.50
UT	0.00	25.06	0.00	39.26	2,233	11.22	17.58
VM	0.00	1.90	0.00	4.00	609	3.12	6.58
VA	0.00	13.40	0.00	44.27	7,079	1.89	6.25
WA	0.00	62.72	0.00	194.86	5,894	10.64	33.06
WV	0.00	8.35	0.00	11.66	1,808	4.62	6.45
WI	0.00	41.63	0.00	50.54	5,364	7.76	9.42
WY	0.00	5.14	0.00	4.07	494	10.41	8.25
US Total	3,246.07	3,494.77	11,219.45	9,297.83	281,422	13.86	23.06
Rest of World	0.00	388.16	0.00	708.24			
World Total	3,246.07	3,882.93	11,219.45	10,006.07			

Note: 2000 population by state were collected from Census 2000 available at www.census.gov.

The direct impact by industry in Table 17 indicates the direct economic losses for the each case area in the Southern California region, resulting from the losses of exports and imports. Because the direct exports and imports losses are part of final demand and value added, respectively, in the I-O account, traditional demand driven NIEMO runs for the former case and supply-driven NIEMO runs for the latter case were applied. For the discussion of supply-driven I-O and an application of supply-driven NIEMO, refer to the study of (Gordon et al., 2009, Park JY. 2008, Park et al., 2013).

5.2 National Interstate Economic Model (NIEMO) Results

The two NIEMO versions in this research involved the economic impact results to estimate demand- and supply-driven effects for the states that were directly affected and that accounted for the additional impacts of the indirect effects in a full interregional trade system. Tables 18 to 20 suggest the economic impacts by each scenario, where foreign and domestic imports and exports are reported.

According to the scenarios, total economic exports and imports losses were diverse; the range of total exports losses is in \$7 billion to \$10.6 billion and that of the total imports is in \$22 billion to \$31 billion. Regarding the per capita impact, except California, Texas, Montana, Louisiana, and Nebraska may take sizable losses in the case of exports closure. Per capita import losses show much more explicit results which are suggested in the last column; however, slightly different from the exports cases, people living in Arizona, Alaska, and Nevada may be economically impacted due to the disturbance of imports from the earthquake.

These results require caveats. NIEMO's loss outputs are annual rates at which losses accumulated across sectors and locations given a sudden interruption in trade flows. A loss of port capacity associated with any scenario earthquake will induce subsequent adjustments in trade flows as economic actors seek and find alternatives, and as the prices for accessing these alternatives adjust. These adjustments will moderate the rate at which losses accumulate, and extrapolating the loss rates provided by NIEMO do not account for these effects. The scenarios examined here are reasonably lengthy, with reductions in port capacity on the order of six months. Without a mechanism for building in the price adjustments that would inevitably occur during this period, NIEMO is necessarily overstating total losses.

A computable general equilibrium (CGE) approach would be more robust framework, because CGE models include endogenous prices. Unfortunately, the data requirements necessary to specify an application at the scale of NIEMO make the CGE approach infeasible in this context.

6 Conclusions

This research attempts to examine the risks imposed on and recoveries of transportation systems in megacities as the result of extreme events such as earthquakes and make a stronger connection between delay and economic cost in order to explore the cost of not preparing our infrastructure systems for extreme events.

The estimation of level of disruption and corresponding damage to the transportation network infrastructure is performed by REDARS. We examine the economic impacts of an earthquake along one of Southern California's active faults. In doing this, we predict which pieces of infrastructure fail as well as the recovery time to repair this infrastructure. We identify critical failed transportation links that carry traffic in and out of the Los Angeles/Long Beach port complex, an economic engine in the Los Angeles Basin. The integrated model consisting of a macroscopic terminal simulator, microscopic traffic simulator, and terminal cost model is developed to estimate the changes in traffic flows due to earthquake and evaluate the economic impact at the local level. NIEMO software is used to evaluate the economic impact of extreme events globally. Southern California is regarded as the region of study. The computational results demonstrate the efficiency of the integrated model.

Further work of this topic would be examining the effect of extreme events on links that carry traffic in and out of other critical economic infrastructure. For example the failure of roads or railroads leading to or from one of Los Angeles' several intermodal rail yards would have serious economic consequences. A complete analysis of earthquakes and their effects on major freight transportation hubs of the Los Angeles region would do much to aid the strategic planning of our infrastructure investment and maintenance. In an era with limited capital for infrastructure investment we realize that we need to prioritize the uninterrupted functioning of certain critical links while we can afford to let other links temporarily fail after an extreme event.

Appendix

Table A1: USC Sector Definition

Classification	USC	Description
Commodity Sectors	USC01	Live animals and live fish & Meat, fish, seafood, and their preparations
	USC02	Cereal grains & Other agricultural products except for Animal Feed
	USC03	Animal feed and products of animal origin, n.e.c.
	USC04	Milled grain products and preparations, and bakery products
	USC05	Other prepared foodstuffs and fats and oils
	USC06	Alcoholic beverages
	USC07	Tobacco products
	USC08	Nonmetallic minerals (Monumental or building stone, Natural sands, Gravel and crushed stone, n.e.c.)
	USC09	Metallic ores and concentrates
	USC10	Coal and petroleum products (Coal and Fuel oils, n.e.c.)
	USC11	Basic chemicals
	USC12	Pharmaceutical products
	USC13	Fertilizers
	USC14	Chemical products and preparations, n.e.c.
	USC15	Plastics and rubber
	USC16	Logs and other wood in the rough & Wood products
	USC17	Pulp, newsprint, paper, and paperboard & Paper or paperboard articles
	USC18	Printed products
	USC19	Textiles, leather, and articles of textiles or leather
	USC20	Nonmetallic mineral products
	USC21	Base metal in primary or semi-finished forms and in finished basic shapes
	USC22	Articles of base metal
	USC23	Machinery
	USC24	Electronic and other electrical equipment and components, and office equipment
	USC25	Motorized and other vehicles (including parts)
	USC26	Transportation equipment, n.e.c.
	USC27	Precision instruments and apparatus
	USC28	Furniture, mattresses and mattress supports, lamps, lighting fittings, and illuminated signs
	USC29	Miscellaneous manufactured products, Scrap, Mixed freight, and Commodity unknown
Non-Commodity (Service) Sectors	USC30	Utility
	USC31	Construction
	USC32	Wholesale Trade
	USC33	Transportation
	USC34	Postal and Warehousing
	USC35	Retail Trade
	USC36	Broadcasting and information services
	USC37	Finance and Insurance
	USC38	Real estate and rental and leasing
	USC39	Professional, Scientific, and Technical services
	USC40	Management of companies and enterprises
	USC41	Administrative support and waste management
	USC42	Education Services
	USC43	Health Care and Social Assistances
	USC44	Arts, Entertainment, and Recreation
	USC45	Accommodation and Food services
	USC46	Public administration
	USC47	Other services except public administration

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