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Abstract

The January 17, 1994 Northridge Earthquake damaged four major freeways in the Los Angeles area, creating the prospect of gridlock in the nation's prototypical automobile city. This paper examines the effect of the transportation damage on business activity. Using survey responses from 559 firms in the Los Angeles area, this paper gives information on the extent and magnitude of the business losses that can be attributed to the transportation disruptions. Despite the fact that the freeway damage was repaired exceptionally quickly, 43% of the firms that reported any earthquake loss stated that some portion of that loss was due to transportation damage. For the firms that attributed some loss to transportation damage, the average response was that 39% of their earthquake-related business losses were due to the disruptions in the transportation system. Comparing information on these and other survey responses yields several policy recommendations, which are summarized at the end of the paper.

In the early morning hours of January 17, 1994, a 6.8 magnitude earthquake struck the densely populated San Fernando Valley in northern Los Angeles. The Northridge Earthquake was the first large earthquake with an epicenter in a major United States city since the Long Beach earthquake of 1933. Initial estimates placed property and structural damage at $15 billion, making this one of the most costly natural disasters in U.S. history (EQE International 1994). In addition to the considerable property losses, four major freeways were damaged to the point that traffic in at least one direction had to be closed for weeks, and in some cases months.

The image of fallen overpasses cutting vital transport links in the prototypical automobile city highlighted the importance of transportation in earthquake planning and response. This paper focuses on the economic losses caused by the disruption in the Los Angeles area's transportation system after the Northridge Earthquake. In particular, this research uses a survey of firms to get information on the following questions:

1. How widespread were business losses due to the Northridge earthquake?
2. What was the relationship between business losses and the transportation damage?
3. How important was the transportation damage relative to other effects of the earthquake?
4. How did the earthquake affect employees' commutes?
5. How did firms respond to the transportation damage caused by the earthquake?

Section I: Earthquakes, Economic Disruptions, and Transportation Damage

Research into economic disruptions caused by earthquakes can be grouped into three categories. The most common studies are those that estimate direct property damage (e.g. Dowrick and Rhoades 1992; EQE International 1994; National Research Council 1992, pp. 77-82). These works typically focus exclusively on structural damage, and often do not consider economic losses dues to business disruptions.

More recent works have focused on the effect of "lifeline" disruptions. Lifeline systems are the major infrastructure projects which facilitate day-to-day activity in any urbanized area (e.g. water, power, sanitation, and transportation systems). The Applied Technology Council (1991) used estimates based on expert judgment to give relationships between lifeline damage and economic impacts. That work is discussed and extended by Chang and Taylor (1995), who used an econometric model to estimate the effect of lifeline disruptions caused by the January 17, 1995 Hanshin earthquake in Kobe, Japan. While both studies share this paper's focus on major infrastructure systems, neither examines in detail the link between business losses and transportation damage.[1]

A third group of studies examines the overall extent of business disruptions caused by an earthquake. Gordon and Richardson (1995) used input-output analysis to estimate the business losses from the Northridge earthquake. They estimated that the business losses due to the Northridge earthquake were $5.945 billion, compared with structural damage of approximately $20 billion (Gordon and Richardson 1995). Kroll, et. al. (1991) analyzed aggregate short-term (e.g. one year) trends in economic data to get information on the impacts of the 1989 Loma Prieta earthquake near San Francisco. Tierney (1995) surveyed businesses in Los Angeles and Santa Monica to determine the extent of losses from the Northridge earthquake.[2]

Overall, past research has either neglected business losses entirely (in the case of studies of physical damage) or has not had sufficient detail to illuminate the role that transportation plays in the aftermath of a major earthquake (in the case of most studies of lifeline disruption and economic losses.) This research is unique in its focus on transportation damage and business losses. Specifically, this paper reports the results of a survey of firms in the Los Angeles area. The survey is designed to get firms' self-reported assessments of the link between the Northridge earthquake's transportation damage and business losses.

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[1] One goal of the Chang and Taylor (1995) study was to examine indirect business losses caused by lifeline disruption, making it close in spirit to this research. Yet Chang and Taylor (1995) examined aggregate data rather than the firm-level data reported in this study.

[2] Tierney's (1995) work, based on a survey of firms affected by the Northridge earthquake, is similar to this study. Yet Tierney's focus was broader than transportation, while this study gives more detailed information on the link between the transportation damage and business losses.

Section II: The Transportation Damage Caused by the Northridge Earthquake

The Northridge earthquake either damaged or destroyed bridges, ramps, roadways and interchanges on the following four freeways: Interstate 5 (I-5, the Golden State Freeway), Interstate 10 (I-10, the Santa Monica Freeway), State Route 14 (SR-14, the Antelope Valley Freeway), and State Route 118 (SR-118, the Simi Valley Freeway). Map 1 displays the location of major freeway damage.

While all four freeway damage locations shown on Map 1 were major disruptions to the ground transportation network, two are especially notable. The collapsed bridges at the SR-14/I-5 interchange severed the highway link between the Santa Clarita Valley and the City of Los Angeles. The Santa Clarita Valley is a group of residential suburbs on the northern fringe of the Los Angeles urbanized area. With few alternative freeway routes into Los Angeles, the damage at the SR-14/I-5 interchange left many commuters with little choice but to endure traffic delays that were initially greater than an hour during peak periods (Barton-Aschman and Associates 1994; Zamichow and Chu 1994).

The portion of the I-10 Freeway which was damaged is the major transportation artery for West Los Angeles, which is home to several of the region's largest employment centers (Giuliano and Small, 1991). While parallel surface streets provided alternatives to freeway travel in the I-10 corridor, the very substantial damage to this heavily traveled freeway caused considerable concern among the public and local officials (Zamichow, 1994).

Work began quickly to repair all the major freeway damage (Yee, Leung, and Wesemann 1995; Barton-Aschman and Associates 1994). Contracts for most of the repair work had been awarded by early February. More notably, contracting rules were modified to allow bonuses for repair work that was completed ahead of schedule and penalties (in the form of reduced payments) for late work. The fallen I-5 bridge at Gavin Canyon was re-opened on May 18, 1994, 33 days ahead of schedule, earning the contractor a bonus of approximately $4.95 million (California Department of Transportation, 1994). The damaged I-10 freeway was re-opened on April 11, 1994, just 84 days after the earthquake and 66 days ahead of schedule. This earned the contractor a bonus of approximately $14.8 million (California Department of Transportation, 1994).

While freeway repairs proceeded quickly, travel delays were substantial in the weeks and months following the earthquake. The California Department of Transportation estimated travel delays for all four major freeway damage locations. This was done with travel time runs along detour routes (Barton-Aschman and Associates, 1994). The travel time data initially showed delays that ranged from ten to sixty minutes for the corridors that were affected by the damage shown in Map 1. Most delays during the first month were greater than thirty minutes. Delays on most corridors stabilized at five to twenty minutes by March, 1994 (Barton-Aschman and Associates, 1994).

Taken as a whole, this transportation damage was substantial but somewhat short-lived. Many damaged freeways were repaired within only a few months of the Northridge Earthquake, and for most corridors travel delays were only a few minutes by March of 1994. The question then is what economic effects can be attributed to the freeway damage.

Section III: Study Design

To determine the impact of the freeway damage on business activity, 2,250 firms in the Los Angeles metropolitan area were surveyed. Those firms were asked questions about business losses, business losses attributed to transportation damage, the severity of a number of transportation and non-transportation impacts, and their response to the transportation damage. The survey instrument is described more completely in Boarnet (1995).

The 2,250 firms were drawn from three areas in the Los Angeles region, as shown on Map 2. The area labeled "San Fernando Valley" includes the earthquake epicenter, all of the San Fernando Valley in northern Los Angeles, portions of the western San Gabriel Valley (e.g. Pasadena), the Santa Clarita Valley, and the high desert area in far northern Los Angeles County (e.g. Palmdale and Lancaster). The area called "Los Angeles City" includes downtown Los Angeles, Los Angeles International Airport, East Los Angeles, and Santa Monica. These two areas experienced the most intense earthquake damage.

For comparison, firms in Orange County were also sampled. Orange County, while in the same consolidated metropolitan area as Los Angeles, was more than fifty miles from the epicenter and was much less affected by the earthquake. Including Orange County gives greater variation in earthquake effects than would be possible by simply focusing on firms near the epicenter. This is especially important in examining how earthquake losses might vary with proximity to both the epicenter and the transportation damage.[3]

For all three study areas, manufacturing, retail, and wholesale firms were surveyed. Those three industry groups were chosen because they account for approximately 40% of the total number of firms in the metropolitan area. Shipping firms were excluded because another research project (under the direction of Professor Richard Willson at California State Polytechnic University at Pomona) was already focusing on goods movements and shipping impacts due to the earthquake.

We decided to survey the manufacturing, retail, and wholesale sectors because those sectors likely depend heavily on the transportation network for daily shopping and shipping

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[3] The study areas were chosen to correspond to a region that was heavily affected by the earthquake and a region that was much less affected. The heavily affected area is bounded by the 105 Freeway on the South, the 605 Freeway on the East, Kern County on the North, and the Pacific Ocean and portions of Ventura County on the West. This area is the combined "San Fernando Valley" and "Los Angeles City" areas shown on Map 2. The less affected area is Orange County. Note that some portions of south Los Angeles County (such as the South Bay communities south of Los Angeles International Airport) were excluded from this study. That area was not heavily affected by the earthquake. Given that Orange County was included to provide comparison with a relatively less affected area, surveying South Bay and nearby communities was judged to be somewhat unimportant. Given the definition of the study region described above, the three areas shown on Map 2 are defined by zip codes as follows: The San Fernando Valley area contains firms with zip codes from 91000 through 91999 plus zip codes larger than 93000; the Los Angeles City area contains firms with zip codes between 90000 and 90999; the Orange County area contains firms with zip codes between 92000 and 92999.

activities. Given the large portion of the region's economy which is in those three sectors, this study provides important insights. Yet because the sample is not representative of all firms in the region, one cannot infer overall economic impacts from this survey. The goal of this study was to understand the relationship between transportation damage and losses for particular types of firms, not to extrapolate the results to the regional economy.[4]

The survey was mailed to 750 manufacturing firms, 750 retail firms, and 750 wholesale firms. The survey technique followed the methods described in Dillman (1978). Each group of firms was drawn randomly from the Dun and Bradstreet database of all firms for the Los Angeles City, San Fernando Valley, and Orange County study areas. The survey was mailed on October 19, 1994, non-respondents were mailed a followup on November 15, 1994, and our research team began to contact non-respondents by telephone in early December of 1994. Telephone followup was completed in January of 1995.

All mail contacts were directed to the chief operating officer of the firm, as identified in the Dun and Bradstreet database. The chief operating officer was asked, in a cover letter, to forward the survey to the person in the firm best suited to answer it. Telephone followup was also directed to the chief operating officer.

Some surveys were not able to be delivered to a firm due to incorrect address information. In all, 216 surveys, or 9.6% of the original population of 2,250 firms, were returned as undeliverable. Of the remaining 2,034 surveys that were delivered to a firm, 559 were completed and returned. This is a 27.48% response rate, which is not unusual for business surveys.[5] As a comparison, Tierney (1995) obtained a 23% response rate when surveying firms following the Northridge Earthquake.

Tables 1 and 2 give summary characteristics for the survey respondents and the entire sample of 2,250 firms. Table 1 shows the distribution of firms by firm type and county for the 2,250 firms that were drawn from the Dun and Bradstreet database. Table 2 shows the same breakdown for the 559 firms that returned surveys.

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4 The construction, service, and financial, insurance, and real estate (FIRE) sectors were excluded because a large number of those firms might presumably experience either economic gains (in the case of, for example, medical or legal services) or disproportionately large losses (in the case of some insurance or real estate companies) that might not be related to the transportation damage caused by the earthquake. The concern was that those large non-transportation impacts might obscure the effect of the transportation damage which was the focus of this study.

5 Alreck and Settle (1985 p. 45) state that, for mail surveys, response rates over 30% are rare. Focusing on a business population brings special difficulties (Hansen, Tinney, and Rudelius 1983). Several researchers have tested various techniques which can be used to boost response rates for mail surveys of industrial and business populations. Examples of that work include the following studies. Kalafatis and Tsogas (1994) surveyed furniture manufacturers, and obtained response rates which varied from 20.3% to 52.4%. Of six different survey techniques tested, only one yielded a response rate larger than 40%, and two gave response rates lower than 30%. Childers and Ferrell (1979) surveyed members of the American Marketing Association and got response rates that ranged from 24% to 39%. Chawla and Nataraajam (1994), in a mail survey of southwestern business firms, obtained response rates that ranged from 29.5% to 37.5%.

Table 1: Firms in Database, by Firm Type and County

	Los Angeles	Orange	Ventura	Total
Manufacturing	498 (22.1%)	223 (9.9%)	29 (1.3%)	750 (33.3%)
Retail	523 (23.2%)	206 (9.2%)	21 (0.9%)	750 (33.3%)
Wholesale	497 (22.1%)	226 (10.0%)	27 (1.2%)	750 (33.3%)
Total	1518 (67.5%)	655 (29.1%)	77 (3.4%)	2250 (100%)

Percentages are in parentheses below frequencies.

Table 2: Completed Surveys, by Firm Type and County

	Los Angeles	Orange	Ventura	Total
Manufacturing	143 (25.6%)	74 (13.2%)	15 (2.7%)	232 (41.5%)
Retail	94 (16.8%)	31 (5.5%)	2 (0.4%)	127 (22.7%)
Wholesale	122 (21.8%)	66 (11.8%)	12 (2.1%)	200 (35.8%)
Total	359 (64.2%)	171 (30.6%)	29 (5.2%)	559 (100%)

Percentages are in parentheses below frequencies.

A chi-squared test rejects (at the 5% level) the hypothesis that the frequencies for respondent firms (in Table 2) give the same proportions as the frequencies for the entire 2,250 firms that were sent surveys ($\chi^2 = 43.59$, df = 4). Additional analysis showed that retail firms were significantly under-represented, manufacturing firms were significantly over-represented, and firms in Ventura County were significantly over-represented among respondents (Boarnet, 1995). While this might cause some concern that the returned surveys are not representative of the underlying population, the key question is whether the differences between respondents and surveyed firms are important for the earthquake impacts being studied here. For that reason, additional analyses were performed to determine if the earthquake influenced either the probability that a survey was not able to be delivered to the address in the database or the completion rate for the surveys.

Undeliverable and response rates were examined in zip code areas that had severe ground shaking or heavy building damage due to the earthquake. Zip code areas were constructed based on the four criteria listed below.[6]

1. HIGH PGA ZIP CODES: All zip codes with average peak ground acceleration (PGA) greater than or equal to 0.5 G, where G is gravitational acceleration (32 feet/second^2). Out of the 263 zip codes in the study area, 13 met this criteria.

2. HIGH MMI ZIP CODES: All zip codes where ground shaking, measured by Modified Mercalli Intensity (MMI), was greater than or equal to VIII. Thirty-six zip codes met that criteria.

3. HIGH BUILDING DAMAGE ZIP CODES: All zip codes where at least 25% of the building stock was inspected by local building authorities.[7] Of the 263 zip codes, 16 met this criteria.

4. MODERATE BUILDING DAMAGE ZIP CODES: All zip codes where at least 10% of the building stock was inspected. Sixty-one zip codes met this criteria.

For each group of zip code areas defined above, the undeliverable and completion rates within the selected zip codes were compared to the rest of the study area. Two-sample t-tests were performed to see if the response and undeliverable rates were significantly different in the areas with severe ground shaking or building damage versus the balance of the study area. Those t-tests showed no evidence that undeliverable or completion rates varied based on the intensity of ground shaking or the geographic distribution of building damage.[8] (For the test results, see Boarnet 1995, Section 3, pp. 31-41.) This gives evidence that the earthquake's effects did not bias either the likelihood that a firm's survey could be delivered or the response rate for delivered surveys. This gives some assurance that inferences about earthquake effects based on the sample are representative of the manufacturing, retail, and wholesale firms studied here.

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[6] The data used to construct the zip code areas are from EQE International and Office of Emergency Services (1995, Appendix C).

[7] Note that this includes buildings that were inspected but which were not found to be hazardous. Still, it is expected that inspections correlate with earthquake damage, since most local building departments inspected structures that were thought to pose a danger to public safety (EQE International and Office of Emergency Services 1995, p. 4-2).

[8] Only in one instance was there a statistically significant difference between areas. The undeliverable percentage was significantly lower in zip codes where MMI was greater than or equal to VIII. Yet if undeliverables are due to earthquake impacts (either because firms moved or went out of business as a result of the earthquake), one would expect a higher undeliverable rate in areas with strong ground shaking.

Section IV: Results

A. Business Impacts

Of the 559 firms that responded to the survey, 194 (35%) stated that the earthquake caused them to lose money. Of the 194 firms that stated that the quake caused business losses, 170 estimated the dollar value of those losses. For those firms, the average self-reported loss was $85,026, with a standard deviation of $225,602.

Of the 559 firms that completed surveys, 58 (10%) stated that the earthquake caused them to gain money. Of the 58 firms that stated that the quake caused business gains, 40 estimated the dollar value of the gain. Excluding two extreme outliers, the average self-reported business gain attributed to the earthquake was $52,235 with a standard deviation of $119,051.

The respondents included 171 Orange County firms which were not expected to have been greatly affected by the earthquake. Excluding Orange County firms, 39% of all businesses reported losses due to the earthquake. Overall, a substantial proportion of businesses experienced earthquake losses.

B. Business Losses and Transportation Damage

Of the 194 firms reporting earthquake losses, 83 (43%) stated that at least some portion of the losses was due to earthquake-related transportation damage. Table 3 tabulates firms reporting that some loss was due to transportation damage, by firm type. The last column of Table 3 also shows t-tests for whether the percentage attributing some loss to transportation damage differed among firm types. (This percentage is calculated based on the number of firms within each group that completed the survey.) The last column shows that, at the 0.05 level, manufacturing firms are under-represented among firms reporting transportation losses and retail firms are over-represented among firms reporting transportation losses.

Table 4 similarly shows the number of firms that reported that some loss was due to transportation, by geographic area. The geographic areas listed in Table 4 are the ones shown on Map 2. The test statistic in the last column of Table 4 shows that, as expected, a significantly smaller percentage of Orange County firms reported business losses due to transportation damage.

Table 3: Firms that Stated that Some of Earthquake Loss was due to Transportation Damage, by Firm Type

Firm Type	Number Stating Some Loss due to Trans. Damage	Number Completing Survey	Percentage Stating Some Loss due to Trans. Damage	Test Statistic
Manufacturing	17	232	7.32%	-3.23
Retail	31	127	24.41%	3.03
Wholesale	35	200	17.5%	1.06
Total	83	559	14.85%	

For each firm type, test statistic tests H_o: Percentage with Transportation Loss = Percentage with Transportation Loss in Full Sample (14.85%)

Table 4: Firms that Stated that Some of Earthquake Loss was Due to Transportation Damage, by Area

Geographic Area	Number Stating Some Loss due to Trans. Damage	Number Completing Survey	Percentage Stating Some Loss due to Trans. Damage	Test Statistic
Los Angeles City	35	219	15.98%	0.475
Orange County	12	149	8.05%	-2.33
San Fernando Valley	36	191	18.84%	1.57
Total	83	559	14.85%	

For each geographic area, test statistic tests H_o: Percentage with Transportation Loss = Percentage with Transportation Loss in Full Sample (14.85%)

Table 5 gives the results of a probit regression for whether or not firms reported that some loss was due to transportation. Only firms that reported that the earthquake caused a business loss are used in the regressions in Table 5.[9] For each firm, six different measures of proximity to transportation damage are used as independent variables.[10] Those measures are defined below.

[9] Thus the probit regressions in Table 5 give results for the probability of reporting that some loss was due to transportation damage, conditional on reporting any earthquake business loss.

[10] The address data for respondent firms was matched to a geographic information system (GIS) map of the study region. That map was used to calculate the distance measures defined below. Inaccuracies in either the GIS TIGER files or the firm address data made it difficult to address match all firms. Only 461 of the 559 respondents were matched to the GIS map, and thus the distance measures are only available for those 461 firms. See Drummond (1995) for a more detailed discussion of issues related to GIS address matching.

d_epic: straight-line distance, in miles, to the earthquake epicenter

d_i10_v: straight-line distance, in miles, to the damaged Interstate 10 overpass at Venice Boulevard

d_i10_lc: straight-line distance, in miles, to the damaged Interstate 10 overpass at La Cienega Boulevard

d_sr118: straight-line distance, in miles, to the damaged portion of State Route 118

d_i5sr14: straight-line distance, in miles, to the damaged Interstate 5/State Route 14 interchange

d_i5: straight-line distance, in miles, to the damaged portion of Interstate 5 at Gavin Canyon

The freeway damage locations are displayed and labeled on Map 1. The fallen overpasses on I-10 at Venice Boulevard and La Cienega Boulevard are very near each other, such that they appear to be one single location on Map 1. Note that only one distance variable is used in each regression, since all six measures are highly correlated. In addition to the distance variables, the independent variables in Table 5 include dummies for retail and wholesale firms. (Manufacturing is the omitted category.)

Table 5: Probit Regressions for Stating that Some Loss was Due to Transportation Damage

Independent Variable	column 1	column 2	column 3	column 4	column 5	column 6
Retail Dummy	0.544 (2.083)	0.547 (2.091)	0.546 (2.090)	0.545 (2.086)	0.548 (2.092)	0.548 (2.093)
Wholesale Dummy	0.515 (2.058)	0.523 (2.089)	0.523 (2.089)	0.519 (2.074)	0.515 (2.067)	0.515 (2.068)
d_epic	0.0003 (0.050)					
d_i10_v		-0.001 (-0.219)				
d_i10_lc			-0.001 (-0.213)			
d_sr118				-0.0005 (-0.082)		
d_i5sr14					0.002 (0.183)	
d_i5						0.002 (0.190)
constant	-0.599 (-2.587)	-0.558 (-2.203)	-0.560 (-2.239	-0.582 (-2.449)	-0.618 (-2.589)	-0.619 (-2.590)
N	165	165	165	165	165	165
log(L)	-109.35	-109.32	-109.33	-109.34	-109.33	-109.33

z-statistic in parentheses below coefficient

Note that no distance variable is statistically significant in the probit regressions reported in Table 5. The regression gives no evidence that the incidence of transportation loss is related to distance from either the damaged freeways or the earthquake epicenter. This is in contrast to most other earthquake effects, which were correlated with distance from the epicenter.[11] Reliance on the transportation network appears to be dispersed throughout the area, so that distance from a damage location is not a significant predictor of whether a firm experienced transportation-related losses.

The regressions in Table 5 do show that both retail and wholesale firms were significantly more likely to experience transportation losses. This might be indicative of those sectors' greater dependence on the transportation system for their day-to-day business operations.

Of the 83 firms that stated that some portion of their loss was due to transportation damage, 77 estimated the percent of their total business loss that was due to transportation. For those 77, the average response was that 39% of earthquake-related business losses were attributed to transportation damage. For the 69 firms with data that allow the value of the firm's transportation-related loss to be estimated, the average value of that loss was $39,148.

C. Severity of Earthquake Impacts

Firms were asked to rate, on a scale of 1 to 5, the severity of ten different possible effects of the earthquake. These earthquake-related impacts are listed in Table 6. A ranking of "1" implies that the impact was "no problem", and "5" means that the impact was a "very severe problem." The average scores for all respondent firms are shown in Table 6. Table 6 also shows the percent of firms that gave each impact a severity ranking of "4" or "5".

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[11] Boarnet (1995) documents that the probability of reporting an earthquake loss, the magnitude of the loss, the probability of reporting an earthquake-related business closure, and the probability of reporting building damage are all correlated with both distance from the epicenter and severe ground shaking.

Table 6: Severity of Earthquake-Related Impacts

Earthquake-Related Impact	average score on 1 to 5 scale	percent of firms choosing "4" or "5"
Customer Access to Business Location	1.52	8.63%
Employee Access to Business Location	1.60	8.87%
Shipping Delays To Business Location	1.94	11.80%
Shipping Delays From Business Location	1.72	10.02%
Building Damage	1.38	4.48%
Utility Cut-Offs	1.69	10.99%
Higher Prices/Costs for Goods & Materials	1.32	3.96%
Inventory Loss or Damage	1.56	9.31%
Repair/Clean Up (not included in Bldg. Damage)	1.70	10.84%
Seismic Retrofit (not included in above)	1.21	2.34%

Table 6 reflects the fact that earthquake impacts were moderate in the context of the entire region. Despite the publicity and the large dollar value losses to property, the average severity ratings for all earthquake-related impacts are less than two. For most firms, the effects of the Northridge Earthquake were not severe.

Given that caveat, transportation related impacts figure prominently among those that were ranked as being the most severe. In Table 6, the two earthquake effects with the highest average severity score are "shipping delays to business location" and "shipping delays from business location." Both the dollar value loss estimates reported earlier and the assessment of the severity of different earthquake effects suggest that transportation damage is a major source of business losses attributed to the Northridge Earthquake.

Table 7 shows severity rankings by geographic area. Note that firms in the San Fernando Valley area gave all impacts more severe rankings, and Orange County firms ranked all impacts as less severe. Close to 20% of San Fernando Valley area firms gave a "4" or "5" to shipping delays from and to their location. Similarly high rankings were obtained in the San Fernando Valley for "repair/clean up", "utility cut-offs", and "inventory loss/damage."

Table 7: Severity of Earthquake-Related Impacts, by Geographic Area

Impact	Average Score			% of firms with 4 or 5		
	L.A. City[b]	Orange County	S.F. Valley	L.A. City	Orange County	S.F. Valley
Cust. Access[a]	1.56	1.20	1.72	7.69%	2.72%	14.61%
Emp. Access	1.68	1.24	1.84	7.77%	3.38%	14.27%
Ship Delay TO	1.91	1.68	2.19	10.53%	4.76%	19.10%
Ship Delay FROM	1.71	1.28	2.10	7.73%	3.45%	18.08%
Bld Damage	1.38	1.14	1.57	2.86%	2.72%	7.82%
Util. Cut-offs	1.69	1.16	2.11	11.00%	3.40%	17.13%
Higher Prices	1.39	1.16	1.38	3.85%	2.05%	5.68%
Inventory Loss/Dmg	1.53	1.16	1.92	8.10%	2.60%	16.20%
Repair/ Clean Up	1.67	1.18	2.18	8.10%	2.74%	20.67%
Seismic Retrofit	1.15	1.15	1.33	1.00%	2.74%	3.59%

[a] See Table 6 for a full description of each earthquake-related effect.
[b] Los Angeles City is abbreviated "L.A. City" and San Fernando Valley is "S.F. Valley".

The average severity scores were calculated for the zip code areas where ground shaking was most intense (as measured by PGA greater than or equal to 0.5 or MMI greater than or equal to VIII) and where building damage was most severe (measured by at least 10% of the building stock being inspected and by at least 25% of the building stock being inspected.) Two-sample t-tests showed that, for all impacts listed in Table 6, the average score was significantly higher (at the 0.05 level) in the zip code areas that experienced more intense shaking or had considerable building damage. For complete test results, see Boarnet (1995, Section 4, pp. 61-69).

D. Impacts on Employees' Commutes

Of the 559 firms responding to the survey, 176 (31%) stated that their employees required longer commutes to get to work.[12] Table 8 shows the firms that stated that their employees had longer commutes, by geographic area.

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[12] While it would have been ideal to survey employees directly about their commutes, this would have necessitated another survey. Since the focus of this study was on business losses, and since a separate survey of employees would have been costly, we chose to ask employers about their impressions of commute time changes. This at least provides information on employers' perceptions about the effect of the earthquake on their employees' travel times.

Table 8: Firms that Stated that their Employees that Had Longer Commutes, by Geographic Area

Geographic Area	Number Stating that Employees had Longer Commutes	Number Completing Survey	Percent with Employees with Longer Commutes
Los Angeles City	81	219	36.97%
Orange County	19	149	12.75%
San Fernando Valley	76	191	39.79%
Total	176	559	31.48%

Table 9 shows a probit regression for whether or not a firm stated that their employees required longer commutes. Wholesale firms were significantly more likely to state that their employees required longer commutes, while distance from the epicenter made a firm less likely to state that its employees required longer commutes.

Table 9: Probit Regression for Stating that Employees had Longer Commutes Due to Earthquake

Independent Variable	
Employees at the Location	0.003 (1.341)
1993 Sales	1.15×10^{-8} (1.064)
Retail Dummy Variable	0.062 (0.357)
Wholesale Dummy Variable	0.347 (2.292)
Distance from Epicenter	-0.028 (-6.410)
Constant	-0.037 (-0.243)
N	461
log(L)	-254.765

z-statistics in parentheses

Firms were also asked how long it took until their employees were able to commute to work as quickly as before the earthquake. The median response was 1 month, although the median response in the San Fernando Valley area was 2 months.

E. Firm Responses to the Transportation Damage

Despite the relatively widespread nature of commuting problems (based on the firm responses tallied in Table 8), only 55 firms (10% of the respondents) stated that their employees used public transit to avoid congested or earthquake-damaged freeways. Table 10 shows firms that stated that their employees used public transit to avoid earthquake-related transportation damage, by geographic area.

Table 10: Firms Reporting that Employees Used Public Transportation to Avoid Earthquake-Related Travel Delays, by Geographic Area

Geographic Area	Number Reporting that Employees used Public Transportation to Avoid Quake Delays	Number Completing Survey	Percent Reporting Employees used Public Transportation to Avoid Quake Delays
Los Angeles City	33	219	15.07%
Orange County	5	149	3.36%
San Fernando Valley	17	191	8.90%
Total	55	559	9.80%

Table 10 suggests that public transportation had limited utility as a solution to earthquake-related transportation problems. Table 10 shows that 15% of the firms in the Los Angeles City area stated that some employees used public transportation -- the highest percentage of any area. This likely reflects the more well developed bus transit network in the Los Angeles City area. While not being able to shed direct light on this question, the results in Table 10 suggest that pre-existing transit patterns might have been the biggest determinant of public transit use after the earthquake. The much publicized extension of the Metrolink rail transit line through Santa Clarita to Palmdale and Lancaster might have had more limited usefulness, although again the data in this study cannot give direct information on that question. (See Ardekani and Shah 1995 and Barton-Aschman and Associates 1994 for a discussion of the Metrolink extension to Palmdale and Lancaster.)

Tables 11 through 16 show the results of asking firms if they implemented three possible transportation policies after the earthquake. Tables 11 and 12 show firms that stated that they "arranged ridesharing, vanpools, or carpools" for employees following the earthquake. Table 11 shows those firms classified by firm type, and Table 12 shows those firms classified by geographic area. In all, only 41 firms (7% of the respondents) stated that they implemented this policy.

Table 11: Firms Stating they "arranged ridesharing, vanpools, or carpools" following the Earthquake, by Firm Type

Firm Type	Number of Firms Stating they Implemented the Policy	Number of Firms Completing Survey	Percent of Firms Stating they Implemented the Policy
Manufacturing	19	232	8.19%
Retail	12	127	9.45%
Wholesale	10	200	5.00%
Total	41	559	7.33%

Table 12: Firms Stating they "arranged ridesharing, vanpools, or carpools" following the Earthquake, by Geographic Area

Geographic Area	Number of Firms Stating they Implemented the Policy	Number of Firms Completing Survey	Percent of Firms Stating they Implemented the Policy
Los Angeles City	20	219	9.13%
Orange County	5	149	3.36%
San Fernando Valley	16	191	8.38%
Total	41	559	7.33%

Tables 13 and 14 show firms that stated that they "encouraged employees to use public transportation" following the earthquake. Table 13 shows those firms by firm type, and Table 14 shows those firms by geographic area. This policy also was not very popular; only 61 firms (11% of the respondents) stated that they encouraged public transit use. Again note that the area with the largest percentage of firms encouraging public transit use was the Los Angeles City area.

Table 13: Firms Stating they "encouraged employees to use public transportation" following the Earthquake, by Firm Type

Firm Type	Number of Firms Stating they Implemented the Policy	Number of Firms Completing Survey	Percent of Firms Stating they Implemented the Policy
Manufacturing	29	232	12.50%
Retail	13	127	10.24%
Wholesale	19	200	9.50%
Total	61	559	10.91%

Table 14: Firms Stating they "encouraged employees to use public transportation" following the Earthquake, by Geographic Area

Geographic Area	Number of Firms Stating they Implemented the Policy	Number of Firms Completing Survey	Percent of Firms Stating they Implemented the Policy
Los Angeles City	35	219	15.98%
Orange County	5	149	3.36%
San Fernando Valley	21	191	10.99%
Total	61	559	10.91%

Tables 15 and 16 show firms that stated that they "allowed employees to change their work hours to avoid traffic" following the earthquake. Table 15 shows those firms classified by firm type, and Table 16 shows those firms by geographic area. Allowing employees to change their work hours was the most popular response to the earthquake's transportation disruptions. 107 firms (19% of the respondents) stated that they allowed employees to change their work hours. The San Fernando Valley area had the highest percentage of firms implementing that policy, with 27% of San Fernando Valley firms stating that they allowed employees to change work hours to avoid traffic after the earthquake.

Table 15: Firms Stating they "allowed employees to change their work hours to avoid traffic" Following the Earthquake, by Firm Type

Firm Type	Number of Firms Stating they Implemented the Policy	Number of Firms Completing Survey	Percent of Firms Stating they Implemented the Policy
Manufacturing	42	232	18.10%
Retail	20	127	15.75%
Wholesale	45	200	22.50%
Total	107	559	19.14%

Table 16: Firms Stating they "allowed employees to change their work hours to avoid traffic" Following the Earthquake, by Geographic Area

Geographic Area	Number of Firms Stating they Implemented the Policy	Number of Firms Completing Survey	Percent of Firms Stating they Implemented the Policy
Los Angeles City	41	219	18.72%
Orange County	15	149	10.07%
San Fernando Valley	51	191	26.70%
Total	107	559	19.14%

Overall, Tables 11-16 suggest that firms primarily responded to the transportation disruptions by allowing employees to use flexible work hours to avoid traffic. The use of that policy very much exceeded the use of carpools and public transit. Furthermore, firms in the heavily affected San Fernando Valley were most likely to use "flextime" to cope with transportation disruptions, yet those firms were not the most likely to encourage employees to use public transit. Unlike public transit, which requires some pre-existing network and infrastructure, implementing flextime was available to firms throughout the region.

Section V: Concluding Comments and Policy Recommendations

The evidence above suggests that transportation damage is an important factor in economic losses following an earthquake. The severity rankings given in Table 6 show that transportation damage was as important as other effects such as utility cut-offs, building damage, and inventory losses. The self-reported loss estimates also show an important role for transportation damage.

Recall that 43% of all firms that reported an earthquake loss stated that some portion of their loss was due to transportation. Those firms estimated that transportation caused 39% of their total earthquake business losses. Multiplying those two numbers together suggests the possibility that 17% of all business losses among surveyed firms were due to transportation damage. Of course, that estimate is only valid if firms that reported transportation losses have losses that are roughly the same size as other firms. The fact that Table 5 shows no relationship between distance from the earthquake and the incidence of transportation losses suggests that such an assumption might be appropriate, at least as an approximation. This highlights the importance of transportation policy in earthquake preparedness planning and response. With that in mind, the following conclusions and policy recommendations are important.

1. Government officials should plan to both prevent earthquake-related transportation damage and to recover quickly from such damage when it occurs.

The Los Angeles area recovered very quickly from the highway damage caused by the Northridge earthquake, and that no doubt helped reduce the size of the economic disruptions caused by the damage. Yet the economic losses from the severed freeways were still a substantial part of the losses that can be attributed to the earthquake. Officials should realize that the benefits of avoiding catastrophic freeway damage include preventing economic losses among firms that rely on the transportation network. If the potential for avoiding economic losses from transportation damage was not previously considered in seismic retrofitting project analysis, the benefits of such work could have been underestimated.

2. The incidence of transportation damage is apparently not directly related to proximity to the damage itself.

While most earthquake effects showed a clear relationship to the epicenter, the incidence of firms experiencing transportation-related economic losses was more dispersed. This reinforces the fact that the transportation network in any urban area is highly inter-related, and firms located some distance from a damaged highway can be affected by that damage.

This, coupled with the magnitude of the losses from the transportation damage, suggests that earthquake transportation planning is a metropolitan and possibly even regional concern. On this count, Los Angeles might have been lucky. Large portions of the affected area were within the City of Los Angeles. This might have facilitated a coordinated response. Other earthquake-prone areas with a more fragmented municipal structure (including other areas in Southern California) should be aware that transportation response can require coordination across several local governments. The planning to facilitate that coordination should occur as part of any region's earthquake preparations.

3. Planners should work with firms to develop flexible responses to earthquake-related transportation damage.

The firms that responded to this survey seemed to prefer flextime over other policies as a response to the transportation damage. Pre-earthquake planning should take advantage of firms' willingness to change their employees work schedules in response to a crisis. For many urban areas, this might prove to be one of the most effective transportation management tools in the days immediately following an earthquake.

Transportation officials should also focus preparedness plans on quickly establishing detours and restoring traffic flow. Along those lines, officials should realize that public transit might only be an effective earthquake response in areas where it was effective before the earthquake. Certainly from the perspective of firms, public transit did not appear to play a major role in the recovery from the Northridge earthquake. Any role played by transit appeared to be larger in areas with already well-developed transit systems (e.g. the Los Angeles City area).

Despite the very quick response to the transportation disruptions caused by the Northridge earthquake, the economic losses from those disruptions were substantial. This should reinforce the importance of planning both to minimize transportation damage in future earthquakes, and to respond quickly when such damage occurs.

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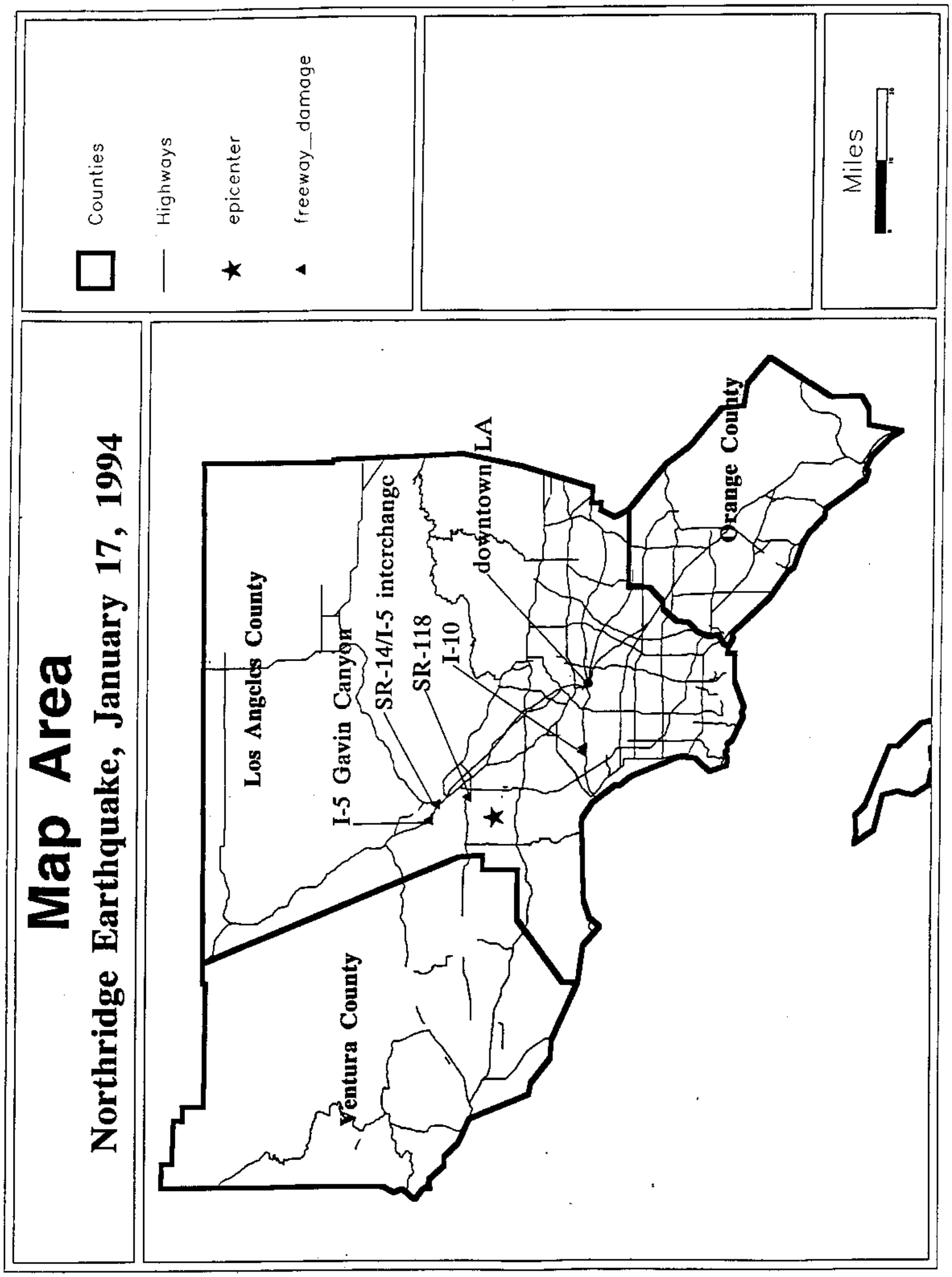
Map 1: Study Area and Freeway Damage



Map 2: Study Area