Volume I Number 2
May 1998
ISSN 1094-8848

SPECIAL ISSUE ON THE NORTHRIDGE EARTHQUAKE

BUREAU OF TRANSPORTATION STATISTICS UNITED STATES DEPARTMENT OF TRANSPORTATION

JOURNAL OF TRANSPORTATION AND STATISTICS

JOURNAL OF TRANSPORTATION AND STATISTICS

SPECIAL ISSUE ON THE NORTHRIDGE EARTHQUAKE

JOURNAL OF TRANSPORTATION AND STATISTICS

Volume I Number 2
May 1998
ISSN 1094-8848

BUREAU OF TRANSPORTATION STATISTICS   UNITED STATES DEPARTMENT OF TRANSPORTATION

About the Bureau of Transportation Statistics

The Bureau of Transportation Statistics (BTS), an operating administration of the US Department of Transportation (DOT), is a national statistical agency, DOT's representative on the Federal Geographic Data Committee, and the home of the National Transportation Library. BTS compiles, analyzes, and makes accessible information about the nation's transportation systems; collects information on various aspects of transportation; and enhances the quality and effectiveness of the Department's statistical programs through research, the development of guidelines, and the promotion of improvements in data acquisition and use.

The *Journal of Transportation and Statistics* is published by the

Bureau of Transportation Statistics
US Department of Transportation
Room 3430
400 7th Street SW
Washington DC 20590
USA
journal@bts.gov

Volumes 1 and 2 each include two issues, plus an issue on a special topic.

Subscription information

To receive a complimentary subscription for Volume 1:

mail	Customer Service Bureau of Transportation Statistics US Department of Transportation Room 3430 400 7th Street SW Washington DC 20590 USA
phone	202.366.DATA
fax	202.366.3640
email	orders@bts.gov
internet	www.bts.gov/programs/jts

Cover and text design Susan JZ Hoffmeyer
Layout Gardner Smith of OmniDigital
Map design Stephen Lewis and Michael Myers of the Bureau of Transportation Statistics

JOURNAL OF TRANSPORTATION AND STATISTICS

Volume 1 Number 2
May 1998

Contents

A Brief Overview of the Northridge Earthquake and Its Transportation Impacts v

Papers in This Issue

Impacts of the Northridge Earthquake on Transit and Highway Use
Genevieve Giuliano and Jacqueline Golob 1

Transport-Related Impacts of the Northridge Earthquake
Peter Gordon, Harry W. Richardson, and Bill Davis 21

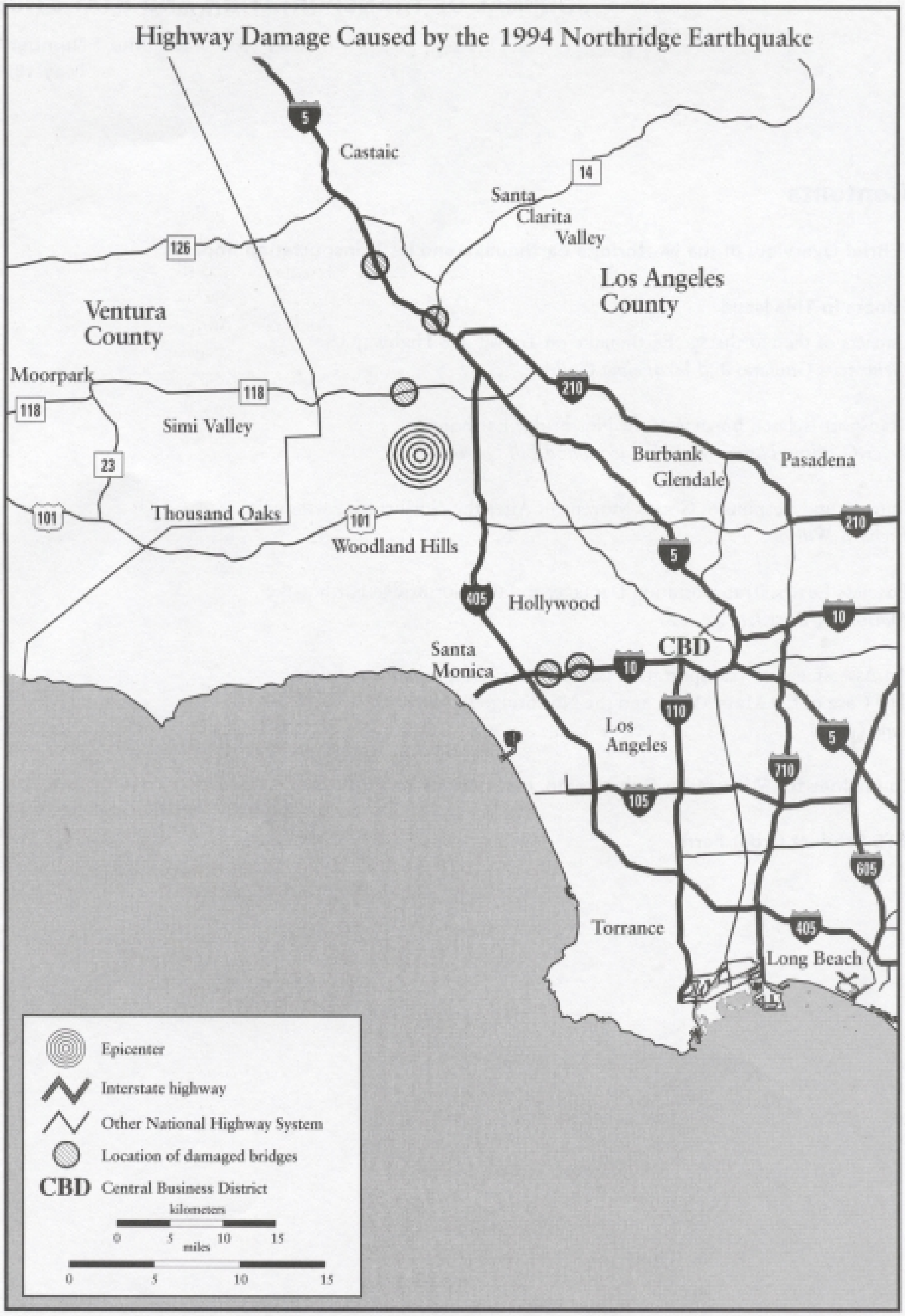
Impacts and Responses: Goods Movement After the Northridge Earthquake
Richard Willson 37

Business Losses, Transportation Damage, and the Northridge Earthquake
Marlon G. Boarnet 49

An Assessment of Transportation Issues Under Exceptional Conditions:
The Case of the Mass Media and the Northridge Earthquake
Jane Gould 65

Guidelines for Manuscript Submission, Instructions to Authors 75

BTS Product Order Form 77


Highway Damage Caused by the 1994 Northridge Earthquake
5
Castaic
14
Santa
Clarita
Valley
126
Los Angeles
County
Ventura
County
Moorpark
118
118
210
Simi Valley
23
Burbank
Glendale
Pasadena
101
Thousand Oaks
101
Woodland Hills
210
5
405
Hollywood
10
CBD
Santa
Monica
10
110
Los
Angeles
5
710
105
605
Torrance
405
Long Beach
Epicenter
Interstate highway
Other National Highway System
Location of damaged bridges
CBD Central Business District
kilometers
0
5
10
15
miles
0
5
10
15

A Brief Overview of the Northridge Earthquake and Its Transportation Impacts

A magnitude 6.8 earthquake rocked the Los Angeles area on January 17, 1994. Centered on the Northridge community in the San Fernando Valley, the earthquake knocked out four freeways, caused the collapse of parking structures, damaged buildings, and ruptured numerous natural gas distribution lines. The interchange between the Golden State Freeway (I-5) and the Antelope Valley Freeway (SR-14) collapsed, severing California's main north-south artery and isolating the rapidly growing suburbs north of the San Gabriel Mountains. The Simi Valley Freeway (SR-118) failed in two places, affecting suburbs to the northwest of Los Angeles. The Santa Monica Freeway (I-10), which normally carries over 300,000 vehicles per day and is the main route between downtown and Los Angeles International Airport, also collapsed. (See map on page iv.)

The transportation system in Los Angeles demonstrated enormous resiliency following the earthquake. Most nonhighway transportation facilities were operational within two days, and alternatives were implemented within a week for the key broken links in the highway system. Alternatives included rerouting of traffic over parallel streets, institution of high occupancy vehicle (HOV) lanes on parts of the reroutes, and rapid expansion of commuter railroad service. For example, commuter service on the railroad that paralleled SR-14 accommodated a jump in patronage from 950 to 22,000 riders per day. Traffic was often diverted from broken links on the National Highway System (NHS) to local arteries not on the NHS.

Subsequent studies by Commuter Transportation Services, a not-for-profit organization that promotes ride sharing and transit use, found that one-half of all commuters in Los Angeles and 80% of commuters in the earthquake zone made some adjustment to their travel, but most changes were temporary. Adjustments were mainly to routes and time of departure. Many commuters stuck with the alternate routes on arteries paralleling the freeways that they "discovered" following the earthquake. One-quarter of the new commuter rail riders have continued to use this service.

Short-term changes in travel patterns were not entirely commuters' responses to disruptions in the transportation system. Many people stayed home for the week following the earthquake to clean up and arrange for repairs to personal property.

A significant number of parking structures, often overlooked as a component of the transportation system, failed. A spectacular example at a local shopping center received substantial media coverage during rescue operations. Another parking garage at the local state univeristy was reduced to a modernistic sculpture.

Commerce was also affected by the earthquake. I-5 is the major north-south corridor of the Pacific Rim states, and was effectively severed for several days. Traffic between the Los Angeles-San Diego area and Northern California could use U.S. 101 without too much added circuitry, but traffic to Bakersfield and the agricultural portions of the southern San Joaquin Valley was diverted via San Luis Obispo or San Bernardino with much greater relative circuitry.

Twenty days after the earthquake, representatives of the Bureau of Transportation Statistics (BTS) delivered special tabulations of census data to assist local transportation planners. While delivering the data, BTS was able to observe the damage and the response of local agencies.

BTS recognized that the Northridge earthquake and its aftermath provided a natural laboratory to examine travel behavior, the reliability of the transportation system, and the impact of transportation disruptions on businesses and the regional economy. With BTS support, the University of California at Los Angeles, the University of California, Irvine, the University of Southern California, and California Polytechnic University, Pomona initiated studies of travel behavior and economic relationships revealed by responses to the earthquake. The studies also made significant methodological strides in the measurement of damage from natural disasters, especially in the identification of economic disruption caused by damage to the transportation system versus direct damage to business facilities versus home-based disruptions to the workforce. This issue presents the results of the BTS-sponsored research.

ROLF R. SCHMITT

Associate Editor

Impacts of the Northridge Earthquake on Transit and Highway Use

GENEVIEVE GIULIANO
University of Southern California
JACQUELINE GOLOB
Jacqueline Golob Associates

ABSTRACT

The Northridge earthquake provided a unique opportunity to examine travel behavior responses to a major emergency. We examine travel patterns in two heavily damaged transportation corridors to determine how trip patterns changed over the recovery period. Our research evaluates the behavioral response to changing transportation supply conditions and the extent to which transit is a viable substitute for the private vehicle under emergency conditions. We also examine cost and subsidy outcomes of the increased supply of transit for emergency response.

The most striking characteristic of the changes in travel patterns observed in the post-earthquake period is flexibility. Travelers responded to the alternatives available. In one corridor, many commuters used commuter rail during the first few weeks, but shifted back to private vehicles as the detour routes were expanded. In both corridors, bus transit patronage did not change; the emergency bus services attracted few riders. To the extent possible in both corridors, travelers remained in their private vehicles and opted to shift routes, travel schedules, and destinations rather

Genevieve Giuliano, School of Policy, Planning and Development, University of Southern California, Los Angeles, CA 90089-0042. Email: giuliano@almaak.usc.edu.

than shift to public transit or ridesharing. Cost and subsidy outcomes reflected these responses. We conclude that transportation system redundancy and the ability of individuals to make a variety of short-term adjustments in travel patterns makes rapid recovery possible even from major disasters.

INTRODUCTION

The transportation infrastructure of Los Angeles suffered extensive damage due to the January 17, 1994 Northridge earthquake. Immediately following the earthquake, the region's transportation, public safety, and utility agencies began setting up detours, developing a reconstruction program, and establishing a transportation program to maximize existing system capacity for the recovery period. Travelers were faced with traffic conditions that changed from day to day in the first few weeks after the earthquake as roads reopened, additional transit service was deployed, and detour routes were refined. By early February, detours and emergency express bus service were in operation; in one freeway corridor four new commuter rail stations opened, and a system of detours was in operation in another. Four months after the earthquake, major portions of the most heavily damaged freeways reopened to traffic.

The purpose of this research is to analyze the travel impacts of the Northridge earthquake. Our paper includes an examination of traveler responses to changing conditions encountered during the recovery period, an assessment of the effectiveness of public transit in serving recovery period travel needs, and an evaluation of our results. Differences in transportation infrastructure between two corridors, together with the changes in transportation services that took place during the recovery period, provided a rich variety of conditions in which to observe travel patterns. These differences make it possible to compare alternative supply strategies and their effects on tripmaking, trip scheduling, and travel mode.

We, therefore, conducted case studies of each corridor, documenting transportation system supply at specific time intervals during the recovery period. Using various data sources, we estimated travel volumes and modal distribution for each of the time intervals. We used travel survey data to further examine individual travel patterns. Finally, we evaluated the cost-effectiveness of emergency transit services.

The remainder of this paper is organized as follows. The second section provides a brief review of the relevant literature, and the third section describes damage and reconstruction in the two corridors. We then present results of our travel analysis and our estimates of costs and subsidies for emergency transit services. The final section presents conclusions and policy implications.

PRIOR RESEARCH

Occurrence of a disaster such as an earthquake requires an immediate adjustment to significantly changed travel conditions. In most cases, these changes are temporary, as damage is eventually repaired and capacity restored. There is an extensive literature on travel behavior; we know a great deal about how travel choices are made, how travelers respond to changes in prices or level of service, etc. This literature deals with everyday conditions, however, not with one-time extreme events.

Prior research on travel behavior responses to major disasters is virtually nonexistent. The University of California Transportation Center sponsored several studies of the 1989 Loma Prieta Earthquake. These studies indicate that travelers responded to the emergency by reducing travel and by using the alternatives available: emergency ferry service and the Bay Area Rapid Transit (BART). Commuters used these alternative modes while the bridge was closed, but shifted back to their regular mode (automobile) once the bridge reopened (Homberger 1990). For example, ferry ridership dropped 50 percent the week after the bridge opened and continued to decline thereafter (Hansen and Weinstein 1991). BART ridership increased 40 percent shortly after the earthquake; one month after the bridge reopened, ridership declined 24 percent from its peak of 314,100 daily passengers (Ardekani 1992). Case studies of six major employers revealed that all offered some form of alternative work schedule, and three of the six provided shuttle services in the early weeks after the earthquake (Bennet and Little 1990). More general discussions of the earthquake impacts note the flexibility of travelers in responding to disaster situations and the importance of redundancy within the transportation system (Gray et al 1990; Webber 1992).

An area of research that may be most closely related to disaster impacts is that of large-scale highway reconstruction. The difference, of course, is the advanced planning and notification that occurs to mitigate reconstruction effects. Several studies were conducted in the 1980s to examine travel behavior impacts of major reconstruction projects (Bullard 1987; Devine et al 1992; Hendrickson et al 1982; Meyer 1985). These projects varied greatly in magnitude, duration, and the extent to which highway capacity was reduced.

Three observations may be drawn from these studies. First, the extent to which travel patterns changed is related to the magnitude of the project. In Pittsburgh, for example, the reconstruction reduced a major highway from four lanes to two in a corridor with few alternate routes for travelers (Hendrickson et al 1982). In contrast, a Houston project kept all lanes open, and a Rhode Island project included just one bridge (0.5 mile in length) (Bullard 1987; Devine et al 1992). Changes in travel patterns were much greater in Pittsburgh than in the other two locations: Pittsburgh travelers made more extreme shifts in departure times, traveled longer distances on alternative routes, and incurred larger travel time increases (Bullard 1987).

Second, shifts in the travel schedule are the most likely response to reduced capacity; travelers shifted to earlier departure times in an effort to avoid anticipated congestion. Modal shifts are least likely, even when capacity is dramatically reduced, as in Pittsburgh. Finally, one study observed a period of experimentation in the early stages of the project, which is reflected in highly varied passenger volumes across routes, modes, and time periods (Meyer 1985).

Other aspects of prior research potentially relevant to this study include short-term responses to changes in traffic or transportation system conditions (e.g., increased fuel prices or transit fares, and increased congestion), and demand elasticities for various types of travel. For example, the 1973 and 1979 fuel crises had the immediate effect of reducing gasoline consumption and automobile travel. The reductions in travel were in discretionary or nonwork trips, for example, trips associated with activities that could be rescheduled, decreased in frequency, or performed at locations closer to home or work (Nivola and Crandell 1995). In contrast, work trips are inelastic; one must arrive at work ontime every workday. Thus, we found that on highly congested highways, the vast majority of trips are work or work-related (Giuliano 1994). Prior research also indicates that changing one's trip schedule or route are more likely responses to traffic congestion than changing mode (Mahmassani et al 1991). These findings suggest that travelers would respond to disaster conditions by making greater changes in nonwork travel than work travel, and by shifting trip schedules and routes rather than mode.

DAMAGE AND RECONSTRUCTION IN THE TWO CORRIDORS

The most severe transportation infrastructure damage occurred on Interstate 5 (I-5) and at the I-5 junction with State Route 14 (SR-14), affecting the corridor north of the junction (both on I-5 and on SR-14 near Santa Clarita—see map on page iv). In addition, the Interstate 10 (I-10) corridor in central Los Angeles was affected (i.e., the corridor between Santa Monica and the central business district. Structural damage to buildings, roads, and utilities occurred over a large area, with the most intense damage in and around Northridge. Substantial damage also occurred on the west side of Los Angeles and in the city of Santa Monica. Reconstruction and establishment of detours began almost immediately. Descriptions of damage and reconstruction in each corridor follow.

The I-5/SR-14 Corridor

The I-5 (Golden State Freeway) is a major intercity route and the primary north-south truck route in the region. It connects the greater Los Angeles metropolitan area with northern and central California. Just north of the I-5/SR-14 junction are located the fast-growing bedroom suburbs of the Santa Clarita Valley; consequently, SR-14 has become a major commute route, connecting these new suburban communities with job centers to the south via I-5, Interstate 210 (I-210), and Interstate 405 (I-405).

Just north of the I-5/SR-14 junction, I-5 has four general purpose lanes plus two truck bypass lanes in each direction. The SR-14 has five lanes in each direction. The junction of the two facilities is a complex set of mainline and connector facilities designed to accommodate large total traffic volumes and heavy truck traffic in very steep terrain. Also due to the terrain, there are few arterials in this area. The California Department of Transportation (Caltrans) estimated the pre-earthquake corridor freeway traffic volume to be about 260,000 vehicles per day (Caltrans 1995). Damage to an overpass near Calgrove Boulevard closed the entire I-5 3.5 miles north of the junction (see map on page iv). Damage to connector ramps at the junction closed down all but two northbound truck bypass lanes. An additional closure occurred on State Route 118 (SR-118), approximately 4.3 miles southwest of its intersection with I-5.

Highway Detours and Reconstruction

Caltrans made an immediate decision to reconstruct the damaged facilities. Reconstruction would take several months, however, and as much capacity as possible had to be provided in the interim. Road closures and traffic detours were set up immediately after the earthquake. Also at that time, two parallel arterials were restriped and operated one-way only (southbound) during peak periods. The remaining northbound truck bypass lanes were opened to all traffic (see figure 1). By the end of January, a series of detours, short-term capacity improvements, and restripings restored lane capacity in the corridor to about 70 percent of the pre-earthquake level. Included in the detour was one High Occupancy Vehicle (HOV) lane in each direction on the I-5/SR-14 truck bypass lanes. At the Calgrove Boulevard I-5 closure, the Old Road was resurfaced and striped to provide two general purpose lanes in each direction. Reconstruction of the I-5 mainline was completed in May. Additional connectors reopened in July 1994, and the last connector ramps within the junction were reopened in November 1994.

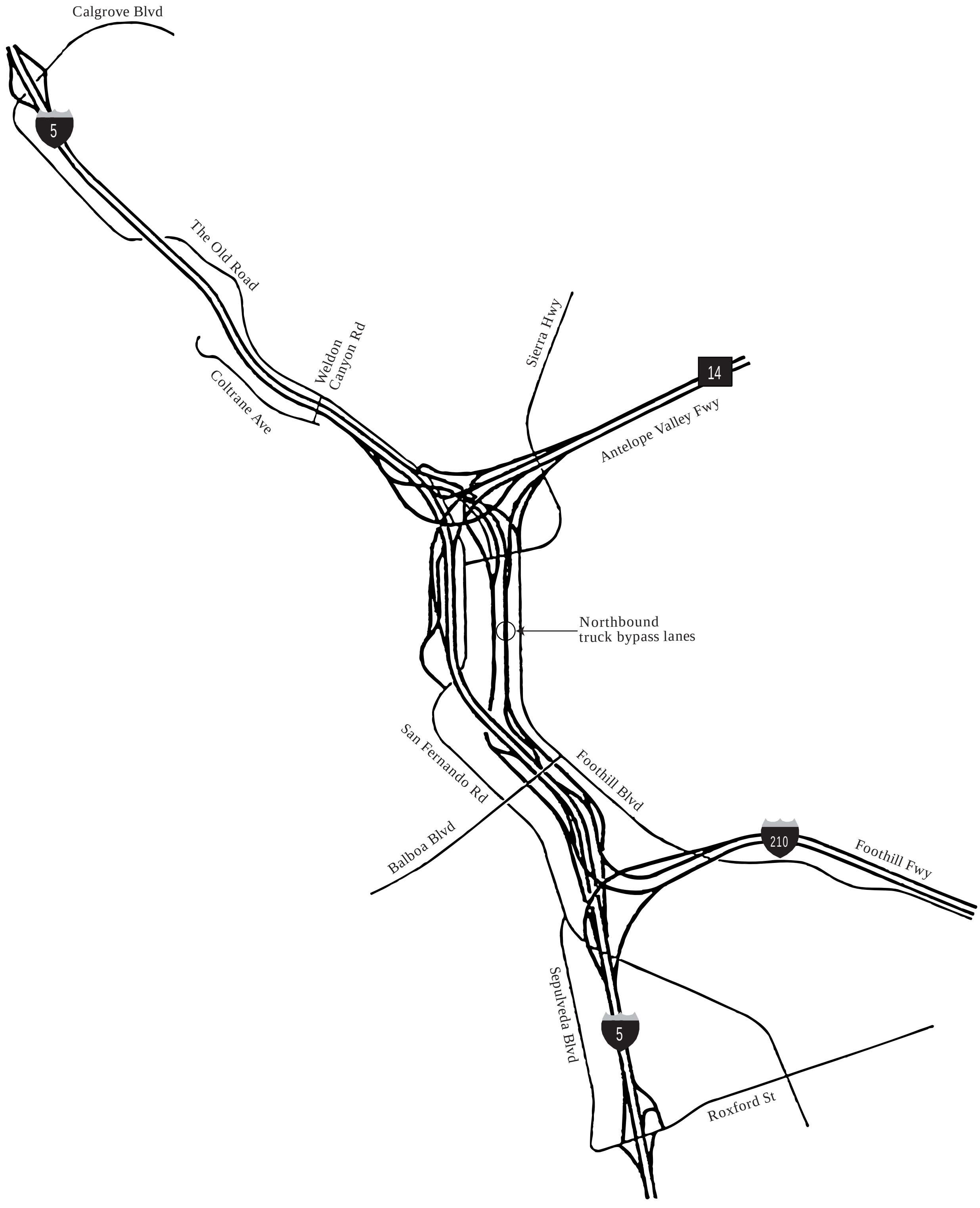
Public Transit Service Expansion

Because very few parallel roads were available in the corridor, public officials focused on expansion of transit services to provide additional travel capacity. The Metrolink Santa Clarita line serves the I-5/SR-14 corridor, and the Ventura line parallels SR-118 to Simi Valley. (For location within the region see map on page iv). Figure 2 shows the extensions to the Metrolink lines, the intercity commuter rail service operating within the region. The Santa Clarita line was extended through the Antelope Valley (a distance of 50 miles), with four additional stations opened by the end of January. A station at Sylmar opened in February. Additional parking spaces were provided at the Santa Clarita station, and additional trains were operated during morning and evening peak periods. To further encourage use of Metrolink, a 50 percent pass discount program initiated for promotional purposes in December 1993 was continued through the end of February. Discounts were again offered in April. Antelope Valley passengers were offered 50 percent discounts; Santa Clarita Valley passengers were offered 25 percent discounts through the end of May.

Service expansions were also made on the Ventura line. The line was extended beyond the Moorpark station to Camarillo and Oxnard in Ventura County, 57 and 66 miles west of downtown Los Angeles, respectively, and a new station was opened in Northridge. A one-zone discount was given to patrons of the two newly extended stations through June 30, 1994. Local bus and shuttle services were also expanded to serve Metrolink passengers. A local shuttle service provided by taxi operators was implemented at the Sylmar, Burbank, and Glendale stations. Service was added to the Metrolink shuttle in downtown Los Angeles, and a new connection to Hollywood was provided. Service on the local downtown Los Angeles circulator service was also increased.

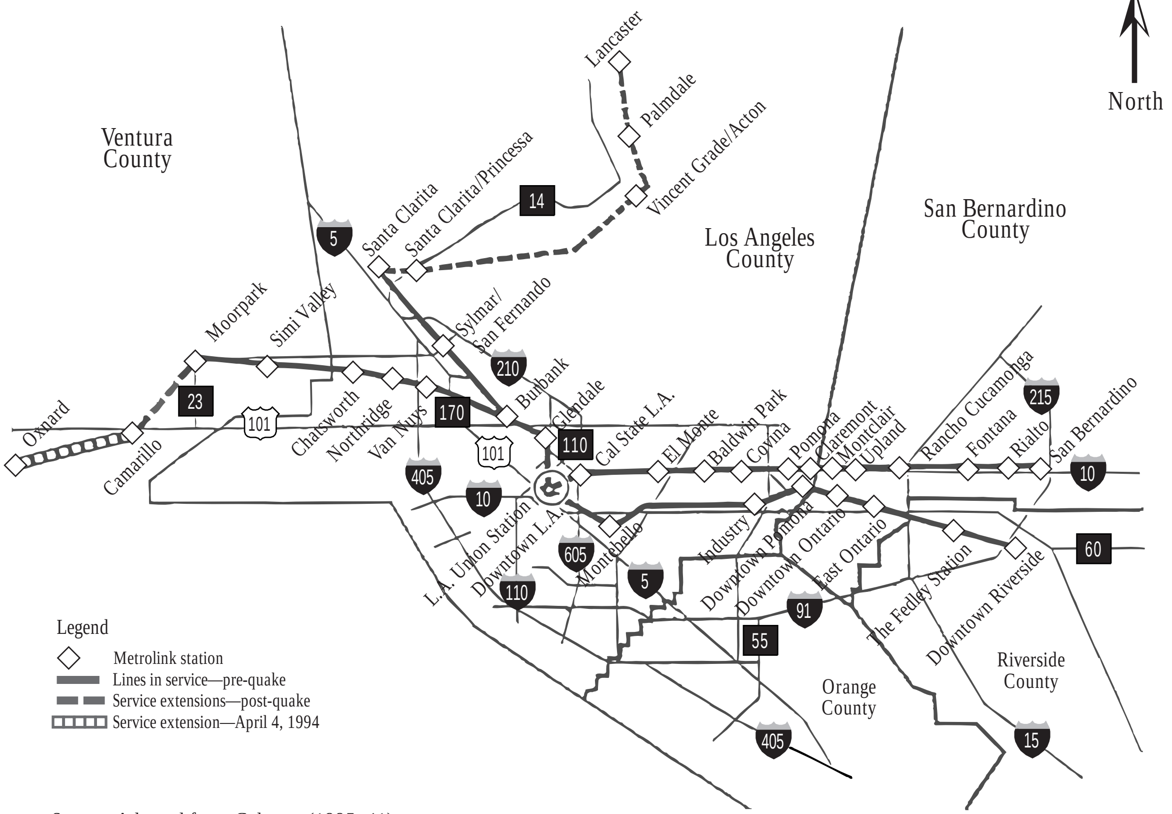
Commuter bus services were not expanded until April 1994. Three new express routes from the northern Los Angeles County cities of Lancaster and Palmdale to employment centers in Van Nuys, the Los Angeles International Airport area, and the west Los Angeles area were provided, and the existing service to downtown Los Angeles was

FIGURE 1 The I-5/SR-14 Junction Area



Source: Adapted from Caltrans (1995, 27).

FIGURE 2 Metrolink Service Extensions



Source: Adapted from Caltrans (1995, 41).

increased. Commuter express bus services operating between the city of Santa Clarita and downtown Los Angeles were rerouted in January and February to better compliment Metrolink, but no additional service was provided.

The I-10 Corridor

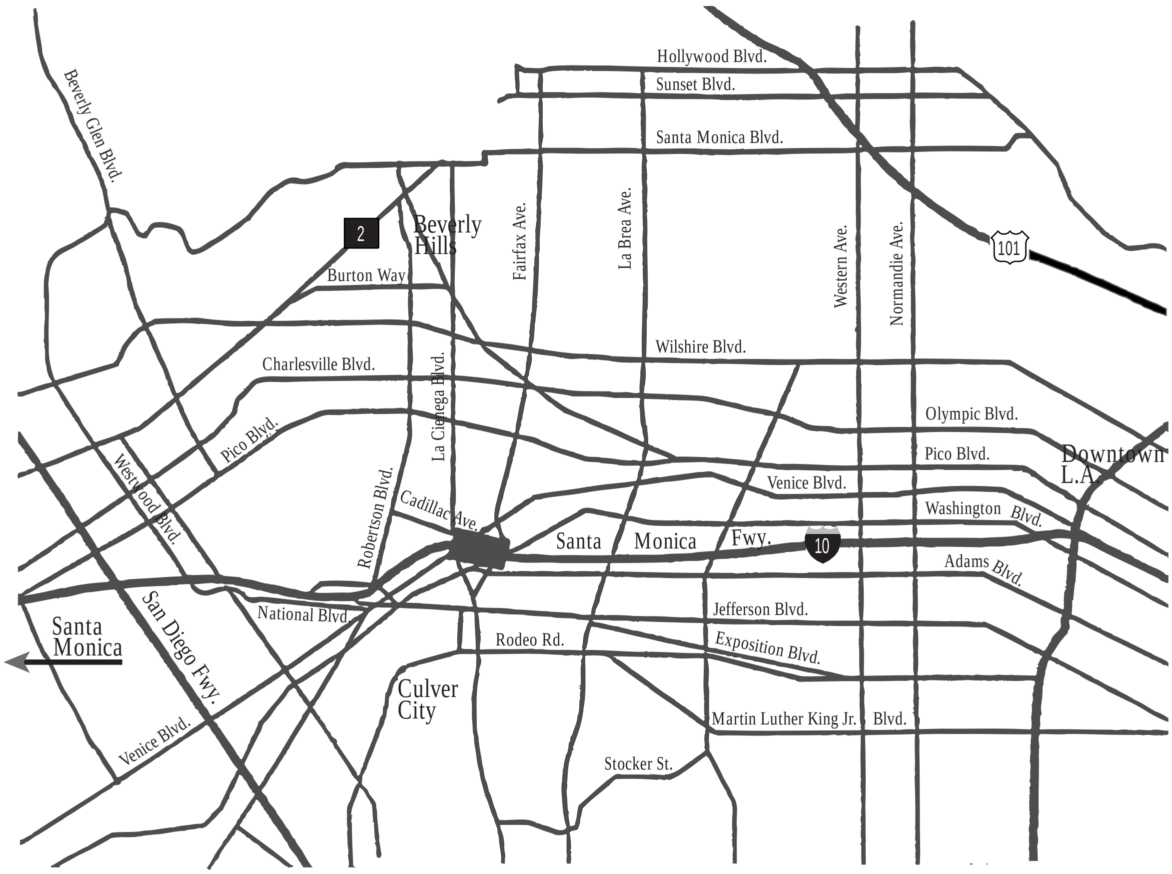
The I-10 (Santa Monica Freeway) is known as "the world's busiest freeway." Caltrans data show that average weekday traffic volumes on the eight-lane facility were about 310,000 in the vicinity of the damage. Just to the east, the freeway has 10 lanes, and an average daily volume over 400,000 (Caltrans 1995, 73). The I-10 connects downtown Los Angeles with cities to the west such as Beverly Hills and Santa Monica. This corridor contains the highest population density and the greatest concentration of jobs in the region. It is a major commuter route in both directions and also is used extensively for business and other travel throughout the day. The freeway operates at or near capacity during most daytime hours.

The freeway is located within a dense network of arterials. In addition, this section of I-10 is part of the Smart Corridor, a Caltrans advanced technology demonstration that is testing a variety of traffic management and information systems. The area of I-10 damage is shown in figure 3. The earthquake caused two bridges to collapse, closing the entire facility. Nearby arterials also sustained significant damage. However, the I-10 damage was not as severe as that of I-5/SR-14, as there was little major damage to ramps or connector facilities. To the west, the I-10 west to I-405 south connector was also closed, but it reopened within a week.

Highway Detours and Reconstruction

As with the I-5/SR-14, reconstruction and establishment of detour routes began almost immediately. The parallel arterials are controlled by the highly sophisticated Automated Traffic Surveillance and Control (ATSAC) system operated by the City of Los Angeles. ATSAC allows for real-time traffic signal control, and thus made it possible to

FIGURE 3 I-10 Corridor Area



Legend: Freeway damage

Source: Adapted from Caltrans (1995, 75).

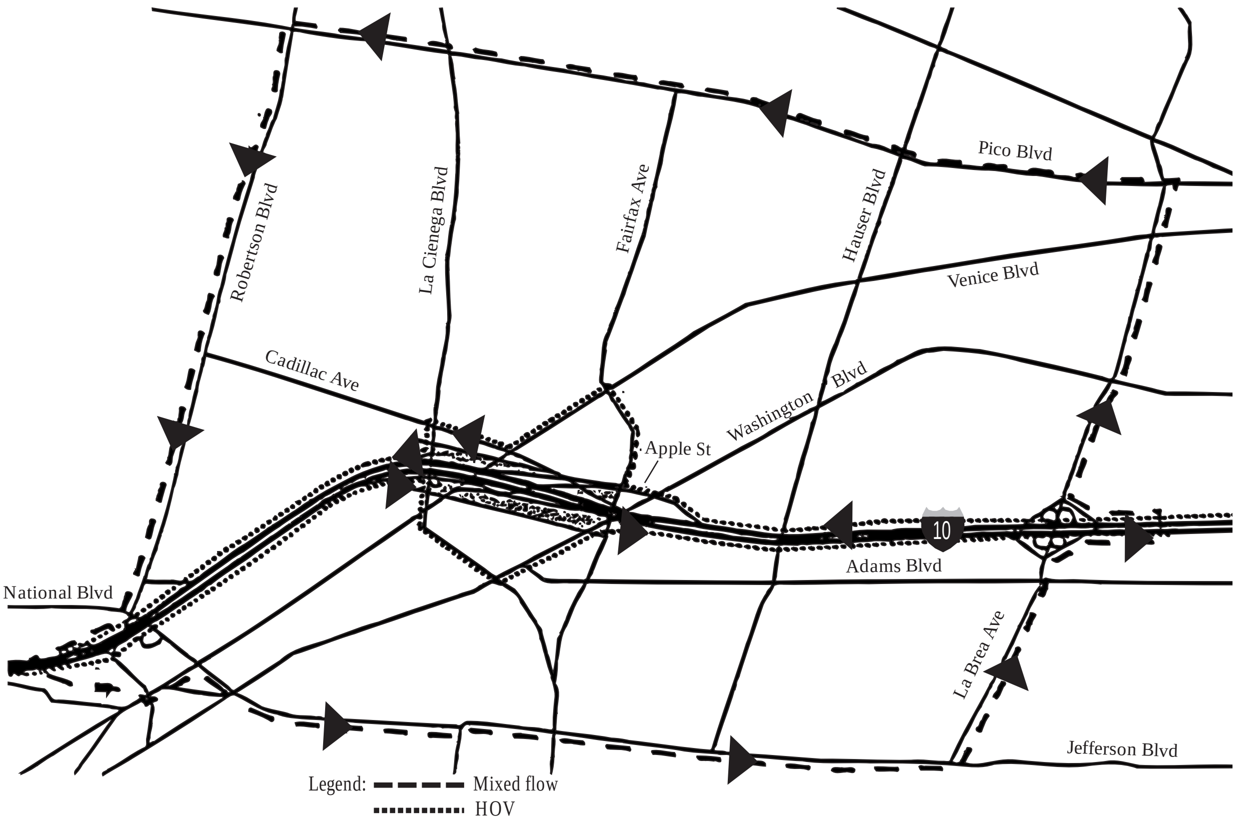
use signalization strategies to increase through capacity on the major detour arterials.

By the end of January the detour was completed. The detour included two designated alternate routes. A shorter detour was reserved for HOVs, while other traffic was diverted off the freeway for a longer distance and onto more distant arterials, as shown in figure 4. On-street parking was removed from the detour arterials, providing additional travel lanes. Medians were restriped to provide additional turning lanes at key intersections, and signal timing was adjusted to favor the through traffic. The Freeway Service Patrol (a roving emergency response service) was expanded to cover the detour arterials. Extensive signage guided travelers along the detour routes. With minor modifications, the detour remained in operation until the freeway reopened on April 12.

Public Transit Service Expansion

The Los Angeles County Metropolitan Transportation Authority (LACMTA) operates an extensive system of bus routes in the west and central Los Angeles areas. Because many streets were damaged, the first task of LACMTA was to establish bus route detours to avoid the damage. LACMTA then added service on commuter express routes. The added service began operating three days after the earthquake. Shortly thereafter, two new emergency services were implemented to serve both westside commuters to downtown Los Angeles as well as Metrolink commuters with destinations on the west side. In mid-February, a third emergency route went into operation, and an existing route was modified to serve the El Segundo employment center located south of Los Angeles International Airport. The Los Angeles City Department of Transportation (LADOT) also provides commuter express service in the corridor; two LADOT routes were expanded. The emergency services remained in operation until mid-April.

FIGURE 4 Designated Mixed Flow and HOV Detours, for I-10



Source: Adapted from Caltrans (1995, 81).

TRAVEL ANALYSIS

Determining how travel behavior changed in the post-earthquake period is a difficult undertaking. First, disasters, of course, are not predictable, and researchers face the same challenge as others in having to respond as quickly as possible to an unanticipated situation. The researcher has no time to develop in advance a suitable research design or appropriate baseline data. The type and extent of data available on conditions prior to the earthquake effectively limit the type of analysis that can be done. Second, recovery from a major disaster takes place over time, and travel conditions change continuously as more people return to school and work, streets and utilities are repaired, etc. Thus, the "recovery period" itself is a time of constant change. Third, research methods that rely on interviews or survey research are problematic. The emotional trauma of the event may color retrospective reports of personal behavior; individuals and firms are occupied with recovery and not inclined to respond to research inquiries; and, of course, responses to how individuals reacted, or what they experienced in terms of travel conditions depend on when during the recovery the questions were asked. In our research, the limited availability of traffic volume data and baseline travel information greatly constrained what could be done and effectively eliminated any type of statistical analysis.

Post-Earthquake Travel in More Severe Damage Areas

Our purpose is to determine how travel behavior changed during the post-earthquake period. As we noted, earthquake damage was more severe near the epicenter and in the west Los Angeles and Santa Monica areas. In these areas, major employment centers, retail centers, and school campuses were closed. There was also more damage to residences in these areas, so people living or working in these areas were more likely to have suffered disruption to daily routines than people living or working in other parts of the region.

Tripmaking was reduced by closures of businesses and schools. In the first week, the Los Angeles Unified School District (LAUSD) closed all schools, affecting approximately 640,000 students. Two large universities, the University of California at Los Angeles (UCLA) (25,000 students) and California State University, Northridge (26,000 students) were also closed, as were all post offices, libraries, and courthouses in the San Fernando Valley. Many businesses and retail centers were closed, and large portions of the Northridge area were without water and power. UCLA and most LAUSD schools reopened in the second week. Businesses that had not sustained major building damage were also opened by the second week, but those that did suffer significant damage remained closed much longer. We, therefore, expected a gradual recovery in travel demand to pre-earthquake levels.

The effects of these disruptions are illustrated in figures 5 and 6.[1] Each figure shows the difference in weekly freeway traffic volumes for 1994 relative to the same week the previous year. Figure 5 gives differences for the I-10 (eastbound direction) at two locations, west of I-405 (within the more severe damage area), and east of I-710 (outside the damage area). Figure 6 gives similar data for I-5 (southbound), south of I-405 (within the severe damage area), and east of I-710 (outside the damage area) (see the map on page iv for locations within the region). These graphs show that, with just one exception, differences are within plus or minus 5% for the locations outside the damage area. In contrast, differences are very large during the first few weeks after the earthquake—up to 36% on I-10 and 54% on I-5—for the locations within the damage areas. Note that in both cases these count locations are five miles or more away from the freeway damage itself. Count stations closer to the freeway damage had even larger drops in traffic volume, as would be expected.

[1] Traffic volume data are drawn from Caltrans traffic count stations. Caltrans compiles continuous traffic count data for a small number of locations. These are the only sources of comparison data. Due to missing data, few week-to-week comparisons could be constructed.

Traffic Volume and Modal Distribution

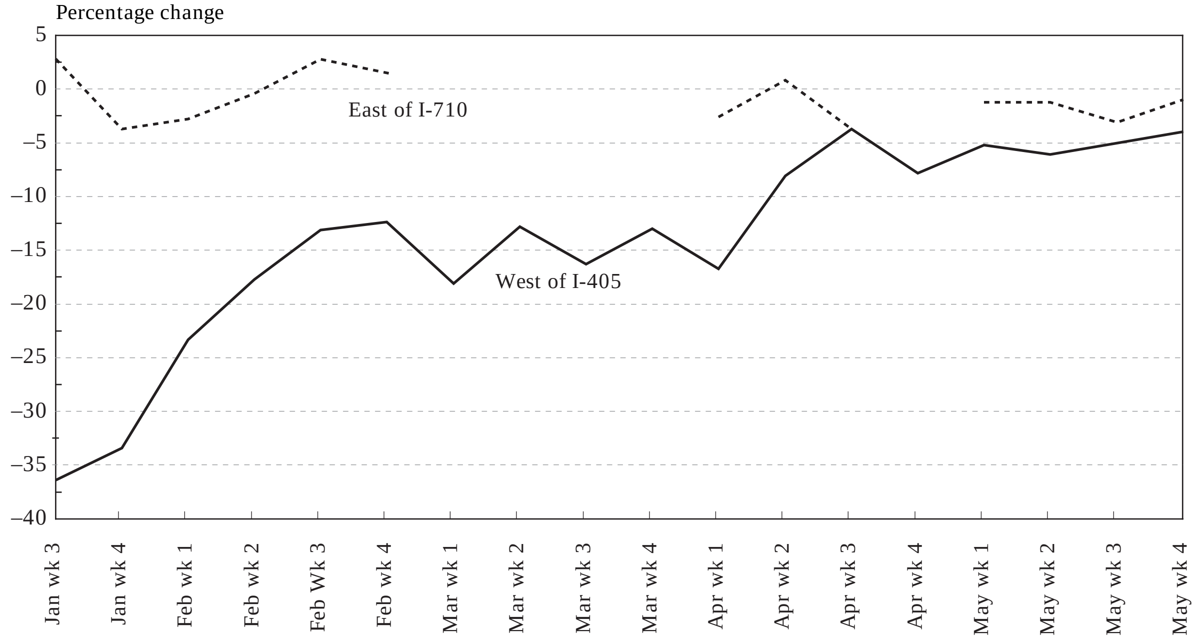
Our central question is, how did travel behavior change in response to the changes in transportation system supply resulting from the earthquake? Travelers could change their trip schedule, route, or mode; origin or destination; or number of trips. When considering trip frequency, we would like to distinguish between the decline in travel attributable to the disruption of the earthquake itself and the deterring effect of reduced capacity (e.g., change in travel demand vs. response to changed conditions). Unfortunately, data constraints preclude us from doing so; we would require information on total tripmaking within a given area before and after the earthquake.

In considering shifts in mode or schedule, however, we must take into account total travel volume. For example, a decline in transit patronage after the earthquake may reflect a decline in overall travel demand, rather than a decline in transit share; it is quite possible that the transit share increased, even with reduced ridership. We decided to conduct our analysis by establishing screenlines for each corridor. The screenline is a line drawn across the corridor in such a way as to capture all the available parallel routes, both highway and transit. We then estimate the total number of person-trips crossing the screenline. We also decided to use total traffic volumes (24-hour) in order to capture any shifting of travel to other times of the day.

Selection of screenline locations were constrained by pre-earthquake data availability; data on freeway traffic, arterial traffic and transit ridership are required in order to examine total travel within the corridor.[2] Possible screenline locations were reviewed with Caltrans traffic operations personnel, and our selection was based on their recommendation. For the I-5/SR-14, a location just to the south of the junction, near Balboa Boulevard was selected (see figure 1). This screenline captures the I-5 mainline, the truck bypass lanes, the two parallel arterials, and the Metrolink Santa Clarita line. Three bus commuter routes are also captured. This screenline effectively captures total corridor

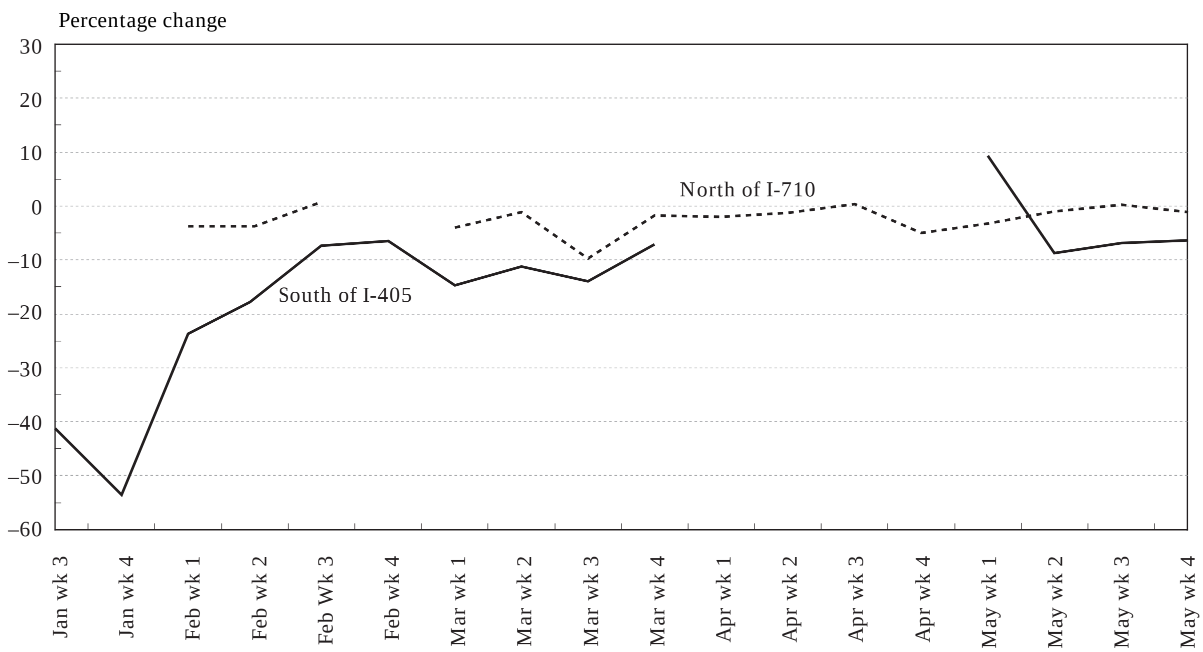
[2] As noted previously, historical freeway traffic volume data are available for selected count stations, but historical arterial traffic data are extremely limited. Route-level transit ridership data are also limited.

FIGURE 5 Change in Weekly Average Traffic Volume on I-10 Eastbound: 1994 vs. 1993



Source: Computed from Caltrans travel volume data.

FIGURE 6 Change in Weekly Average Traffic Volume on I-5 Southbound: 1994 vs. 1993



Source: Computed from Caltrans travel volume data.

traffic, because there are no other alternative routes available in the area.

A suitable screenline for I-10 could not be established, because of limited availability of arterial data and the density of the street network. In addition, the corridor includes 22 bus routes operated by four different transit agencies, and none of the transit operators could provide sufficient route-level data for such an analysis.

For the I-5/SR-14 screenline we estimated total average weekday traffic volume in person-trips for each month, January through June 1994. Sufficient baseline data were available to make comparisons to the same month last year. Such a comparison accounts for seasonal factors, but does not account for generic growth in traffic.

Person-Trip Estimation Method

In order to estimate total person-trips, we needed traffic volumes on the freeway and on parallel arterials before and after the earthquake, vehicle occupancy data, and transit ridership. Data are collected differently for each facility. Freeway traffic volume data is collected by Caltrans. For the pre-earthquake period, Caltrans had daily average volumes by week for selected count stations. These are calculated from the 24-hour totals over an entire week. For the post-earthquake period, Caltrans provided the daily volume totals. No vehicle occupancy data for the pre-earthquake period were available for I-5/SR-14. Vehicle occupancy was estimated only for the HOV detours and only for the peak hour in the post-earthquake period. Arterial traffic volumes are collected by LADOT. Arterial counts for the pre-earthquake period are available from 12-hour counts collected on a randomly chosen weekday each month. In the post-earthquake period, traffic counts were conducted one day each week for arterials in the I-5/SR-14 area. No vehicle occupancy data are collected for arterial traffic.

The I-5/SR-14 corridor is served by Metrolink rail service and by express commuter bus service. Metrolink has the most complete data, as passenger counts by station are collected weekly. Commuter express bus services have monthly passenger totals by route.

Screenline person-trips were estimated as follows. For the freeways, the average weekday counts were calculated as the average over the entire month. To generate person-trips, we applied the Caltrans vehicle occupancy factors of 1.4 for general-purpose lanes.[3] Our I-5/SR-14 corridor screenline has no HOV facilities in the pre-earthquake period, but has one HOV lane on the truck bypass detour in the post-earthquake period. Vehicle occupancy counts performed by a Caltrans consultant indicated that vehicle occupancy on the combined designated detours was 1.5 (Caltrans 1995). We used the 1.5 factor for the truck bypass and 1.4 for all other freeway routes. For arterials, we used the 12-hour counts, factored up by 1.5 to generate 24-hour equivalents and multiplied by the vehicle occupancy factor of 1.4 to generate person-trips.[4]

Transit patronage was estimated as follows. For Metrolink, we had weekly average daily boardings, from which we calculated a monthly (daily) average. Boardings by station make it possible to estimate total passengers crossing the screenline. For commuter express (two routes), we had total monthly boardings; we computed the average based on number of operating days each month.

I-5 Corridor

Results are given in table 1. The first six rows of data show that nearly all travel in 1993 is by private vehicle on the freeway; the two arterials carry about 3% of the trips. Commuter bus trips had a consistent 0.3% share, and Metrolink had about a 0.2% share. Over the six-month period, traffic volume increased by about 15%, reflecting the rapid growth occurring in the Santa Clarita Valley.[5]

After the earthquake, corridor highway capacity was reduced by about two-thirds, as the entire

[3] The vehicle occupancy factor of 1.4 is for all trip purposes and is based on a 1991 regional household travel survey conducted by the Southern California Association of Governments.

[4] The 12-hour factor of 1.5 is based on the average ratio of 12- to 24- hour freeway traffic volumes, which is used by both Caltrans and LADOT.

[5] In the early 1990s, the Santa Clarita Valley was the fastest growing suburb in Southern California. Traffic counts at other locations on SR-14 are consistent with this increase.

Table 1 I-5 Corridor Screenline Person-Trip Estimates Between South of I-5/SR-14 Junction and Balboa Blvd.

Month	Mainline	Truck bypass	Arterials	Metrolink	Bus	Corridor total	1993 vs. 1994
PRE EARTHQUAKE							
Jan-93	274,200	54,810	12,740	510	1,100	343,360	
	79.86%	15.96%	3.71%	0.15%	0.32%	100%	
Feb-93	287,440	56,490	13,010	620	1,230	358,790	
	80.11%	15.74%	3.63%	0.17%	0.34%	100%	
Mar-93	306,850	61,860	13,400	690	1,090	383,890	
	79.93%	16.11%	3.49%	0.18%	0.28%	100%	
Apr-93	313,500	63,390	13,800	750	1100	392,540	
	79.86%	16.15%	3.52%	0.19%	0.28%	100%	
May-93	313,840	63,000	14,220	780	1180	393,020	
	79.85%	16.03%	3.62%	0.20%	0.30%	100%	
Jun-93	325,580	61,870	14,650	860	1180	404,140	
	80.56%	15.31%	3.62%	0.21%	0.29%	100%	
POST EARTHQUAKE							
Jan-94	20,280	81,040	26,040	13,700	1080	142,140	–59%
	14.27%	57.01%	18.32%	9.64%	0.76%	100%	
Feb-94	120,000	162,010	26,040	8,170	870	317,090	–12%
	37.84%	51.09%	8.21%	2.58%	0.27%	100%	
Mar-94	127,970	174,670	58,380	8,150	1,030	370,200	–4%
	34.57%	47.18%	15.77%	2.20%	0.28%	100%	
Apr-94	148,150	184,820	53,590	5,170	1,130	392,860	0%
	37.71%	47.04%	13.64%	1.32%	0.29%	100%	
May-94	146,320	178,180	48,890	4,280	1,210	378,880	–4%
	38.62%	47.03%	12.90%	1.13%	0.32%	100%	
Jun-94	188,470	172,010	44,450	3,400	1,190	409,520	1%
	46.02%	42.00%	10.85%	0.83%	0.29%	100%	

mainline and the southbound truck bypass lanes were closed. Total travel was down about 60% from pre-earthquake levels. Despite the reduction in travel, the media carried reports of three-hour delays on the commute from Santa Clarita to Los Angeles. These delays were short-lived, however: one week later delays were estimated to be about one hour. Trips were redistributed in response to altered capacity. Arterial traffic volume doubled, and Metrolink carried nearly 10% of all trips, generating the highest transit mode share for the entire recovery period.

By February, traffic volumes increased to about 88% of 1993 levels, reflecting the recovery of most businesses and other activities, as well as the availability of the Old Road and one-way detours on the two arterials (see figure 1). Transit use dropped significantly, arterial volumes remained stable, and freeway volumes increased. In March, arterial volumes again nearly doubled, likely due to improved management of the one-way lanes as well as to experimentation of travelers seeking better routes. Volumes of this magnitude suggest substantial peak spreading of trips. After March, freeway volumes increased as capacity was restored, while arterial volumes and Metrolink ridership declined. Consequently, by June, transit accounted for just over 1% of all trips. Arterial volumes remained high, suggesting that even after the reopening of the freeway mainline some travelers found the arterial routes preferable.

Throughout the recovery period, bus ridership remained relatively stable. In contrast, Metrolink ridership soared to 13,700 shortly after the earthquake and then gradually decreased to 3,400 by June. Transportation agencies focused on Metrolink improvements and conducted a massive public information campaign to persuade commuters to use it. Transit use is discussed further in a later section. Results from the screenline analysis suggest that: 1) travelers adapted to emergency conditions based on the supply of alternatives available, 2) travelers were more inclined to change route than to change mode, and 3) responses were short term.

Commuter Survey Data

We were able to further explore these ideas using post-earthquake survey data collected by Commuter Transportation Services, Inc. (CTS, now Southern California Rideshare). The survey sample of 1,000 workers was obtained via random digit dialing using prefixes in Los Angeles and Ventura Counties. It was conducted in February 1994 and elicited information on how the individual's commute was affected by the earthquake. Responses were geocoded by place of residence and place of work, making it possible to identify respondents who either lived or worked in the two corridor areas. We were able to identify home and work locations by area for 846 respondents and segment them into three groups: live or work in the I-5 area, in the I-10 area, or in an area not significantly damaged in the earthquake.

Table 2 shows changes people made in their work trip. Since the CTS data are drawn from a random sample, we were able to conduct statistical tests of differences between groups. Respondents with their home or work location in the impact areas were more likely to make changes in the time they left home to go to work and in their route than commuters in other areas. Differences between the two impact areas on these changes are not significant. Shifting to earlier departure times reflects anticipated longer trips. As expected, these changes were far less frequent for commuters in other areas. The CTS survey asked about work arrival times; these responses confirmed longer delays for I-5 commuters than for I-10 area commuters, likely because of the greater availability of alternative routes in the I-10 corridor. Although relatively few commuters formally changed their work schedule as a result of the earthquake, many apparently had some flexibility, as indicated in work departure time shifts. As a consequence of the earthquake, 23% percent of the impact area commuters stated that their work day had been shortened (CTS 1994).

In contrast, there were few shifts to other modes or work schedules; differences across the three groups are not significant. Note that in the impact areas more commuters changed home or residence location than changed mode. Finally, the greater

Table 2 Impact of Earthquake on Commuting

	Home/work location (percent)		
	I-10	I-5	Other
Change trip schedule			
Leave from home[1]			
earlier	18.7	21.7	6.5
later	7.5	7.9	6.5
Leave from work			
earlier	8.2	10.5	15.5
later	12.9	12.9	12.2
Change mode			
drive alone to car/vanpool	5.4	5.8	4.1
drive alone to transit	0.2	0.3	0.0
car/vanpool to drive alone	2.8	2.4	3.3
transit to drive alone	0.7	0.0	0.0
Change route[1]	30.8	31.2	5.7
Change work schedule			
to 4/40	2.3	4.4	0.0
to 9/80	0.7	0.7	0.0
to 3/36	0.2	0.7	0.0
to other	1.2	1.4	0.0
Change origin/destination[2]			
change home location	1.2	5.4	0.0
change work location	2.8	4.8	0.8
Number of observations	*428*	*295*	*123*

[1] Difference across home/work location groups significant at $p \leq .05$; difference between impact areas (I-10 and I-5) not significant.
[2] Difference across home/work location groups significant at $p \leq .05$, and difference between impact areas significant at $p \leq .05$.

Key: 4/40 = work 40 hours in 4 days per week.
9/80 = work 80 hours in 9 days per 2 weeks.
3/36 = work 36 hours in 3 days per week.

Table 3 Changes in Commute to and from Work, Gorden et al. Survey

	Home to work	Work to home
Change trip schedule	29.4%	23.9%
Change mode	6.5%	5.3%
Change route	35.0%	30.0%
Number of observations	214	209

damage in the I-5 corridor is reflected in the significantly higher percentage of respondents who reported a change in the location of residence or work.

Results from the CTS survey are supported by the Gordon et al. (1998) survey data. The Gordon et al. survey targeted respondents in the impact areas, and asked whether any aspect of the commute to or from work had changed in response to the earthquake. Forty-four percent changed some aspect of the trip to work, and 38% reported changes in the trip from work. Changes made are quite similar to those reported in the CTS survey, as shown in table 3.

We also used the CTS data to estimate delays experienced by commuters in the two corridors. Respondents were asked how long their trip to or from work usually took before the earthquake, and how long their trip took "this past week," meaning mid- to late February. We grouped respondents by residence and work location, and selected those who most likely were traveling in the two corridors. Results are given in table 4. As expected, all groups reported longer trips after the earthquake (all before/after differences are significant, despite the small sample sizes), and I-5 corridor commuters experienced much greater travel time increases than I-10 commuters. It bears noting that the survey was taken early in the recovery period, and therefore the estimates are probably high rather than low. Also, these are very subjective responses and thus are suggestive only.

The CTS survey data complements our screenline travel volume estimates, though the survey focused only on the work trip. Commuters adjusted to the crisis by changing the travel schedule or route, rather than by changing mode. We surmised that the observed reduction in travel through the corridor was in discretionary (nonwork) trips, which could be more easily shifted to other destinations or avoided altogether. Information on nonwork trips is limited. One source is the survey data collected as part of the Caltrans-sponsored earthquake evaluation. In this survey, respondents were asked about the trip they made most frequently on the given freeway (I-5, I-10, SR-14, SR-118). Table 5 shows that in all but one case, a larger share of nonwork trips was discontinued due to the earthquake.

A reduction in nonwork travel is also supported by the Gordon et al. survey data. Respondents

Table 4 Travel Time in Minutes Before and After Earthquake

	From home to work			From work to home		
	Before	After	Change	Before	After	Change
Live West LA, work Central or East LA (n = 34)	30.6	42.3	38.2%	32.3	41.4	28.2%
Live East or Central LA, work West LA (n = 35)	32.9	41.1	24.9%	36.5	46.1	26.3%
Live North LA County, work East or West Valley (n = 9)	29.4	51.1	73.8%	28.3	47.8	68.9%
Live East or West Valley, work North LA County (n = 11)	30.5	46.4	52.1%	31.8	46.8	47.2%

Note: All differences between means, before vs. after, are significant at $p \leq .05$.

Table 5 Freeway Share of Most Frequently Made Trip That was Discontinued Due to Earthquake

Freeway	Work (percent)	Nonwork (percent)
I-5	13	28
I-10	14	13
SR-14	9	14
SR-118	9	23

Source: Compiled from AMPG (1994).

were asked about grocery shopping and other shopping frequency before and since the earthquake. Forty-nine percent of respondents reported changing the frequency of grocery shopping; for those who changed, average frequency declined from 2.2 to 1.7 times per week. For other shopping, 75% changed frequency, and for those who changed, average frequency declined from 1.1 to 0.7 times per month.

Public Transit Use

Public transportation agencies made great efforts to expand public transit services in the two corridors. As noted earlier, the Ventura and Santa Clarita Metrolink lines were extended, and service frequency was increased. In the I-10 corridor, emergency express bus commuter services were provided. This section further examines ridership patterns.

I-5 Corridor

An extensive public information campaign encouraged Santa Clarita and Antelope Valley commuters to use Metrolink. Travelers responded; weekly average boardings on the Santa Clarita line reached an all-time high of 19,000 in the second week after the earthquake. By the end of the second week, the Old Road detour opened; weekly boardings in the following week dropped to about 10,000 and continued to drop thereafter, leveling off at about 2,800 as shown in figure 7. The decline in ridership occurred even as more train capacity, stations, parking, and connecting shuttle services were provided.

Ridership data show that the added stations accounted for 21% to 25% of Santa Clarita line total passengers in March and April, respectively. By June, ridership from these stations accounted for 41% of the total. Thus, the decline in ridership was greater for the less distant stations. Comparing ridership for the portion of the line that was operating before the earthquake shows that patronage approximately doubled, from about 1,000 passengers per day to about 2,000 during the Fall months of 1994. We attribute the increase to service frequency; number of trains operating per weekday increased from 16 to 23 on this portion of the line.

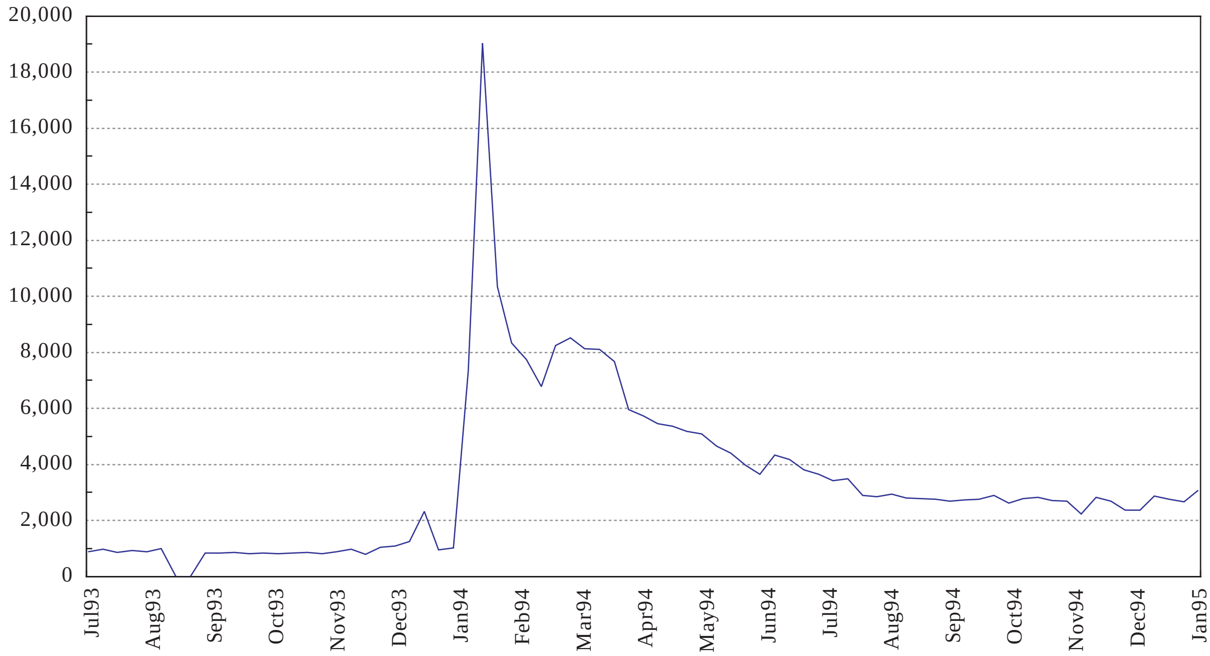
Given the extremely limited alternatives available to I-5 corridor commuters, Metrolink's failure to retain most of its new ridership under such conditions merits discussion. First, initial demand overwhelmed the system. News reports described parking shortages, trains too crowded to board, and lengthy travel delays due to the frequent aftershocks that occurred during the first two weeks after the earthquake. These early problems likely discouraged many commuters from continuing with Metrolink. Second, even with the additional connecting services, Metrolink was accessible to relatively few employment destinations. Los Angeles is well-known for its decentralized urban form. The greater downtown area, for example, has the largest concentration of jobs (406,300 in 1990), but accounts for just 5.8% of all jobs in the region. Whatever travel-time savings resulted from using Metrolink through the corridor could easily be offset by the additional time required get to the station and to reach the final destination. The new riders were drawn primarily from auto commuters (72%) and thus had a car available. It was, therefore, an easy choice to return to driving, particularly as the detour routes were improved.

I-10 Corridor

Lack of data prevents any analysis of overall transit use in the I-10 corridor. This is particularly unfortunate, as the corridor has an 8% transit mode split, far higher than any other location outside the greater downtown area.[6] Ridership was monitored

[6] Using data from October 1993, we estimated total daily person-trips in the area of freeway damage at 810,000, allocated as follows: 57%, freeway; 35%, auto trips on arterials; and 8%, transit. Transit mode share for all trip purposes is 4% in Los Angeles County, based on a 1991 survey by the Southern California Association of Governments.

FIGURE 7 Santa Clarita Metrolink Weekly Ridership



Source: Computed from Metrolink data.

only on the emergency bus services, so we had no means for examining use of the existing services during the post-earthquake period. Ridership on the emergency services was very low, and most of this service was abandoned by mid-April. We surmise that the emergency services did not attract riders, because bus transit is subject to the same delays as the automobile. Although the HOV detour was about two miles shorter than the official general traffic detour, there were numerous other shorter alternate arterial routes available.

PUBLIC TRANSIT COSTS AND SUBSIDIES

To further evaluate the effectiveness of public transit emergency services, we estimated operating costs and subsidies for Metrolink and for the LACMTA emergency bus service.

Metrolink

The 34.3 mile Santa Clarita line began operation in October 1992. The regular one-way fare from Santa Clarita to Los Angeles Union Station is $7.50, and monthly passes are $208. In December 1993, the monthly pass was discounted 50%. This discount continued through February, and various discounts were offered throughout the recovery period. Prior to December 1993, Santa Clarita line ridership averaged about 19,000 boardings per month, or 2.5 passengers per revenue train-mile (RTM). The discount increased ridership to over 31,000 in December.

For analysis purposes, we assumed that, absent the earthquake, ridership would have remained at the December level. Thus, all passengers in excess of the December count are attributed to the earthquake. Similarly, we assumed that all service hours in excess of the December level are attributed to the earthquake. Metrolink calculates operating costs on a flat per unit basis; we used the same method. We did not consider capital costs, either for the existing (pre-earthquake) services or the additional services.[7]

Only two operating cost figures were provided by Metrolink: total fiscal year (FY) 1993–94 operating costs, and total operating costs of earthquake-related services as reported to the Federal Emergency Management Agency (FEMA). These numbers generated an operating cost of $60.24 per RTM for regular service and $87.00 per RTM for

[7] Data on capital investments were not available.

earthquake emergency service. No explanation was provided for the difference in these costs. It is reasonable to assume that the additional emergency services were more costly; however, the actual amount of the additional costs cannot be determined.

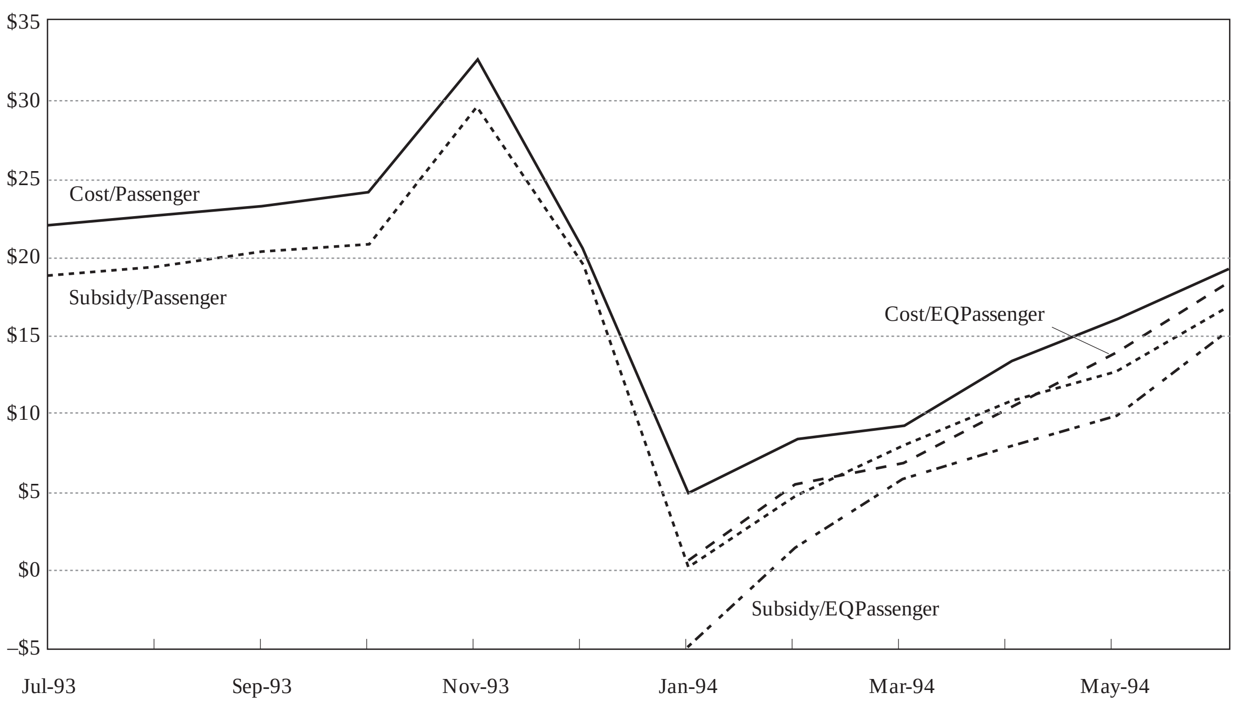
We used the cost and passenger revenue data provided by Metrolink to generate cost and subsidy per passenger for each month in FY 1993–94. Figure 8 shows cost and subsidy per passenger for total monthly passengers and for the additional passengers (and additional emergency service). Throughout the recovery period the cost per passenger is lower for the emergency service than for total service. The number of additional passengers far exceeded the quantity of additional service provided, more than offsetting the greater cost of the emergency service. More intensive service utilization is also reflected in subsidy per passenger. The large increase in ridership in January actually resulted in a net revenue gain. As ridership declined in the following months, subsidy cost increased, reaching nearly $16 per additional passenger in June.

Emergency Bus Service

Emergency bus services were provided in the I-10 corridor, the I-5 corridor, and as connector or feeder services to Metrolink. In addition to LACMTA, four small transit operators participated in the provision of emergency services. We concentrated on the I-10 corridor area bus services. Additional capacity was added to regular LACMTA lines operating on the major arterials paralleling I-10. Most of these increases were eliminated within a few weeks due to lack of ridership. New emergency express lines were also established: LACMTA Lines 634, 644, and 646. These lines were operated by other municipal providers under the administrative management of LACMTA.

We were able to obtain sufficient data to estimate costs only for the new emergency lines. Data on vehicle-hours were provided directly by LACMTA. Costs were estimated using FY 1993 audited cost figures for the three providers, with costs based on the number of revenue vehicle-hours (RVH) provided by each operator. Ridership estimates are based on the daily counts collected by Caltrans consultants. We were unable to obtain

FIGURE 8 Cost and Subsidy Per Passenger, All Passengers, Earthquake Passengers



Source: Computed from cost and ridership data provided by LACMTA.

passenger revenue data, and hence were unable to calculate subsidies for the emergency services. Table 6 gives results for the three emergency lines. Cost per RVH ranges from $78 to $99. (The municipal providers have lower operating costs than LACMTA). Ridership was very low, ranging from 3.5 boardings per RVH to 2 per RVH. Low productivity results in very high costs per passenger: from $22 to $50—much higher than the Metrolink costs.

To place these figures in perspective, the lower portion of table 6 gives some comparison figures for the other LACMTA lines in the I-10 corridor. We computed averages for 10 local service lines and 5 express lines. The local service is very heavily used and therefore cost per passenger is quite low. The more comparable figures are for the express service, with an estimated operating cost per passenger of $4.96. Given the general level of transit demand in the corridor, the lack of demand for the emergency services is somewhat surprising, and suggests that public awareness of the services may have been quite limited.

LACMTA billed FEMA for the emergency service at a flat rate of $77.37 per RVH. This is the average systemwide operating cost per RVH for FY 1993–94. Given the operating cost estimates in table 6, the actual costs to LACMTA were apparently substantially higher than the cost recovered from FEMA.

CONCLUSIONS

Our analysis of traveler responses to the Northridge earthquake indicates that most travelers adjusted to the crisis conditions by changing routes and travel time schedules, and avoiding discretionary trips in the damaged areas. Public transit and ridesharing played a more limited role. With the exception of the short-term surge in Metrolink ridership on the Santa Clarita line, transit use remained relatively stable. Survey data are consistent with the screenline analysis; few commuters chose to change modes; many more changed their route or travel schedule. As soon as the freeway reconstruction was completed, travel patterns quickly reverted to pre-earthquake conditions.

Explaining Traveler Responses

It is interesting that even in the extreme circumstance of the I-5 corridor, the shift to Metrolink was short-lived. The detours provided about 70% of pre-earthquake capacity in terms of lane-miles, but actual capacity was less, because high-speed lanes were lost. Nevertheless, the vast majority of corridor travelers chose to remain in their private vehicle (or not make the trip) rather than use Metrolink. As we noted, housing and job locations are highly dispersed in Los Angeles, so a single rail line can effectively serve only a small proportion of the many possible origins and destinations of travelers within the corridor. Bus transit was a less

Table 6 Cost and Ridership on Emergency Bus Lines

Emergency service

Line	Start	End	Type	Operating cost/RVH	Boarding per/RVH	Cost per boarding
634	1/20/94	4/18/94	Local/express	$77.86	3.5	$22.17
644	1/31/94	3/14/94	Express	$99.34	2.0	$50.45
646	2/14/94	5/2/94	Express	$89.23	3.3	$27.12

Averages for regular MTA service in I-10 corridor[1]

Number of lines	Type	Operating cost/RVH	Boarding per/RVH	Cost per boarding
10	Local	$90.75	71.14	$1.60
5	Express	$120.54	26.78	$4.96

[1] Compiled from LACMTA, *Line Performance Trends Report*, 13 July 1994.

effective alternative, because, with the exception of the HOV detours, buses shared the same limited street capacity, and hence were subject to the same delays as private vehicles. In both corridors, the HOV detours were relatively short, so the potential travel-time savings from using them were limited.

Travel behavior research suggests additional reasons for the limited substitutability of transit under emergency conditions. First, there are information costs. Metrolink conducted an extensive public information campaign (including mailings to Santa Clarita and Antelope Valley residents), but there was nevertheless substantial uncertainty about parking availability, shuttle connections, etc. Moreover, bus transit information is often difficult to obtain. Second, a shift to transit requires a greater behavioral change than shifting routes or travel-time schedules. Leaving one's car means giving up its flexibility—something that may be of great value in emergency situations.

The strategy of Los Angeles officials was to provide capacity through all means available. The existing freight rail system made it possible to extend commuter rail service quickly. The region's bus transit operators were mobilized, placing into service all available rolling stock. Parallel arterials were enhanced quickly by removing on-street parking, restriping, dedicating them to one-way traffic during the peak, and adjusting signal timing. An extensive public information campaign, together with regular news reports, provided travelers with up-to-date information on travel conditions and options. Employers provided options at the workplace, making it possible for workers to adjust work and travel schedules, and in some cases, work locations. The result was that travelers had many different alternatives for coping with the damaged transportation system. The strategy of tailoring emergency services to the specific conditions and resources available proved to be highly effective.

How do these results compare with those of other types of disruptions? First, the emphasis on changing routes and travel schedules in response to changed conditions was observed during the 1984 Los Angeles Olympics, and for several major reconstruction projects (Giuliano 1988; Devine et al 1992). Second, the quick return to previous behavior once capacity was restored was observed after the Olympics, after the Loma Prieta earthquake, and after the reconstruction projects. It would appear that travelers are highly adaptive: adjustments are made to short-term conditions, and these adjustments end as soon as they are no longer necessary.

A Word on Disaster Research

We noted earlier that disaster research poses challenges to the researcher. Our experience leads us to the following conclusions. First, the availability of data on basic measures of transportation system performance is critical. In this case, for example, freeway traffic volume counts, even for designated count locations, had extensive missing data, making it impossible to develop a valid time series profile of volume patterns. Arterial count data was also very limited, even for locations for which such data are collected via automated computer logs. Ultimately, the issue is one of cost: it is costly to collect and verify data regularly, and it is costly to develop programs and procedures to process automated data. The highway performance monitoring systems currently in place are designed for general monitoring; the data are neither extensive enough nor disaggregate enough to provide a basis for highly localized analysis of an unanticipated event. Transit information is equally problematic. Transit agencies keep detailed information on a systemwide basis, but have little information on specific routes. Again, cost is an issue: detailed ridership data must be collected manually.

Data limitations frustrated many parts of our work. The lack of data made it impossible to conduct even basic statistical analysis. For example, we were unable to calculate demand elasticities for transit (the I-5 corridor was potentially a great example of responses to changing travel times), and we were unable to determine the extent to which reduced capacity (versus reduced overall demand) affected the drop in total tripmaking. Because of this very fundamental data problem, future studies of disasters are likely to face the same limitations we had in this research.

Second, a quick start is important. Public agencies have no choice but to respond immediately to the crisis. Conditions begin to change immediately.

If responses to changing conditions are of interest, behavioral data collection must begin as rapidly as possible. This urgency is not compatible either with the usual pace of research or the institutional structure of research funding, which suggests that it might be beneficial to conduct some disaster research planning. It would also be useful to consider the establishment of an "emergency research funding policy" that would allow researchers to circumvent the usual institutional process.

Finally, we should perhaps have more realistic expectations of what can be done in disaster research. This type of research must be more exploratory, less comprehensive, and more suggestive and qualitative than we would like.

ACKNOWLEDGMENTS

This research was supported by the U.S. Department of Transportation (DOT), Bureau of Transportation Statistics, and by the University of Southern California. Comments by anonymous referees are greatly appreciated. Views expressed are those of the authors, and not necessarily those of DOT or the University of Southern California. Any errors and omissions are the responsibility of the authors.

REFERENCES

Applied Management and Planning Group (AMPG). 1994. Home Interview Survey of Travelers Impacted by the Earthquake, prepared for Caltrans District 7, Office of Operations, Los Angeles, CA.

Ardekani, S. 1992. Transportation Operations Following the 1989 Loma Prieta Earthquake. *Transportation Quarterly* 46, no. 2:219–233.

Bennet, A. and D. Little. 1990. Earthquake Effects on Employee Transportation. *Studies on the Loma Prieta Earthquake*, *No. 2*. Berkeley, CA: University of California Transportation Center.

Bullard, D. 1987. Commuter Perceptions of Traffic Congestion During the Reconstruction of I-45 North Freeway in Houston. *Transportation Research Record* 1132:25–33.

Caltrans District 7. 1995. Northridge Earthquake Recovery Report, prepared by Barton-Aschman Associates, Inc. for Caltrans District 7, Office of Operations, Los Angeles, CA.

Commuter Transportation Services, Inc. (CTS). 1994. *1994 State of the Commute Report*. Los Angeles, CA.

Devine, S., J. Bucci, and D. Berman. 1992. Traffic Management During the I-195 Providence River Bridge Repair Project. *Transportation Research Record* 1360: 1–3.

Giuliano, G. 1988. Testing the Limits of TSM: The 1984 Los Angeles Summer Olympics. *Transportation* 15:143–161.

____. 1994. Equity and Fairness Considerations of Congestion Pricing. *Curbing Gridlock: Peak Period Fees To Relieve Traffic Congestion,* Transportation Research Board Special Report 242. Washington, DC: Transportation Research Board, National Research Council.

Gordon, P., H. Richardson, and B. Davis. 1998. Transport-Related Business Interruption Impacts of the Northridge Earthquake. *Journal of Transportation and Statistics* 1:2.

Gray, G., J. Roberts, and J. Markowitz. 1990. Aftershock: Dealing with the Highway Crisis After the Loma Prieta Earthquake. *TR News*. July–August.

Hansen, M. and S. Weinstein. 1991. East Bay Ferry Service and the Loma Prieta Earthquake. *Studies on the Loma Prieta Earthquake*, *No. 5*. Berkeley, CA: University of California Transportation Center.

Hendrickson, C., R. Carrier, T. Dubyak, and R. Anderson. 1982. Traveler Responses to Reconstruction of Parkway East (I-376) in Pittsburgh. *Transportation Research Record* 890:33–39.

Homberger, W. 1990. The Loma Prieta Earthquake: What Happened to the Trip Makers? A Preliminary Report, ITE Compendium of Technical Papers, 43rd Annual Meeting.

Mahmassani, H., S. Hatcher, and C. Caplice. 1991. Daily Variation of Trip Chaining, Scheduling and Path Selection Behavior of Work Commuters, in Methods of Understanding Travel Behavior in the 1990's: Proceedings of the International Conference on Travel Behavior, Quebec, Canada.

Meyer, M. 1985. Reconstructing Major Transportation Facilities: The Case of Boston's Southeast Expressway. *Transportation Research Record* 1021:1–9.

Nivola, P. and R. Crandell. 1995. *The Extra Mile*. Washington, DC: The Brookings Institution.

Webber, M. 1992. Redundancy: The Lesson from the Loma Prieta Earthquake. *Access* 1:15–19, Fall.

Transport-Related Impacts of the Northridge Earthquake

PETER GORDON
HARRY W. RICHARDSON
BILL DAVIS
School of Urban Planning and Development
University of Southern California

ABSTRACT

This research estimates the transport-related business interruption impacts of the 1994 Northridge earthquake using a spatial allocation model, SCPM (the Southern California Planning Model) and surveys of businesses and individuals. Total business interruption losses are estimated at more than $6.5 billion, sizeable but much smaller than total structural damage (over $25 billion), with an associated job loss of 69,000 person-years. The four types of transport-related interruptions (commuting, inhibited customer access, and shipping and supply disruptions) totaled more than $1.5 billion, or 27.3% of all local business interruptions, with a job loss of more than 15,700 person-years. In addition, there were commuting travel time losses of at least $33 million and some dislocation of shopping patterns and frequencies. These losses would have been much higher had it not been for the substantial redundancy in Los Angeles' highway system.

Peter Gordon, School of Urban Planning and Development, Von Klein Smid Center 351, University of Southern California, Los Angeles, CA 90089-0042. Email: pgordon@almaak.usc.edu.

INTRODUCTION

One of several dramatic consequences of the Northridge earthquake was the damage to several major freeways and arterials. (See Overview on pp. iv–vi.) Highways returned to normal service at different rates, but relatively quickly when compared with the 1989 Loma Prieta earthquake. Nevertheless, some transport-related impacts were longer lasting because they were affected by other factors; for example, extensive damage to the mall nearest to the earthquake (the Northridge Fashion Center) affected shopping behavior for more than a year.

Two types of transport-related impacts are examined in this paper: business interruption as revealed from a survey of firms, including their indirect and induced effects on the regional economy; and disruptions to commuting trips and nonwork trips, obtained from a telephone survey of individuals.

Business interruptions can be the result of stationary factors (e.g., damage to structures) or mobility factors (e.g., problems with delivery of raw materials and/or final products, and employee commuting problems). The distinction between the two is somewhat blurred; for example, damage to loading/unloading facilities can interfere with freight transportation, and employee tardiness or absence because of commuting problems can result in lost output or revenues at the production site. The few business interruption studies that have been undertaken (including our own) focus more on structural damage effects than on the transportation impacts. The main goal of this paper is to correct this omission.

The Survey

We developed two telephone interview surveys, one directed to firms and another to individuals (targeted at commuters). Both surveys focused on an identified impact zone. The primary purpose of the research was to obtain the best possible estimate of the transport-related business interruption impacts of the Northridge earthquake.

Telephone interviews provided information on 990 sites, involving 528 firms. The firms were selected from *Ward's Business Directory of U.S. Private and Public Companies* and from the *Million Dollar Directory: America's Leading Public and Private Companies*. Because these sources underrepresent smaller firms, especially in the services sectors, yellow page listings were used to identify companies and establishments in health, personal, and educational services. At each company or site, the person best able to provide information on the performance of company operations since January 17, 1994, was identified and interviewed.

The sample of firms was stratified by location and economic sector. Maps showing the distribution of damage identified a "direct impact zone." This zone consists of 16 Community Plan Areas within the city of Los Angeles and the cities of Santa Monica, San Fernando, and Glendale. These areas convert to 11 geographic zones in the Southern California Planning Model (SCPM), the model used in this research for economic impact analysis. The industry stratification consists of 15 economic sectors (construction; nondurable manufacturing; durable manufacturing; transportation; communications and utilities; wholesale trade; retail trade; finance, insurance, and real estate; business/repair services; personal services; entertainment and recreation; health services; educational services; other personal services; and public administration). Agriculture and mining were excluded from the survey, and are not included in the direct impacts. This is unlikely to be a major omission, although minor indirect and induced effects in these sectors are picked up via the operations of the model.

The survey instrument established general characteristics of the firm, including location, longevity, number of establishments in the impact zone, tenure at each site, employment, and type of firm. Earthquake impacts include: whether or not the firm suffered any business interruption; if so, how many days it was completely out of operation; how many days it operated at reduced levels of performance, and by how much; changes in the level of employment (direction, magnitude, and duration); declines in revenue; increases in operating costs; capacity to recoup business interruption losses; and reasons for business interruption.

With respect to transport-related impacts, questions were asked about preexisting alternative commuting programs, new programs induced by the earthquake, classification by type, and their effectiveness. The survey also inquired about shipping and receiving practices: volume of shipping and receiving; reliance on in-house transportation versus use of commercial freight services; and changes in shipping and receiving services associated with the earthquake. From the point of view of business interruptions, four transport-related effects were identified: 1) commute interruptions that impeded employee access; 2) obstacles to customer access; 3) interference with shipments of output; and 4) disruptions to the supplies of inputs. The primary aim of the research was to quantify the relative importance of each of these impacts and how important they were in the context of total business interruption.

The Sample Area

This research builds on a sample survey developed to estimate total business interruption effects, not merely transport-related impacts. The sample was drawn from an "impact zone" defined largely in terms of structural damage. The transportation system damages were more narrowly defined geographically, focused on four freeways: Interstate 5 (I-5), State Route 14 (SR-14), and State Route 118 (SR-118), which are geographically clustered; and, some distance away, Interstate 10 (I-10). A survey targeted solely at freeway damage might have been more geographically circumscribed. Another problem, related specifically to our commuter survey, is that we interviewed individuals living in the impact zone: we have no idea where they work, and some of them undoubtedly commute away from it. Individuals living outside the impact zone but working in or close to it were not counted in the survey.

An interesting question is whether the sample survey areas in this study are consistent with those defined in other studies of the transport-related impacts of the Northridge earthquake (e.g., Willson 1998; Boarnet 1998). Consistency would have increased the comparability of results across the different studies. On the other hand, if results are similar with differently designed surveys in terms of sampling area and methodology, it indicates a degree of robustness.

The study of goods movement based on a trucking firm survey by Willson (1998) targeted firms throughout Los Angeles County on the basis that, in this industry, location of the firm gives no indication of area of operation; in other words, firms located within Los Angeles County can be expected to cover the region as a whole. Boarnet (1998) studied the effect of transportation damage on business activity based on a survey of 559 firms (the respondents to a mailed questionnaire to 750 firms in each of three sectors—manufacturing, retail trade, and wholesale trade). He used a broad geographic area bounded by the 105 Freeway to the south, the 605 Freeway to the east, Kern County to the north, and the Pacific Ocean and parts of Ventura County to the west; this is the "experimental" area. He also used a "control" area, consisting of Orange County, which is more than 50 miles south of the earthquake's epicenter. We recognized the importance of using controls, but chose not to include a control in our survey because of cost. In Boarnet's study, the proportion of respondents stating that they suffered losses because of transportation was 8.1% in the control area compared with 18.8% in the experimental area, confirming the disproportionate concentration of impacts closer to the epicenter. This result suggests that our research design may have underestimated total impacts, but it also indicates that impacts, while not negligible, are much lower at considerable distances from the earthquake's epicenter.

ECONOMIC IMPACT MODEL

Business interruption effects are calculated by estimating the decline in final demand by economic sector, and then running these final demand changes through our model (SCPM) to quantify the direct, and indirect and induced, employment and output impacts of business interruption by geographic zone (the model disaggregates spatial impacts in the five-county Los Angeles region into 289 zones, in effect, each city and clusters of census tracts in unincorporated areas). The SCPM reveals that the geographic distribution of total impacts is different from the geographic distribution of earthquake damage.

The major inputs into the SCPM in this study are estimates of final demand losses in output and employment in the 11 impact zones directly affected by the Northridge earthquake. These final demand losses were derived by multiplying the percentage of employee-days lost in each sector and zone by the 1994 baseline employment level by sector and zone obtained from updates of the 1990 census (see table 1), and then using inverse multipliers to deflate the gross employment changes from the survey into final demand employment changes.

The employment ratios are shown by economic sector in table 2. The average employee-days lost is about 4.9% of total employee-days available. Health services, personal services, and retail trade suffered above-average employment losses. The same losses are distributed by major impact zone in table 3 (the two zones, Sylmar and San Fernando were treated as one sample zone for input purposes because of sample size problems). The biggest

Table 1 Baseline Employment by Sector and SCPM Zone

Sectors	Zone 1	Zone 5	Zone 7	Zone 9	Zone 10	Zone 13	Zone 16	Zone 18	Zone 21	Zone 22	Zone 23	Total
Agriculture, Forestry, and Fisheries	1,704	2,167	1,196	1,190	1,916	530	399	355	1,017	579	776	11,829
Mining	149	114	50	50	297	27	8	49	61	15	39	859
Construction	8,155	9,623	5,777	6,339	9,811	2,783	1,110	2,136	4,967	1,511	5,651	57,863
Manufacturing (nondurable)	8,934	7,583	7,056	7,071	8,944	2,816	1,527	3,003	2,850	2,321	4,838	56,943
Manufacturing (durable)	17,847	16,863	21,603	7,181	12,627	6,158	3,950	2,456	5,631	2,574	5,519	102,409
Transportation	4,550	4,256	2,622	3,598	6,757	2,222	874	1,489	1,694	377	2,354	30,793
Communication and Other Public Utilities	2,884	2,858	1,707	8,010	4,932	924	258	1,250	1,949	547	1,185	26,504
Wholesale Trade	6,912	6,156	6,541	4,645	7,599	2,327	907	1,742	3,049	993	2,838	43,709
Retail Trade	18,010	25,155	15,497	19,861	28,937	6,016	2,010	6,484	14,483	3,178	14,593	154,224
Finance, Insurance, and Real Estate	8,041	24,134	8,005	8,474	14,857	2,804	713	1,820	7,689	577	12,637	89,751
Business and Repair Services	7,406	10,706	6,008	11,268	13,457	3,377	829	2,406	5,882	1,160	5,220	67,719
Personal Services	3,865	7,368	3,246	6,377	6,670	1,238	697	1,410	3,904	565	2,657	37,997
Entertainment and Recreation Services	2,818	4,400	1,899	21,892	12,495	790	404	853	2,914	217	2,769	51,451
Health Services	10,130	13,206	4,156	13,041	11,938	2,873	2,494	3,150	8,629	672	7,449	77,738
Educational Services	8,858	7,919	6,747	6,067	8,092	3,009	1,127	3,580	4,147	1,230	4,512	55,288
Other Professional and Related Services	6,734	14,127	4,466	10,118	14,324	2,612	820	2,258	11,160	774	6,323	73,716
Public Administration	2,730	2,877	2,054	2,230	4,625	1,097	457	1,050	2,055	468	2,365	22,008
Total	119,727	159,512	98,630	137,412	168,278	41,603	18,584	35,491	82,081	17,758	81,725	960,801

Note:

Zone 1 = City of Los Angeles (Arleta/Pacoima/Granada Hills/Knollwood/Mission Hills/Lakeview Terrace/Shadow Hills/Sunland/Sun Valley/Tujunga)
Zone 5 = City of Los Angeles (Canoga Park/Woodland Hills/Encino/Tarzana)
Zone 7 = City of Los Angeles (Chatsworth/Porter Ranch/Northridge)
Zone 9 = City of Los Angeles (Hollywood)
Zone 10 = City of Los Angeles (North Hollywood/Van Nuys/North Sherman Oaks/Sherman Oaks/Studio City/Toluca Lake)
Zone 13 = City of Los Angeles (Reseda/West Van Nuys)
Zone 16 = City of Los Angeles (Sylmar)
Zone 18 = City of Los Angeles (West Adams/Baldwin Hills/Leimert Park)
Zone 21 = City of Santa Monica
Zone 22 = City of San Fernando
Zone 23 = City of Glendale

Table 2 Employee-Days Lost by Economic Sector

		A	B	C	D	E	F	G	H	I	J	
Economic sector	Frequency	Employee-days lost from days completely out of operation	Number of employees in sample	Additional employee-days required to adjust for companies working more/less than 260 days/year	Total employee-days in sample	Percentage employee-days lost from days completely out of operation	Employee-days lost from days partially out of operation or operating at reduced levels of performance	Number of employees in sample	Additional employee-days required to adjust for companies working more/less than 260 days/year	Total employee-days in sample	Percentage employee-days lost from days partially out of operation or operating at reduced levels of performance	Total percentage of employee-days lost in business interruption
					B*260+C	A/D				G*260+H	F/I	E+J
A) Construction	28	1,940	2,290	11,596	606,866	0.32%	665	2,178	11,596	577,746	0.12%	0.43%
B) Manufacturing (nondurable)	70	72,853	10,914	385,606	3,223,246	2.26%	34,687	10,912	385,398	3,222,518	1.08%	3.34%
C) Manufacturing (durable)	144	166,965	39,423	292,552	10,542,402	1.58%	132,612	36,909	290,394	9,886,604	1.34%	2.93%
D) Transportation	32	1,133	933	38,636	281,086	0.40%	1,829	906	38,636	274,066	0.67%	1.07%
E) Communication/ Utility	33	693	7,544	40,885	2,002,325	0.03%	7,062	7,444	30,585	1,966,025	0.36%	0.39%
F) Wholesale	43	4,892	2,213	43,160	618,540	0.79%	4,775	2,202	42,536	615,056	0.78%	1.57%
G) Retail	73	26,839	2,512	125,184	778,174	3.45%	17,976	2,247	122,923	707,013	2.54%	5.99%
H) Financial, Insurance and Real Estate	77	14,043	6,978	37,128	1,851,408	0.76%	7,253	6,978	37,408	1,851,688	0.39%	1.15%
I) Business/Repair Services	70	4,512	1,936	47,346	550,706	0.82%	2,812	1,892	47,346	539,266	0.52%	1.34%
J) Personal Services	44	95,060	2,938	273,494	1,037,244	9.16%	8,203	2,895	273,494	1,026,064	0.80%	9.96%
K) Entertainment/ Recreation	30	2,446	1,731	7,618	457,548	0.53%	5,242	1,731	7,618	457,548	1.15%	1.68%
L) Health Services	53	91,629	18,882	1,637,000	6,546,320	1.40%	772,058	18,922	1,815,560	6,735,280	11.46%	12.86%
M) Educational Services	258	225,866	29,790	-1,460,218	6,285,114	3.59%	310	29,790	-1,460,218	6,285,114	0.00%	3.60%
N) Other Personal Services	34	3,271	2,039	122,148	652,158	0.50%	1,309	2,000	122,148	642,018	0.20%	0.71%
Total	989	712,141	130,119	1,602,135	35,433,137	2.01%	996,792	127,002	1,765,424	34,786,006	2.87%	4.88%

Table 3 Employee-Days Lost, by Impact Zone

		A	B	C	D	E	F	G	H	I	J	
SCPM zone/community plan areas/city	Frequency	Employee-days lost from days completely out of operation	Number of employees in sample	Additional employee-days required to adjust for companies working more/less than 260 days/year	Total employee-days in sample	Percentage employee-days lost from days completely out of operation	Employee-days lost from days partially out of operation or operating at reduced levels of performance	Number of employees in sample	Additional employee-days required to adjust for companies working more/less than 260 days/year	Total employee-days in sample	Percentage employee-days lost from days partially out of operation or operating at reduced levels of performance	Total percentage of employee-days lost in business interruption
					B*260+C	A/D				G*260+H	F/I	E+J
1 Arleta/Pacoima Mission Hills/ Sepulveda/ Panorama City Granada Hills/ Knollwood Sun Valley Sunland/Tujunga/ Shadow Hills/ Lake View Terrace	114	55,400	12,214	–117,297	3,058,337	1.81%	123,156	12,102	-117,297	3,029,217	4.07%	5.88%
5 Canoga Park/ Winnetka/ Woodland Hills Encino/Tarzana	136	103,258	21,834	264,949	5,941,714	1.74%	52,269	20,778	460,889	5,863,224	0.89%	2.63%
7 Chatsworth/ Porter Ranch Northridge	116	224,046	29,274	275,932	7,887,068	2.84%	78,812	29,136	274,377	7,849,763	1.00%	3.84%
9 Hollywood	65	14,158	5,099	–77,374	1,248,273	1.13%	3,746	5,091	-77,374	1,246,323	0.30%	1.43%
10 North Hollywood Van Nuys/North Sherman Oaks/ Studio City/ Toluca Lake	144	126,115	12,484	186,245	3,431,994	3.67%	17,411	12,407	186,037	3,411,766	0.51%	4.19%
13 Reseda/ West Van Nuys	65	31,496	6,498	137,919	1,825,524	1.72%	21,349	6,418	140,455	1,809,130	1.18%	2.90%
16 and 22 Sylmar/ San Fernando	72	37,887	8,235	-5,673	2,135,445	1.77%	21,366	8,168	-5,673	2,117,895	1.01%	2.78%
18 West Adams/ Baldwin Hills/ Lemert	59	14,221	4,453	–136,145	1,021,666	1.39%	5,399	4,427	-136,145	1,014,906	0.53%	1.92%
21 Santa Monica	69	82,797	8,685	417,811	2,675,859	3.09%	591,667	8,650	395,411	2644,359	22.37%	25.47%
23 Glendale	47	3,210	9,908	306,189	2,882,269	0.11%	2,218	9,903	306,189	288,0969	0.08%	0.19%
Impact zone total		692,589	118,683	1,252,555	32,110,148	2.16%	917,394	117,080	1,426,868	31,867,551	2.88%	5.04%
Other areas		20,952	11,786	349,580	3,413,995	0.61%	79,398	10,273	338,556	3,009,461	2.64%	3.25%
Total		713,541	130,469	1602,135	35,524,142	2.01%	996,792	127,352	1,765,424	34,877,012	2.86%	4.87%

losses were experienced not at the epicenter (Chatsworth-Northridge) but in Santa Monica, because of major damage to its hospitals.

The output results are obtained indirectly via the output-employment coefficients embedded in the model. The changes in final demand are fed through a highly disaggregated (513 economic sectors) input-output model to generate the direct, indirect (impacts associated with intermediate suppliers), and induced (secondary consumption) employment and output effects. These sectoral impacts are then allocated over the five-county region into the 289 geographic zones. Direct impacts are allocated to the 11 impact zones based on the survey results; indirect effects are allocated in proportion to the distribution of employment by zone and sector; and induced impacts are traced back from the workplace to the residential site via a journey-to-work matrix and from the residential site to the place of purchase and/or consumption via a journey-to-services matrix. For the purposes of geographic allocation, the 513 input-output sectors are collapsed into 15 sectors.

To put the output and job losses resulting from a major earthquake into perspective, we compared these to estimates of annual employment and gross regional product for the five-county region. The gross regional product estimates, which are less reliable than employment estimates, were derived by applying Southern California/State of California ratios to the state estimate of gross state product.

This procedure yielded an estimate of aggregate business interruption effects that provides a benchmark against which the transport-related business interruption estimates can be assessed. However, the same estimation process (e.g., starting from employee-days lost) is used in calculating each of these transport-related impacts.

FINDINGS

More than four-fifths of the respondents experienced some degree of business interruption, but more than one-quarter (including some affected by business interruption) benefited from the earthquake in the sense that their sales and revenue increased.

Table 4 Sources of Business Interruption

	Proportion of positive responses
Employees attending to personal matters	73.3
Damage to place of business	72.3
Interruption to utility services	63.1
Inhibited employee access to work	60.4
Getting to work	81.4
Getting into the building	58.1
Not able to make shipments	32.6
Inhibited customer access	30.4
Getting into the business	60.1
Getting into the building	56.0
Other reasons	30.9
Inventory losses	24.0
Not receiving supplies	20.1
Credit problems	4.1

The survey instrument permitted firms to identify multiple causes of business interruption, although managers had difficulty in prioritizing and quantifying these causes. Table 4, which sums up the responses, is important for this study because the relative frequency of a positive response was used as an adjustment coefficient to estimate the relative size of the corresponding business interruption impact. The greatest number of positive responses was for employees attending to personal matters, for example, damage to their homes (73.3%). Although the latter is not a transport-related impact *per se*, it results in a decline in commuting; the research explored this issue in the survey of individuals. Damage to the business site was also important (72.3%). Other important reasons were interrupted utilities (63.1%) and inhibited employee access (60.4%). Most other reasons (e.g., inhibited customer access, inability to make shipments or receive supplies, inventory losses, or credit problems) affected less than one-third of the respondents.

ESTIMATES OF AGGREGATE BUSINESS INTERRUPTION

Running the final demand impacts of total business interruption through the SCPM to generate direct, and indirect and induced impacts over the five-county region generates dollar losses of output and

Table 5 Business Interruption Losses from the Northridge Earthquake
(Jobs in person-years, output in 1994 dollars)

	Direct		Indirect and induced		Total	
Area	Jobs	Output	Jobs	Output	Jobs	Output
Arleta/Pacoima Mission Hills/Sepulveda/ Panorama City Granada Hills/Knollwood Sun Valley Sunland/Tujunga/Shadow Hills/ Lake View Terrace	5,073.1	457,023.9	231.4	28,045.7	5,304.5	485,069.6
Canoga Park/Winnetka/Woodland Hills Encino/Tarzana	3,023.8	272,409.9	287.8	30,242.7	3,311.6	302,652.6
Chatsworth/Porter Ranch Northridge	2,734.0	246,297.5	178.7	22,866.0	2,912.6	269,163.5
Hollywood	1,421.5	128,058.8	188.0	19,000.9	1,609.5	147,059.7
North Hollywood Van Nuys/North Sherman Oaks Sherman Oaks/Studio City/Toluca Lake	5,077.4	457,416.7	329.9	35,226.4	5,407.3	492,643.1
Reseda/West Van Nuys	870.9	78,458.9	79.6	9,783.2	950.4	88,242.1
Sylmar	372.9	33,591.4	34.7	4,441.2	407.5	38,032.6
West Adams/Baldwin Hills/Lemert	492.3	44,350.0	70.1	7,575.7	562.4	51,925.7
Glendale	111.0	10,001.0	218.9	22,491.0	329.9	32,492.0
San Fernando	356.3	32,098.1	69.8	7,589.3	426.2	39,687.3
Santa Monica	15,072.2	1,357,822.1	216.0	22,329.1	15,288.2	1,380,151.2
Impact zone total	34,605.4	3,117,528.3	1,904.9	209,591.2	36,510.1	3,327,119.4
Rest of Los Angeles City			2,119.9	232,021.2	2,120.2	232,021.2
Rest of Los Angeles County			10,668.2	1,067,914.1	10,668.0	1,067,914.3
Rest of region[1]			8,260.7	877,532.0	8,260.8	877,532.0
Region total	34,605.4	3,117,528.3	22,953.7	2,387,058.5	57,559.1	5,504,586.9
Rest of world	11,454.4	1,031,901.9	NA	NA	11,454.4	1,031,901.9
Total	46,059.8	4,149,430.3	22,953.7	2,387,058.5	69,013.5	6,536,488.8

[1] Carried forward but not complete.

companion job losses (see table 5). These estimates of aggregate business interruption[1] provide the basis for estimates of transport-related business interruption. The details are discussed elsewhere (Gordon et al 1996), and only a brief summary is presented here. The key findings are:

1. aggregate business losses totaled $6.536 billion, a sizeable impact although much smaller than the magnitude of structure damage (in excess of $25 billion);
2. $3.118 billion of these losses, or 47.7% of the total, were from direct business interruptions within the impact zones;
3. once indirect and induced impacts are taken into account, the impact zones' contribution to aggregate business losses rises to 50.9%. This is not a sizeable increase, implying that the vast majority of indirect and induced effects were outside the directly impacted zones;
4. substantial business losses (about $1.032 billion, or 15.8% of the total) were suffered outside the region, and some of these were sustained abroad because Southern California is an integrated part of the global economy;
5. *intraregional* business interruption output losses are equivalent to about 1.35% of the five-county area's annual gross regional product.

In terms of business-interruption-related job

[1] This discussion refers only to aggregate business interruption effects on the economy at large. Although this is based on survey data, the micro-measure is employee-days lost, which, after aggregation, are converted into output losses. An alternative approach would be a detailed accountancy analysis of the changes in costs and revenues at the level of the individual firm. In fact, this approach has become a rapidly growing area in the business interruption insurance claims field (MacDonald 1997).

losses, the Northridge earthquake resulted in a loss of 69,014 person-years of employment (approximately 1.1% of the region's employment), 52.9% of which occurred within the impact zone, while 16.6% of the jobs were lost outside the region.

The geographic distribution of business interruption impacts in part depends on the distance from the epicenter of the earthquake (i.e., Northridge itself), but not entirely, as a "thrusting"-type can generate significant damage at some distance (e.g., in this case, Santa Monica, South Central Los Angeles, and Hollywood). Aside from the distance from the epicenter, the geology of the city, particularly its liquefaction potential, and its economic structure determine the strength of the indirect and induced linkages. Considering the total job losses distributed among the 11 impact zones, there is a wide range of variation in these impacts. Once indirect and induced business interruption effects and liquefaction potential are taken into account, proximity to the earthquake becomes a relatively modest predictor of economic impacts. For example, the largest impact (41.9%) occurs not in the zones adjacent to Northridge, but some distance away in Santa Monica. The seven San Fernando Valley zones combined accounted for 51.3% of job losses. Hollywood and South Central Los Angeles were also impacted. Clearly, the impacts are very uneven among the zones. However, an equally interesting finding is that the indirect and induced effects outside the impact zones but within the region are substantial; in the rest of Los Angeles County, 12,778 jobs were lost (although this is only 0.40% of employment), while in the other four counties, 8,261 jobs were lost (0.39% of total employment).

Nevertheless, these business interruption losses are a modest, if significant, proportion of total damages. Building structural damages (including contents) are estimated to be $25 billion (about 2.5% of the gross fixed capital stock of Los Angeles and Orange Counties), while the fatality and injury costs (more conjecturally) might amount to $200 million, lower than could have been expected if the earthquake had happened later in the day. Thus, our business interruptions estimate is not an estimate of total damages, but accounts for about 20.6% of an overall estimate of $31.74 billion.

METHODOLOGY

The major problem in quantifying the specific transport-related business interruption effects of the Northridge earthquake is the difficulty that company officials had in evaluating their relative importance in the face of multiple sources of business interruption.[2] In these circumstances, our procedure was to derive specific transport-related impacts from the estimates of aggregate business interruption impacts according to the relative frequency of responses on each of these impacts among the total sources of business interruption reported. The drawbacks of this approach are obvious:

1. it assigns each response the same weight;
2. it implies an unweighted average estimate that does not allocate interruption impacts by source at the individual respondent level; and
3. the proportionality assumption ignores the skewness of indirect and induced effects toward transport-related sectors.

The relative frequencies of all responses were 11.2% for commuting interruptions, 4.2% for inhibited customer access, 7.4% for shipping disruption, and 4.6% for interrupted supplies. These numbers show an *intraregional* impact (direct, and indirect and induced) of $615.413 million for commuting-related interruptions and a *total* impact of $730.779 million, $228.991 million and $271.918 million respectively for inhibited customer access, $407.890 million and $484.354 million respectively for shipping problems, and $251.560 million and $298.718 million for supply interruptions. Adding up the intraregional impacts for all four types of transport-related disruption yields a total of $1.504 billion, or 27.3% of all local business interruption impacts (see tables 5 and 6). More than 60% of these impacts occurred within the impact zone, but the remaining 40% were elsewhere in the region. In addition, another $282 million of transport-related impacts were felt outside the five-county region. The corresponding local employment impacts were 6,435 person-years of

[2] Boarnet (1998) uses a different methodology, but produces results that are consistent with those found in this paper.

Table 6 All Business Interruption Proportioned to Transportation Interruption: Summary
(Jobs in person-years, output in thousands of 1994 dollars)

	Commute		Customer access		Shipping		Supplies		Total	
	Jobs	Output	Jobs	Output	Jobs	Output	Jobs	Output	Jobs	Output
Arleta/Pacoima Mission Hills/Sepulveda/ Panorama City Granada Hills/Knollwood Sun Valley Sunland/Tujunga/Shadow Hills/ Lake View Terrace	593.0	54,230.8	220.7	20,178.9	393.1	35,943.7	242.4	22,167.7	1,449.2	132,521.1
Canoga Park/Winnetka/Woodland Hills Encino/Tarzana	370.2	33,836.6	137.8	12,590.3	245.4	22,426.6	151.3	13,831.2	904.7	82,684.7
Chatsworth/Porter Ranch Northridge	325.6	30,092.5	121.2	11,197.2	215.8	19,945.0	133.1	12,300.8	795.7	73,535.5
Hollywood	179.9	16,441.3	67.0	6,117.7	119.3	10,897.1	73.6	6,720.6	439.8	40,176.7
North Hollywood Van Nuys/North Sherman Oaks Sherman Oaks/Studio City/Toluca Lake	604.5	55,077.5	224.9	20,494.0	400.7	36,504.9	247.1	22,513.8	1,477.2	134,590.2
Reseda/West Van Nuys	106.3	9,865.5	39.5	3,670.9	70.4	6,538.7	43.4	4,032.7	259.6	24,107.8
Sylmar	45.6	4,252.0	17.0	1,582.2	30.2	2,818.2	18.6	1,738.1	111.4	10,390.5
West Adams/Baldwin Hills/Lemert	62.9	5,805.3	23.4	2,160.1	41.7	3,847.7	25.7	2,373.0	153.7	14,186.1
Glendale	36.9	3,632.6	13.7	1,351.7	24.4	2,407.7	15.1	1,484.9	90.1	8,876.9
San Fernando	47.6	4,437.0	17.7	1,651.0	31.6	2,940.8	19.5	1,813.7	116.4	10,842.5
Santa Monica	1,709.2	154,300.9	636.0	57,414.3	1,132.9	102,269.2	698.7	63,072.9	4,176.8	377,057.3
Impact zone total	4,081.8	371,971.9	1,518.8	138,408.2	2,705.4	246,539.5	1,668.5	152,049.4	9,974.5	908,969.0
Rest of L.A. City	237.0	25,940.0	88.2	9,652.1	157.1	17,192.8	96.9	10,603.4	579.2	63,388.3
Rest of L.A. County	1,192.7	119,392.8	443.8	44,425.2	790.5	79,132.4	487.5	48,803.7	2,914.5	291,754.1
Rest of region	923.6	98,108.1	343.6	36,505.3	612.1	65,025.1	377.5	40,103.2	2,256.8	239,741.7
Region total	6,435.1	615,412.8	2,394.5	228,990.8	4,265.1	407,889.9	2,630.5	251,559.6	15,725.2	1,503,853.1

employment (PYEs) for commute interruptions, 2,395 PYEs for customer access, 4,265 PYEs for shipping, and 2,631 PYEs for supply problems.

RESPONSES OF FIRMS

A major question is the extent to which firms responded to the transport-related interruptions of the earthquake. The survey shed some light on this issue. It is difficult if not impossible for individual firms to do much about customer access problems, but they had some control over the other sources of interruption: 28.6% of respondents increased their participation in alternative commuting programs, 14.3% changed their shipping procedures and/or patterns, and 6.6% altered their supply arrangements. If firms responded to problems, we would expect those firms that had experienced particular transport-related difficulties to be more likely to address them by revising their procedures. Table 7 shows the results of testing this hypothesis. Firms that had an employee access problem were much more likely to have increased alternative commuting programs (69 out of 92 firms) than firms that did not report a problem (although 85 out of 172 firms did make changes); nevertheless, the difference in proportions were statistically significant. The same significant result was obtained for changes in shipping practices: 22 out of 93 firms expressing problems made changes, whereas only 13 out of 164 firms without a stated problem altered their practices. However, for receiving/supply situations, there was no significant difference between those firms reporting problems (5 out of 53 firms responding) and those without problems (12 out of 203 firms responding). This is not surprising. Firms have a much stronger influence via incentives and work flexibility on their employees' commute and on their shipping practices than on the behavior of their suppliers. Because 68% of the transport-related business interruptions were more likely to be under the control of firms (employees' access and shipping) than customer access and suppliers' behavior, this suggests the possibility of more effective earthquake risk management using advanced preparation rather than *ex post* adjustments.

Table 7 Response Compared to Identification of Problem

	Existence of problem: Yes	Existence of problem: No	Chi-square	Probability*
Increased alternative commuting program	69/92	85/172	16.138	0.000
Changed shipping practices	22/93	13/164	12.481	0.000
Changed receiving or receiving conditions	5/53	12/203	0.841	0.359

*Probability of wrongly rejecting the null hypothesis.

THE COMMUTER SURVEY

To complement the survey of business firms, we also surveyed individuals to investigate the effects of the Northridge earthquake on commuting behavior and on shopping and other nonwork travel. In addition, this latter survey tested the results of the business firm survey by obtaining data on days of work missed and the reasons for missing work. We found that the responses were consistent with the results from the previous survey. The majority of employed respondents missed work because of the earthquake and the major reasons for missed work were damage to their work site and/or to their residence. Damage to the commute route was a relatively minor factor. The earthquake also impacted shopping and other nonwork trips; in particular, shopping trips increased in both frequency and average duration.

The study area for the commuter survey is the same impact zone used in the business firms survey. This choice obviously misses affected commuters living outside the impact zone, but in retrospect the choice was partly justified by the results (e.g., the importance of damage to the home). To distribute the survey evenly across the 11 geographic areas within the impact zone, segments of streets were randomly selected from the Haines Criss-Cross Directory. Street segments falling within the impact area were identified and one residential address from each block of that street segment was randomly selected. Up to three attempts were made to contact each residence—one in the afternoon, one in the evening, and if needed, one in the morning. After three unsuccessful attempts the contact was dropped. This process was continued until 30 to 45 successful interviews had been completed in each of the 11 geographic zones.

Table 8 Distribution of Employment Status and Work Missed
(Percent)

<table>
<tr><td>Not employed 32.5</td><td colspan="3">Percent employed 67.5</td></tr>
<tr><td rowspan="4"></td><td>Missed no work 32.7</td><td colspan="2">Missed work 67.3</td></tr>
<tr><td rowspan="3"></td><td>Missed no full days 3.7</td><td>Missed full days 96.3</td></tr>
<tr><td>Missed no partial days 66.4</td><td>Missed partial days 33.6</td></tr>
<tr><td>Missed only full or only partial days 70.5</td><td>Missed full days and partial days 29.5</td></tr>
</table>

Out of 357 respondents, 67.5% were employed at the time of the earthquake (see table 8). Of the 248 employed respondents, 67.3% reported missing work because of the earthquake. However, while 96.3% of those that missed work missed some full days, only 33.6% missed some partial days, and 29.5% missed both full days and partial days.

The results are consistent across both surveys, both in terms of days missed and the average duration of time missed (see table 9). The only major differences are that more commuters missed no days than businesses (33% compared with 17%) and that the average of full-day equivalents missed was higher for firms (14 days compared with 11.2 days). The probable explanation of these anomalies is that employees in many firms were required to come to work for cleanup duties before the site was open for business.

Table 9 Comparison of Business Firm and Commuter Surveys

	Businesses (%)	Commuters (%)
Missed no days	17.4	32.7
Missed full days only	43.4	45.0
Missed partial days only	6.9	2.7
Missed full and partial days	30.2	19.9
	Number	Number
Average number of full days missed	9.4	9.8
Full-day equivalent of partial days missed	4.6	1.4
Total days missed	14.0	11.2

Of the respondents who reported missing work, 59% missed work because of damage to the work site, 46% missed work because of damage to the home, 15% missed work because of damage to the commute route, and 35% missed work because of other reasons (the totals add up to more than 100% because multiple reasons were accepted). On average, those missing work and citing damage to the work site missed an equivalent of 9.0 full days, those missing work and citing damage to the home missed an equivalent of 10.1 full days, those missing work and citing damage to the commute route missed an equivalent of 3.6 full days, and those missing work because of other reasons missed an equivalent of 4.8 full days. Once again, commuting problems were not the major source of absenteeism.

More than 43% of all commuters reported a worse commute to work. After the earthquake, it took on average 26 minutes longer (weekly total) to get to work the first week, but this gradually declined to 16 minutes longer by the second month. On average, the journey to work returned to normal 79 days after the earthquake. A similar proportion (41%) reported a deterioration in the commute home: 30 minutes longer (weekly total) to return home from work the first week after the earthquake, once again declining to 20 minutes by the second month. The commute home returned to normal on average 91 days after the earthquake.

Commuters were also asked whether or not their work normally required travel to different locations during the day. Out of 247 respondents, 38.7% reported traveling to an average of 3.6 different locations per day for work during a normal week. Of those who traveled to different locations, 34.4% reported traveling to an average of 2.1 fewer locations for an average period of 63 days after the earthquake.

When asked whether or not their commuting behavior had changed (mode, route, time of day) about the journey to or from work, 44% of the respondents reported changing the trip to work and 38% of the respondents reported changing the commute home. The major type of change was a route change (77% to 79%), followed by the time of the trip (63% to 66%), with only 14% to 15% changing mode. Such changes were much more common among commuters who had to miss work in the days immediately after the earthquake. The major response (changes in route and departure times) to earthquake-induced commuting problems, coupled with the relatively small impact these problems had on work, is consistent with the findings of other earthquake-related transportation research (Willson 1998).

We used the survey results to construct an estimate of the travel time losses of all workers living in the impact zone. Applying the average travel time loss of commuting employees in the survey to total employment by residence in the impact zone (654,337), including adjustments for those who missed work and hence did not commute on full days lost, generates 6.57 million hours of additional travel time. Using an approximate estimate of $5.00 per hour for the average value of travel time[3] generates estimated total travel time losses of $32.85 million. This is an underestimate because it excludes the travel time losses of workers living outside the impact zone and the time losses associated with nonwork travel. Nevertheless, even an adjusted estimate would still be small in the context of aggregate transport-related business interruption losses, or even relative to the business interruption component resulting from disrupted commuting. Moreover, even for the workers affected, in many cases these imputed commuting time losses were small in comparison with lost wages because of missed work.

The Northridge earthquake also impacted shopping and other nonwork trips (see table 10). Overall, 67% of all respondents changed characteristics of their shopping or other nonwork travel after the earthquake. Of those that changed, 49% said that they changed the frequency of their grocery shopping. More than 31% of respondents increased the frequency of their grocery shopping, but the average change in frequency was a decrease of 0.5 times per week, lasting an average of 48 days. More than one-fifth of respondents changing grocery shopping behavior reported that the travel time changed for an average of 62 days, increasing by 17 minutes (one-way). Additionally, three-quarters of respondents making changes reported that the frequency of nongrocery shopping had changed for an average of 99 days, with frequency decreasing on average by 0.4 trips per month. For 54% of respondents, travel time for nongrocery shopping also changed, increasing on average by 22 minutes (one-way) for an average period of 101 days. Nevertheless, expenditures on nongrocery shopping increased for more than two-fifths of the 61% reporting expenditure changes, with an average increase of $318 per month over 110 days. Thus, neither declines in shopping frequency nor increases in travel time necessarily implied a reduction in shopping expenditures. Moreover, changes in shopping behavior were induced much more by damages to retail buildings (e.g., the Northridge Fashion Center mall was closed for several months) than by changes in road and traffic conditions.

Finally, the changes in other nonwork trips affected fewer respondents, with only 28% of those changing nonwork travel changing their nonshopping trips and only 14% reporting longer travel times (24 minutes longer over a period of 103 days). However, the frequency of other nonwork travel was changed by one-half of the respondents changing their trip behavior.

COMPARISONS WITH KOBE

An interesting issue among earthquake analysts is whether comparisons are possible between the effects of the much more damaging Great Hanshin (Kobe), that occurred exactly one year later to the day than Northridge, and the Northridge earthquake. A recent paper on commuting patterns after Kobe (Sato and Spinks 1996) provides another opportunity for such a comparison. The main findings of this Kobe survey were:

[3] It would have been possible to measure this more accurately by examining the distribution of occupations and wages of all workers in the impact zone, but given the range of assumptions about the percentage of the wage at which travel time should be valued, such an exercise is probably not worth the effort.

Table 10 Changes in Nonwork Trips

	Changed something about shopping or other nonwork trip behavior 67.0%			
	Grocery shopping trips		Other shopping trips	
Changed shopping frequency	49.0%		75.0%	
Direction of frequency changed	Increased 31.3%	Decreased 68.7%	Increase 12.5%	Decrease 87.5%
Magnitude of change (trips)	1.8/week	–1.5/week	1.7/month	–0.7/month
Average change in frequency (trips)	–0.5/week		–0.4/month	
Period frequency changed	48 days		99 days	
Reporting increased travel time	20.9%		54.3%	
One-way travel time increase	17 minutes		22 minutes	
Period travel time changed	62 days		101 days	

1. whereas 77% of commutes were less than one hour before the earthquake, only 15.1% were less than one hour in the aftermath. However, by October 1995 the less-than-one-hour commute share was back up to 69.1%;
2. prior to the earthquake, the vast majority of commuting trips (more than four-fifths) were by public transit (train, bus, or subway); immediately after the earthquake, a significant proportion of workers either walked or cycled to work. By October 1995, the pre-earthquake modal split had returned;
3. the nonmechanized modes were able to take up such a high proportion of commuting, because commuting distances are much lower in Kobe than in larger metropolitan areas such as Tokyo and Los Angeles;
4. this adjustment would have been impossible in Tokyo because of the longer commuting lengths —walking, for example, would have required many commuters to walk eight or nine hours a day, obviously an impossibility;
5. 89.3% of workers had returned to work within one week of the earthquake.

The modal split in Los Angeles is very different from that of Kobe with a heavy reliance on the private automobile (87.8% of commuters) and minor use of public transit (4.5% of commuters). As in Tokyo, commuting distances are too long to permit much substitution of nonmechanized modes. The interesting point is that the average full-day equivalents of work missed were higher in Los Angeles than in Kobe, despite the much more severe damage in Kobe. A more disastrous earthquake in Los Angeles could have very severe disruptive impacts on commuting, and this possibility raises the importance of earthquake preparation and mitigation (e.g., faster seismic refitting of bridges). This is the same implication drawn for Tokyo by Sato and Spinks; their policy recommendation is the promotion of telecommuting and the expansion of telework centers, an interesting idea but not a surprising one in view of the survey's sponsors, the Japanese Ministry of Posts and the Telecommunications Research Institute.

CONCLUSIONS

A local impact of at least $1.5 billion associated with transportation disruptions is a significant proportion of overall business interruption (27.3%), even though the number appears modest relative to the total cost of the Northridge earthquake (perhaps $27 billion) or the more than $40 billion that stimulated the economy after the earthquake. Moreover, the special circumstances of the Northridge earthquake should not be forgotten: its more peripheral rather than central epicenter; the time of day on an important public holiday; its focus on residential neighborhoods with retail and service activities rather than on industrial or high-profile commercial locations; and the surprisingly limited degree of highway damage. Our estimates of an equivalent earthquake on the longer and more dangerously located Newport-Inglewood Fault (USC Planning Institute 1992) yielded a potential total cost impact of about $80 billion (with a much higher business interruption component of $33 billion); applying the same ratios resulting from the Northridge analysis generates a transport-related business interruption cost of $9.0 billion.

Another important finding is that damage to the commute route was not one of the major reasons explaining why workers missed work, compared with damage at the work site and/or the home.

Firms might be better prepared for future earthquakes by having adjustment procedures in place to accommodate potential disruption. For example, it is easier to implement flextime as a means of avoiding congestion because of disrupted commutes if the firm has prior experience with flextime. Also, a main focus of the Sato and Spinks (1996) research was to explore the potential for telecommuting as a means of avoiding earthquake risks in metropolitan Tokyo. While it is unreasonable in the Los Angeles region to extend telecommuting solely on the grounds of earthquake preparedness, in sectors where telecommuting is feasible and advantageous this becomes an additional and compelling rationale. Although damage to the home was a significant factor in the Northridge earthquake in explaining why workers missed work, the availability of telecommuting increases by at least a factor of two the possibility that work will not be interrupted.

Finally, our commuter survey supports the finding of Giuliano (1998) that flexibility is key, that is, adjustment of route, trip frequency, and time rather than changing mode, facilitated by system redundancy and the extreme dispersion of all economic activities (Gordon and Richardson 1996). These adjustments may be easier in Los Angeles than in other earthquake-prone cities in the rest of the world.

ACKNOWLEDGMENTS

The authors are grateful for the support of the U.S. Department of Transportation. National Science Foundation support for earlier work that made this research possible is also appreciated.

REFERENCES

Boarnet, M.G. 1998. Business Losses, Transportation Damage and the Northridge Earthquake. *Journal of Transportation and Statistics* 1:2.

Giuliano, G. 1998. Impacts of the Northridge Earthquake on Transit and Highway Use. *Journal of Transportation and Statistics* 1:2.

Gordon, P. and H.W. Richardson. 1996. Beyond Policentricity: Los Angeles, the Dispersed Metropolis, 1970–90. *Journal of the American Planning Association.*

Gordon, P., H.W. Richardson, and W. Davis. 1996. The Business Interruption Effects of the Northridge Earthquake, paper presented at the Western Regional Science Association, Napa, CA.

MacDonald, E. 1997. Tornadoes? Earthquakes? Bring in the Accountants. *The Wall Street Journal*. 28 March.

Sato, K. and W.A. Spinks. 1996. Commuter and Work Pattern Changes After the Great Hanshin Earthquake: Policy Implications for Greater Tokyo, paper presented at the Western Regional Science Association, Napa, CA, February 1996.

University of Southern California Planning Institute. 1992. The Business Interruption Effects of a Catastrophic Earthquake on the Newport-Inglewood Fault Zone.

Willson, R. 1998. Impacts and Responses: Goods Movement After the Northridge Earthquake. *Journal of Transportation and Statistics* 1:2.

Impacts and Responses: Goods Movement After the Northridge Earthquake

RICHARD WILLSON

California State Polytechnic University, Pomona

ABSTRACT

The 1994 Northridge earthquake disrupted goods movement on four major highway routes in Southern California. This paper examines the impacts of the earthquake on Los Angeles County trucking firms, and finds that the impact was initially widespread but relatively short-lived. Congestion delay and circuitous routing were the most common impacts. Rerouting and rescheduling strategies were ad hoc, rather than part of prearranged earthquake responses. The financial impacts of the earthquake were modest: mean first quarter revenues declined 0.2% while mean first quarter costs increased 3.5%. These impacts were smaller than expected because of quick restoration of highway access, made possible by redundancy in the road network and quick action by public agencies.

INTRODUCTION

The 1994 Northridge earthquake destroyed key highway infrastructure in Southern California. The magnitude of the damage and the dramatic initial disruption led many to expect significant, continu-

Richard Willson, Department of Urban and Regional Planning, California State Polytechnic University, Pomona, 3801 West Temple Avenue, Pomona, CA 91768-4048. Email: rwwillson@csupomona.edu.

ing operational and financial impacts on goods movement in the region (see map on page iv). This research uses a telephone survey of Los Angeles County trucking firms to explore responses to the disruption and to measure the financial impacts that trucking firms experienced over the first two quarters of 1994. It includes data from two California Department of Transportation (Caltrans) commissioned studies of responses to the earthquake: a telephone survey of dispatchers at Los Angeles County trucking companies (CIC Research Inc. 1994); and an intercept survey of trucking companies that asked about delay and rerouting activities (AMPG 1994).

MEASURING EARTHQUAKE DISRUPTIONS

There are numerous studies of earthquake disruptions (National Research Council 1992; Applied Technology Council 1991), but few of these look at disruptions to goods movement at the trucking-industry level. The only comparable study found in the literature is an examination of the goods movement impacts of the Loma Prieta earthquake in the San Francisco Bay area (Hansen and Sutter 1990). Such examinations are crucial, because efficient goods movement is essential to the nation's trade-oriented economy (Caltrans 1994).

Many factors determine how earthquakes affect goods movement. The extent of the impact depends on the magnitude of the earthquake, its location, geologic factors, the strength of highway facilities and buildings, and the responses of trucking companies and public agencies. Trucking firms must develop routing and scheduling strategies on almost an hourly basis, so their resourcefulness is important. That resourcefulness, however, depends in part on efficient public sector provision of information, workable detours, and ultimately, rebuilt facilities. Furthermore, business disruption among trucking firms' customers, which may have nothing to do with goods movement, influences the demand for goods movement after an earthquake.

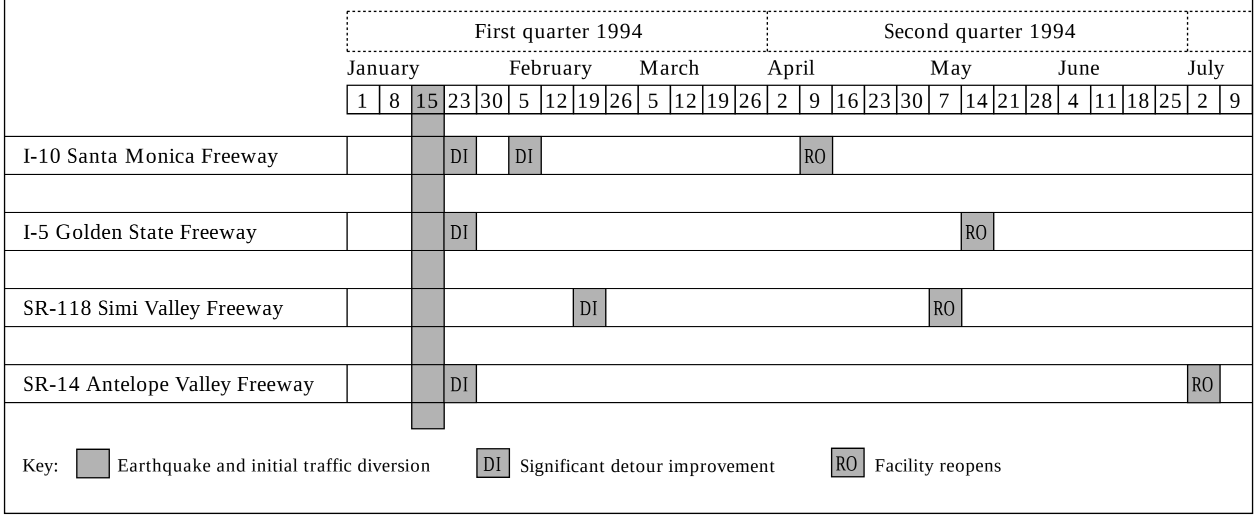
The type of transportation network affected is also a significant factor. A disruption to a hierarchical branching network is more disruptive than a similar impact on a network with many parallel routes and closed circuits. The Northridge earthquake illustrates the disruption of key trucking routes where suitable short-term parallel routes could be utilized. Moreover, the earthquake did not cause serious disruption to marine, air, rail, or pipeline goods movement.[1] The "bottom line" reported here, therefore, represents a complex amalgam of factors that is unlikely to be duplicated in the same combination in possible future earthquakes. This underscores the need for data on disaster impacts, so that a wide range of circumstances are represented.

Public officials moved quickly to restore transportation services after the earthquake. The initial responses were to plan and publicize detours. Then, better detours were made available on a gradual basis, and finally reconstructed facilities were opened at various times during 1994. As a result, the level of disruption changed rapidly. For example, the initial detour for the Golden State Freeway (I-5) was a circuitous route using the 101 Freeway, but during the first few weeks, closer-in detours were developed and used. Eleven days after the earthquake, the I-5 "Old Road" detour was created and trucking "appeared to return to almost exactly its pre-earthquake patterns"(AMPG 1994, 150). A similar pattern of responses occurred at each of the disrupted sections of freeway as detours and reconstruction occurred. Figure 1 provides a timeline of the restoration of transportation capacity in the key affected corridors.

The freeway system is an important component of the multimodal goods movement network that serves local business, intra- and interstate commerce, and international trade. The earthquake primarily had a disruptive effect on intraurban and intrastate truck-based goods movement involving agricultural products, household goods, and heavy specialized equipment (AMPG 1994, 18). Using the I-5 as an example, the most frequent origin/destination pairs for truck trips were central and east Los Angeles, Kern County, and other California

[1] Disruption to other modes was screened through telephone interviews and a review of government documents. The following disruptions were identified: Port of Los Angeles—one ship was redirected, but otherwise had normal operations; no disruption at Los Angeles International Airport; Southern Pacific Railway—the Northridge line was out of service for 48 hours because of a derailment; one crude oil pipeline (San Joaquin Valley Line 1) was out of service for over 3 months.

FIGURE 1 Time Sequence for Reopening Damaged Freeway Segments



counties to the north; less than 5% of the destinations and origins were outside California (AMPG 1994, 19).

METHODOLOGY

The research design is built around two objectives: measuring impacts and understanding the process of responding to the earthquake. The main research instrument is a survey of Los Angeles County trucking companies (hereafter referred to as the Cal Poly Pomona (CPP) survey), conducted during July/August 1994. Because so little comparative data are available on trucking industry responses to earthquakes, a goal of the research design was to increase opportunities for comparison with the small number of studies available.

Natural disasters pose special challenges to researchers. They require collaboration and ad hoc arrangements between organizations and agencies that do not usually work together. In this case, Caltrans almost immediately contracted with consultants to monitor and analyze the disruptions to the transportation system. This occurred before the academic research programs were initiated, and it presented opportunities to link the consultant and academic research efforts.

The first step in this project was reviewing the consultant surveys, particularly the CIC Research survey (hereafter referred to as the CIC survey), and surveys on this subject in other areas such as the Loma Prieta earthquake study by Hansen and Sutter (1990). These two projects are linked, since Caltrans requested that the CIC survey use similar questions as the Hansen and Sutter survey.

CIC and Hansen and Sutter surveyed dispatchers at trucking firms, asking about the following: exposure to damaged facilities, impacts on operations, responses to disruptions, and cost impacts. CIC Research purchased a list of Los Angeles County shippers and companies from a commercial provider. They drew a random sample from this list, stratified into two groups: trucking and manufacturing (80%); and wholesale, retail, and direct mail (20%). They contacted 847 firms and completed 300 telephone survey questionnaires. They received a low response on the surveys of the wholesale, retail, and direct mail group, often because the respondent had no trucks or did not use the freeway system. The surveys were conducted between May 23, 1994 and June 1, 1994.

The CIC survey provided good data on impacts and responses, by disrupted facility. However, the questions concerning financial impacts were ambiguous, and no information was collected on earthquake preparedness. Given this situation, the most productive approach for the CPP survey was to resurvey the firms responding to the CIC survey, asking the Chief Executive Officer (CEO) or Chief Financial Officer (CFO) about financial impacts and earthquake preparedness. The sample was narrowed to the trucking firms in the CIC survey (Standard Industrial Classification (SIC) 42) for which a good sample size (n=269) was available.

The key issues in survey design concerned the best way to measure impacts and to obtain sensitive financial information. Financial performance during a pre-earthquake period is not a reliable measure, because many factors affect a business's costs and revenues, such as seasonal fluctuations and changes in the regional economy. Instead, respondents were asked to compare actual financial performance with that which they expected if the earthquake had not occurred. The results, therefore, represent the best judgment of CEOs and CFOs.

Options for the survey instrument included case studies, telephone surveys (Gordon and Richardson 1995; Hansen and Sutter 1990), and mail-back surveys (Boarnet 1998; Lockheed Information Management Services Company 1993). Two approaches were used in this study: a telephone survey of CEOs or CFOs; and a followup financial worksheet that was faxed to the respondent at the end of the telephone interview (to be mailed or faxed back). The attempt to collect detailed financial information with the "fax-back" form was unsuccessful. Despite numerous call-backs, firms were unwilling to return the financial worksheet because of confidentiality concerns and the time and effort to provide the information. However, respondents did estimate percentage changes in costs and revenues, and indicated the major components of the cost and revenue change during the telephone interview.

The CPP telephone survey included 25 questions about cost and revenue impacts, response strategies, earthquake preparedness, and firm characteristics. These questions built off the CIC survey. The sample frame for the survey was the CIC survey respondents, because linkages were sought between the CIC data and the CPP data.

The CPP survey sought at least 115 responses to estimate cost and revenue impacts within 2% (using the standard deviation found by Hansen and Sutter and a 95% confidence interval). A 62% response rate (of the CIC respondents) was achieved—164 telephone surveys were completed—exceeding the target sample size. These responses represent 8% of the trucking firms in the Los Angeles/Long Beach primary metropolitan statistical area (PMSA).

The CPP survey focused on the three SICs that are direct trucking operations: SIC 4212 "local trucking w/o storage" (hereafter referred to as couriers); SIC 4213 "trucking, except local" (hereafter referred to as intra- and interstate trucking); and SIC 4214 "local trucking w/ storage" (hereafter referred to as movers). The 116 completed intra- and interstate trucking interviews represent 19% of such firms in the Los Angeles/Long Beach PSMA (U.S. Department of Commerce 1990). Twenty-seven responses from couriers represent 2% of the population, and the 21 responses from movers represent 7% of the population. Poor representation in these latter categories stems from low response on the CIC questionnaire. Responses from those last two categories should be interpreted as exploratory. The sample was not stratified, because of concerns that questions about sensitive financial information might reduce response rates. CPP surveyors contacted all 269 firms that responded to the CIC survey.

The CIC and CPP databases were merged so that relationships between variables in each survey could be explored. Chi square tests were used to examine differences between categorical variables, t tests were used for differences in means, and Kendall's tau rank correlations were used for ordinal data.

Finally, comparisons were made with the results of Hansen and Sutter's study of the Loma Prieta earthquake. That study was based on a random sample from a list of 327 members of the California Trucking Association (CTA). Of 67 initial telephone contacts, 37 surveys were completed. The small sample size, the potential bias stemming from the CTA-provided list, and the inability to distinguish between types of trucking firms means that comparisons drawn later in the paper should be viewed as exploratory. However, such exploratory comparisons are justified because of the paucity of data in this area.

IMPACTS ON TRUCKING OPERATIONS

Trucking companies in Los Angeles County faced varying degrees of exposure to the damaged facilities, depending on the frequency with which they normally used those facilities. The CIC survey asked about the frequency of use of the affected routes before the earthquake. Respondents answered “no use,” or one of four quartiles. Figure 2 shows that three-quarters of the respondents said that at least some of their routes used the I-10 or the I-5. Fewer than half the respondents said that at least some of their routes used State Route 14 (SR-14) or SR-118.

A composite measure of exposure to damaged facilities (EXPOSURE) was created using the midpoint values of four answer categories described above, and calculating the average response for the I-5, the I-10, SR-118, and SR-14. Calculating the mean EXPOSURE by type of trucking firm revealed no significant differences. Couriers, intra- and interstate trucking companies, and movers were exposed to disrupted facilities in about equal proportions.

The CIC survey asked an overall question about the types of impacts, offering respondents eight answer categories. Figure 3 summarizes the five most important impacts, showing the percentage responding that they experienced “moderate” and “severe” impacts. CIC surveyors did not define “moderate” and “severe” to respondents, so the most unambiguous interpretation is that grouping “moderate” and “severe” indicates a significant impact. Congestion delays and circuitous routing were reported by many respondents as they dealt with rerouting and detours around damaged facilities. Overloaded telephone lines hampered communication and planning, and dispatching was inefficient. Some trucking firms *gained* customers, as there was a need to transfer or deliver goods so that their customers could resume operations. Not shown are the less frequent responses: 15% of respondents lost customers, and only 7% of respondents had equipment damage.

FIGURE 2 Proportion of Runs Using Damaged Freeways

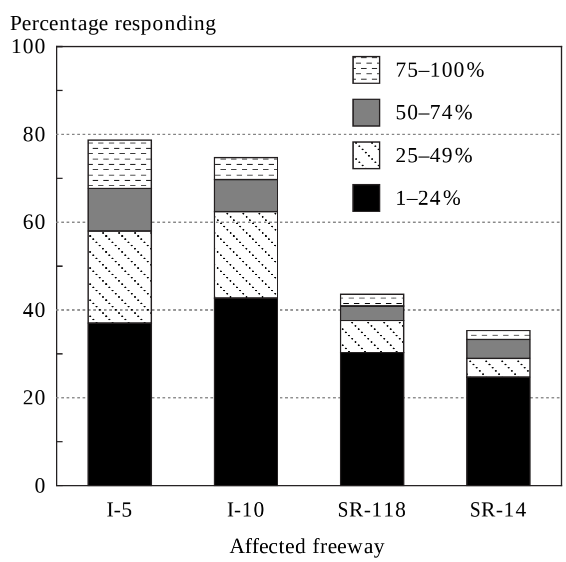
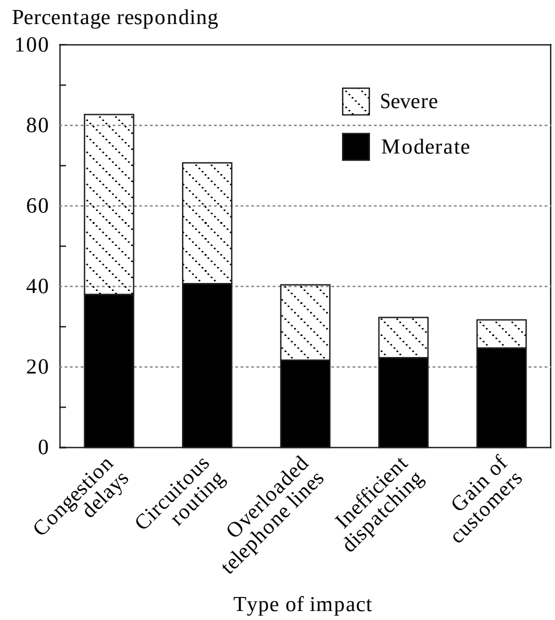


FIGURE 3 Impact on Trucking Operations



One would expect that greater exposure to damaged freeways would lead to greater reported impacts. A composite measure of impacts (IMPACT) was developed, assigning a weight of “1” to little or none, “2” to moderate, and “3” to severe in each category of impact, and then summing the values for each impact category. The combined measure of impacts excludes the “gain in customers” response. A Kendall’s tau rank order correlation between EXPOSURE and IMPACT confirmed this positive relationship ($r=.23$, $p<.05$). We calculated IMPACT by SIC to see if there were significant differences in impact, but found none (@ $p<.05$).

To test for a spatial relationship between location of the firm and impact, we segmented the data by geographic areas subject to the strongest ground shaking. Maps provided by the State Office of Emergency Services show areas subject to Modified Mercalli Index (MMI) VIII, IX, and X, which in total comprise 21 zip codes and 33 CIC survey respondents. We constructed a measure called SHAKE, which assigned a value of "3" to MMI X, "2" to MMI IX, "1" to MMI VIII, and "0" to all other areas. The +0.04 rank correlation between SHAKE and IMPACT suggests a positive relationship between ground shaking and impact, but is not statistically significant (@ $p<.05$). Proximity to ground shaking is not a significant explanatory factor, because of the weak connection between trucking firm location and the routes used by those firms.

The CPP survey asked about levels of absenteeism immediately after the earthquake. One-quarter of the respondents experienced increased absenteeism in the first week after the earthquake; the average absenteeism rate was 5.7%. The average absenteeism rate declined to 1.5% the second week; only 10% of the respondents experienced increased absenteeism. Despite these relatively low rates of absenteeism, trucking companies had the greatest need to develop contingency strategies during the highest absenteeism period.

The CIC survey asked about actions taken by trucking firms in response to the earthquake for each of the affected freeways. Figure 4 summarizes those impacts, averaging responses for all freeways. Combining the responses might seem to ignore important variation in actions among affected freeways, but a chi square test showed that there were no statistically significant differences between freeways. (See CIC Research Inc. 1994 for a detailed breakdown.)

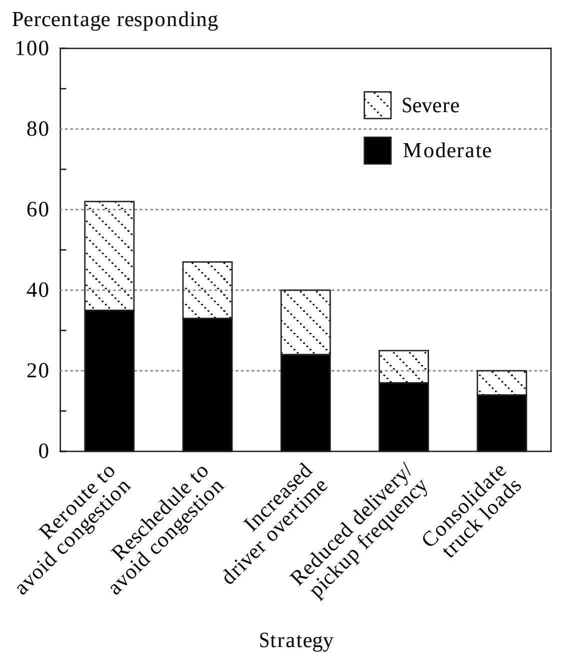
Most of the measures used were short-term responses, including rerouting, rescheduling (commonly starting earlier or delaying deliveries), increased overtime, reduced delivery/pickup, and consolidation of loads. There was little use of longer term strategies, such as using alternative rail or air modes. Respondents said that most of these actions (96%) were no longer being used by mid-May when the CPP survey took place.

CIC survey responses rated the acceptability of the primary detour for each of the damaged freeway segments they used. They overwhelmingly rated them as acceptable. Responses of "acceptable" ranged from 80% to 89% depending on the freeway, and the highest frequency of an "unacceptable" rating was 4%.

PLANNING, COMMUNICATIONS, AND COLLABORATION

Most trucking companies did not have an earthquake response plan in effect prior to the earthquake, nor did it stimulate them to prepare one. Of the 23% of CPP respondents that did have a plan, the dominant form was an emergency preparedness plan for employees, not an operational plan. Only a handful of respondents had a rerouting plan, a communications plan, an operations management plan, or arrangements with customers. Some respondents commented that the earthquake was one of a host of external factors that affected their business—other examples include the Los Angeles civil disturbance, a 1994 Teamster's strike, and economic restructuring. Earthquake prepared-

FIGURE 4 Response Strategies



ness, therefore, had not garnered substantial management interest in contingency and preparedness planning. On the other hand, these firms have operational experience under unforeseen circumstances, and therefore may be better equipped to cope with disruption.

The earthquake required firms to engage in a broad planning and management effort to respond to employee absenteeism, to coordinate deliveries with customers, and to plan rerouting and rescheduling. One-third of the respondents to the CPP survey changed their operations in response to the earthquake. There were significant differences in the frequency with which firms changed their operations—couriers did so most frequently (52%), followed by intra- and interstate truckers (36%), and movers (19%). Couriers may have changed their routes more often because of their complex set of locally based origins and destinations, and may have been more affected by highway disruption and short-term business closures.

As described previously, the primary activity was rerouting. Among those firms that rerouted, there was an even split between those who let drivers decide on new routes versus those who had dispatchers establish them. Few firms (less than 5%) reported having to reassign employees or create special teams or task forces. The couriers that reported greater operations changes were more likely to create special task forces, and more likely to let the driver select detour routes.

Trucking firms' greatest initial need was information that would enable them to develop rerouting and response plans. The most common information sources used were radio and television; newspapers ranked fourth. The most frequently used specialized information source was the California Highway Information Network, which ranked third. The use of nontrucking information sources was common, because the media was saturated with coverage of earthquake information, and apparently these sources were useful to trucking operations. Table 1 summarizes the most frequent sources of information. Respondents ranked the importance of these information sources, but assigning weights to the responses did not change their order. Weighting did reinforce the importance of commercial radio and television as the primary information sources.

TABLE 1 Responses to Survey Question: What information sources did you use to determine how to respond to the earthquake? (multiple responses permitted)

Frequency of responses	Unweighted (number of responses)
Highest	Commercial radio (85)
Second highest	Commercial television (36)
Third highest	California Highway Information Network (35)
Fourth highest	Newspapers (20)
Fifth highest	Other truckers (19)
Sixth highest	Contacts at California Highway Patrol (10)
Seventh highest	Customers (5)
Eighth highest	California Trucking Association telephone/fax(5)

Slightly more than one-third of respondents had communications problems after the earthquake. The median time of disruption was one day and the mean time was three days. Virtually all of the disruption was to telephone lines—a few respondents reported power and CB radio outages. The rapid resumption of telephone and fax capabilities may have made unnecessary the extensive use of other communications technologies. Other communications strategies used by Caltrans, such as changeable message signs, were not mentioned by respondents, but that may be because managers, not drivers, responded to the survey.

The earthquake motivated only 15% of the CPP survey respondents to prepare plans for future earthquakes. Because the survey was conducted in July and August 1994, there had been some time for these firms to develop these plans after they recovered from the earthquake. The most common type of plan created was an emergency preparedness plan for the firm (5%), followed by a communications plan (4%). Operations management plans and arrangements with customers were mentioned by a handful of respondents. A number of respondents thought about or intended to prepare plans, but had not done so. One respondent said: "I pray harder."

TABLE 2 Responses to Survey Questions: Were your cost/revenues different from what you would have expected if the earthquake did not occur? What was the percent change?

	First quarter		Second quarter	
	Revenue (n=148)	Cost (n=138)	Revenue (n=149)	Cost (n=157)
Mean	–0.20%	+3.53%	+0.80%	+0.75%
Standard deviation	14.2	11.8	5.2	8.8
Median	0%	0%	0%	0%
Range	–60% to +50%	–50% to +40%	–40% to +50%	–30% to +37%

IMPACTS ON REVENUE AND COSTS

The revenue and cost impacts of the earthquake reflect effects that are quite complex. Increased costs, such as wages or fuel, were expected, but firms also incurred increases or decreases in revenues, depending on their circumstances.

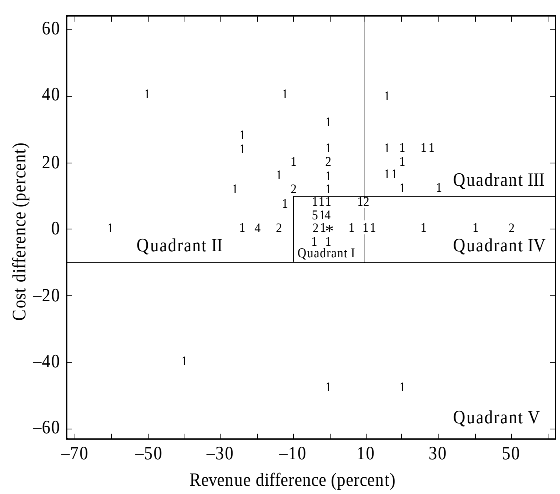
The CPP survey asked CEOs or CFOs of each company for estimates of cost and revenue impacts for the first and second quarters of 1994. The mean size of the firms in the survey was 32 employees, and their mean first quarter sales level was $837,534. Table 2 summarizes the impact of the earthquake on revenues and costs. Respondents were asked to estimate the change in total revenues and costs over what was expected if the earthquake had not occurred. This technique relied on the respondent's judgment to control for non-earthquake-related fluctuations in the economy and other disruptions such as the May 1994 Teamster's strike. Respondents provided a good response rate on these questions and did not report having difficulty in estimating earthquake impacts apart from other factors. The result shows a modest overall impact on trucking operations in Los Angeles County. The only change larger than 1%, either positive or negative, was an mean cost increase of 3.5% in the first quarter. The large standard deviation indicates the impacts experienced by individual firms varied widely. The median change in costs and revenues was 0% for both quarters.

The average and median data indicate overall impacts but mask larger impacts felt by a smaller group of firms. A 15% average decrease in first quarter revenues was experienced by 35 firms, while 23 firms had revenue *increases* averaging 22%. Revenue decreases are associated with lower levels of operations or less customer demand. On the other hand, the earthquake created an immediate need for additional trucking activities as firms relocated or changed production strategies, creating additional revenues for some respondents.

The average first quarter increase in costs for the 48 firms that reported an increase was 13%, a substantial impact for those firms. However, some cost increases resulted from a higher business volume. Five firms reported cost decreases averaging 30% (presumably because of scaled-back operations).

Figure 5 plots first quarter revenue and cost data to provide a better picture of the distribution and combinations of cost and revenue impacts. The data is grouped into five quadrants that represent different combinations of revenue and cost impacts. Quadrant I contains the majority of firms (93 of 135), with cost or revenue changes within plus or minus 10%. Quadrant II contains 24 firms that experienced more significant negative impacts—through increases in cost, decreases in revenue, or both. Quadrant III contains firms that had revenue increases and commensurate increases in costs. Quadrant IV includes five firms that had rev-

FIGURE 5 Plot of Revenue and Cost Impacts: First Quarter



Key: # indicates number of observations; * = 70 observations

TABLE 3 Kendall's Tau Rank Correlations of Revenue and Cost Impacts: First Quarter

	Revenue	Cost
Exposure	0.06	0.14**
Impact	–0.004	0.09*
Employees	–0.10*	0.11*
Sales	0.07	0.07
Shake	–0.05	0.10*

* Significant at 0.10 level
** Significant at 0.05 level

enue increases with no increase in costs, perhaps as the result of more efficiently using their capital and labor. Finally, Quadrant V contains a few firms that had large cost decreases. The plot reinforces the findings that most firms had small impacts and that the number of firms that were worse off was modest—24 firms in quadrant II.

We expected that the first quarter financial impact would be correlated to a variety of descriptors of exposure, impact, and firm characteristics. Table 3 shows Kendall's tau rank correlations for these variables with the percentage revenue change (REVENUE) and the percentage cost change (COST).

Only one significant relationship existed regarding revenues. Larger firms (as measured by number of employees) had a significantly greater decrease in revenues, perhaps because of differences in impacts on their customer base (@ $p<.1$). The correlation between EXPOSURE and REVENUE produced a positive sign but was not significant, reflecting the stimulating effect of the earthquake for some firms.

The impact on costs was more predictable. The relationships between COST and EXPOSURE, and COST and IMPACT, are positive and significant. Exposure to disrupted facilities is associated with cost increases, as is reported impacts on operations. Number of employees and proximity to ground shaking (SHAKE) are also positively and significantly related to COST.

Financial impacts were also expected to vary by type of trucking firm. Table 4 summarizes REVENUE and COST for each of the three types of trucking firms. Intra- and interstate truckers had the largest decline in revenue and the only cost increase that was not associated with greater revenue. The decline in revenue appears to have resulted from short-term disruption of shipping activities rather than a slowing of economic activity in the region. This sector has a greater probability of using the I-5 for north/south access out of the region and may have been more affected for that reason.

Couriers had virtually no change in revenues and a decrease in costs. Their greater reliance on local streets may have made them less affected by the earthquake, but clear reasons for the decrease were not identified. Movers, as one would expect, had a larger increase in revenues (because of greater moving activity) and lesser increases in costs. No movers reported revenue decreases. However, none of these differences are statistically significant ($p<.05$) because of the large variation in responses and the low representation of couriers and movers.

The CPP survey asked respondents to rate the most important factors in the changes in revenues and costs. Table 5 summarizes the top four factors in revenue and cost impacts. Business volume increases and decreases were the top responses on the revenue side, while labor and fuel costs were the dominant cost impacts.

When the first quarter revenue impact responses were weighted by the respondents' rank of importance there was no difference in rank order.[2] In the second quarter, increased business volume

[2] Unweighted tallies added together the responses for each category regardless of whether they were ranked first, second, third, or fourth in order of importance. Weighted tallies assigned a weight of 3 to the most important reason, 2 to the second most important reason, and 1 to the third most important reason.

TABLE 4 Mean Revenue and Cost Change by Trucking Firm Type: First Quarter

	Revenue		Cost	
	Mean	Standard deviation	Mean	Standard deviation
Overall sample	–0.2%	14.2	3.5%	11.8
Couriers (n=27)	0.3%	10.9	–3.4%	16.1
Intra- and interstate truckers (n=116)	–2.9%	12.9	4.7%	10.4
Movers (n=21)	12.5%	17.1	5.7%	11.5

TABLE 5 Responses to Survey Question: What were the main components of the change of costs/revenues in the first quarter?

	Revenue	Cost
Most frequent	Decreased business volume (44 responses)	Labor costs (57 responses)
Second most frequent	Increased business volume (22 responses)	Fuel costs (50 responses)
Third most frequent	Storage of goods (8 responses)	Vehicle maintenance (7 responses)
Fourth most frequent	Packaging (1 response)	Repair equipment (6 responses)

was the most important reason for a change in revenues. Respondents did not identify many revenue impacts that we initially hypothesized might have occurred: surcharges for additional mileage, changes in prices, penalties for late deliveries, or earthquake-related insurance or Federal Emergency Management Administration payouts.

The order of the first quarter *cost* responses did not change when they were weighted, and were in the same order for the second quarter of 1994. The primary impacts are related to costs of sales (e.g., delivering goods) rather than costs of operations (e.g., running the company). Increased costs for rent, insurance, vehicle rental, and telephone and/or communications did not appear in the responses. In addition, facility or equipment damage was not a major impact.

An additional check on possible impacts on goods movement can be made by examining the consumer price index (CPI) for the region, both overall and in the various sectors affected most strongly by goods movement (U.S. Department of Labor 1994). If large cost increases occurred or shortages existed, one might see a higher rate of inflation in these costs. A multitude of factors affect CPI trends, so one cannot discern the effect of the earthquake from other economic variables without detailed econometric modeling, but the results show what did not happen: there was no post-earthquake spike in either the overall CPI for Los Angeles or the transportation or food indexes. This reinforces the survey findings that cost impacts and the impacts of late or delayed deliveries were relatively modest.

COMPARISONS WITH THE LOMA PRIETA EARTHQUAKE

Hansen and Sutter (1990) studied the impact of the Loma Prieta earthquake on Bay Area truckers. Their survey was the basis for the design of the CIC survey, so comparisons can be made between the two earthquakes. As mentioned previously, the comparisons must be considered exploratory because the Loma Prieta results are based on a small sample (37 survey responses).[3]

Both surveys asked identical questions about impacts. The frequency of "moderate to severe" responses were similar for congestion delay, circuitous routing, overloaded telephone lines, and inefficient dispatching (all within eight percentage points). The major difference was that Los Angeles trucking companies cited increased business more frequently—33% versus 8%. The type of disruption created by the Northridge earthquake seems to have created greater needs to move and ship goods as firms resumed their operations.

The Loma Prieta and CIC surveys also asked about response strategies. The Loma Prieta survey simply asked whether a strategy was used, while the CIC survey asked for a rating on how severe the action was. We combined CIC responses of "small," "moderate," and "severe" to compare with the Loma Prieta results. The results should be interpreted with caution because of potential differences in meaning of these categories. Table 6 shows that the most frequent responses were similar.

The Northridge earthquake respondents more frequently used response strategies in part because the geographic area of the CIC sample was smaller, so respondents were more likely to be close to

[3] Drawing the sample from CTA membership probably underrepresents small firms. It is also important to note that the Loma Prieta survey covers the region, while the CIC and CPP surveys are based on Los Angeles County only.

TABLE 6 Comparison of Affirmative Responses to CIC Research Survey and Hansen et al Questions: Please tell me if you took the action [I will read] after the earthquake.

Northridge earthquake (CIC)			Loma Prieta earthquake (Hanson et al)		
Response	Initial	Still in effect	Response	Initial	Still in effect
Rerouted to avoid congestion	81%	5%	Rerouted to avoid congestion	57%	37%
Rescheduled to avoid congestion	69%	4%	Rescheduled to avoid congestion	46%	22%
Increased use of driver overtime	55%	5%	Increased use of driver overtime	38%	19%
Reduced frequency of delivery and pickup	38%	1%	Stopped service to certain areas	38%	0%
Increased truck load through consolidation	29%	4%	Reduced frequency of delivery and pickup	24%	11%

the earthquake. The striking difference, however, is that very few Northridge earthquake respondents were still using response strategies four months after the earthquake, unlike Loma Prieta earthquake respondents. Normal (or near normal) traffic operations were restored much faster following the Northridge earthquake.

The Loma Prieta and CPP surveys asked cost impact questions a bit differently, so precise comparisons cannot be made. The Loma Prieta study found that the mean cost impact one month after the quake was an increase of 7.1%. The CPP survey found a 3.5% cost increase for the first quarter of 1995, which included 2½ months of post-earthquake conditions. It appears that the short-term cost impacts were roughly on the same order of magnitude. However, the longer lasting effects of the Loma Prieta earthquake (unmeasured in that survey) could mean that overall cost impacts were greater.

There are important differences in the revenue side. Loma Prieta truckers reported a revenue decrease of 5.3%, while the CPP survey found a revenue decrease of 0.2% for the first quarter. This larger revenue loss suggests that more extensive business closures occurred, or that inaccessibility prevented deliveries. In the Northridge case, increases in business by some sectors counteracted the loss experienced by others.

Despite these differences, it appears that the impacts on revenues and costs were modest in both cases. Perhaps this similarity exists because both earthquakes primarily affected highway and arterial movement. In both cases, rerouting and rescheduling strategies were used to avoid damaged facilities, and costs and revenue impacts were relatively contained.

CONCLUSIONS

The Northridge earthquake tested the capacity and flexibility of Southern California's highway-based goods movement system, as well as the ability of public agencies and trucking firms to respond to rapidly changing conditions. By most measures, the systems and the institutions passed the test. The rapid restoration of transportation capacity was a key factor, making longer term strategies such as mode shifting unnecessary, and it moderated the financial impacts. There was considerable variability in the level of impact among individual firms, and those firms demonstrated ingenuity in devising response strategies under stressful, rapidly changing conditions.

What then does this analysis indicate about possible disruptions from future earthquakes? We suggest caution in drawing broad conclusions based on these results. The most obvious consideration is that the Northridge earthquake was not of a magnitude as great as is possible in Southern California. Even if a future earthquake was of a similar magnitude, however, it could bring different results.

An earthquake that affected key nonhighway goods movement facilities, such as a port or airport, major pipelines, or key rail lines might have a much larger impact. The Northridge earthquake affected the goods movement mode with *the greatest level of flexibility and redundancy*. As well, an earthquake epicenter closer to the region's core goods movement facilities would likely be more disruptive. For example, the Newport-Inglewood fault, which traverses central Los Angeles, is a major threat to the region's highway, airport, port, rail, and pipeline facilities.

The earthquake provoked little planning and preparedness activities among trucking companies. The tone of the interviews suggested that the earthquake was one of many disruptions that trucking firms experienced over the previous five years. It was seen as one of a series of operational challenges, rather than an event that permanently shifted perceptions. Trucking companies have continual experience in dealing with natural and manmade disruptions in Los Angeles. However, the ability of public and private actors to coordinate mode-switching strategies for goods movement was largely untested. Significant constraints may exist in that area.

Natural disasters place special requirements on researchers and public agencies. Restoring mobility is of chief importance, but survey research must be immediate as well. The surveyors in this study benefited from respondents' good will, partly due to a feeling of community cooperation after the earthquake and partly due to satisfaction with Caltrans' quick restoration of mobility. However, the experience of the earthquake is short-lived; immediate data collection is needed to capture these effects. Pre-arranged research protocols might include strategies for collecting data, standards for comparing results from different disasters, and coordination between public agencies and research institutions.

ACKNOWLEDGMENTS

This report would not have been possible without the assistance of trucking companies, trade association representatives, and government officials who generously shared their time and knowledge. Also, the cooperation of CIC Research Inc. and Caltrans in sharing data is most appreciated. Thanks also to Cal Poly Pomona urban planning students Steve Ross, Dan Kezar, and Danny Wu who provided invaluable assistance. Dr. Charles Hotchkiss and Stan Parkhurst provided valuable comments on the methodology.

REFERENCES

Applied Management and Planning Group (AMPG). 1994. *Report on the Trucking Intercept Survey*. Los Angeles, CA: California Department of Transportation.

Applied Technology Council. 1991. *Seismic Vulnerability and Impact Disruption of Lifelines in the Coterminous United States*. Redwood City, CA.

Boarnet, M. 1998. Business Losses, Transportation Damage, and the Northridge Earthquake. *Journal of Transpotation and Statistics* 1:2.

Caltrans. 1994. *Goods Movement in Southern California*. Los Angeles, CA.

CIC Research, Inc. 1994. *Report on the Survey of Shippers/ Companies in the Los Angeles Basin*. Los Angeles, CA: California Department of Transportation.

Gordon, P. and H. Richardson. 1995. *The Business Interruption Effects of the Northridge Earthquake*. Los Angeles, CA: Lusk Center Research Institute.

Hansen, M. and J. Sutter. 1990. The Shake with Freight: Effects of Bay Area Earthquake on Urban Goods Movement. The University of California Transportation Center, Berkeley, CA.

Lockheed Information Management Services Company. 1993. Truck Operations Survey Results. Los Angeles, CA: South Coast Air Quality Management District.

National Research Council. 1992. *The Economic Consequences of a Catastrophic Earthquake*. Washington, DC: National Academy Press.

U.S. Department of Commerce, Bureau of the Census. 1990. *1987 Census of Transportation*. Washington, DC.

U.S. Department of Labor, Bureau of Labor Statistics. 1994. *CPI Detailed Report*. Washington, DC.

Business Losses, Transportation Damage, and the Northridge Earthquake

MARLON G. BOARNET
Department of Urban and Regional Planning
University of California at Irvine

ABSTRACT

The 1994 Northridge earthquake damaged four major freeways in the Los Angeles area. Southern California firms were surveyed to assess the role that these transportation disruptions played in business losses. Of the firms that reported any earthquake loss, 43% stated that some portion of their business 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. Overall, the survey results suggest that transportation damage played an important role in business losses following the earthquake.

INTRODUCTION

For years, earthquake research and recovery efforts have focused almost exclusively on the immediate property losses and injuries caused by the disaster. Scholars have only recently begun to estimate the economic losses due to business interruptions that follow a major earthquake. Those early estimates

---

Professor Marlon Boarnet, Department of Urban and Regional Planning, University of California, Irvine, CA 92697. Email: mgboarne@uci.edu.

suggest that total economic losses add approximately 30% to damage estimates that are based only on the value of property damage (Gordon and Richardson 1995). This in turn suggests that economic disruptions are an important and yet poorly understood result of major earthquakes.

This paper summarizes a study of the link between business losses and the transportation damage that resulted from the Northridge earthquake. The results are from a survey of firms in the Los Angeles region. The survey asked firms to assess both their business losses due to the earthquake and how those losses were linked to the transportation disruptions. The results demonstrate that while transportation damage was not the only source of business losses, it was arguably as important as many other factors, including structural damage, property losses, and utility cut-offs. The implication is that the metropolitan transportation system plays an important role in business losses, and thus in economic recovery, following a major earthquake.

BACKGROUND

Prior Research

Research into economic losses caused by earthquakes can be grouped into three categories. Most studies of earthquake losses estimate direct property damage and do not consider broader economic losses (e.g., Dowrick and Rhoades 1992; EQE International 1994; National Research Council 1992, 77–82). More recently, "lifeline studies" have examined the link between regional economic performance and the major infrastructure systems that are vulnerable to damage during and following an earthquake (Applied Technology Council 1991; Chang and Taylor 1995). A third, and related, strand of research has estimated the value of the economic losses caused by various earthquakes (Gordon and Richardson 1995; Kroll et al 1991; Tierney 1995[1]).

Both the lifeline studies and the research on regional economic losses share this study's focus on business impacts. However, most previous studies aimed at estimating the total value of any regional economic disruption caused by an earthquake. While important, this emphasis on regional economic aggregates obscures the detailed link between business losses and particular sources of damage, including transportation damage, which is the focus of this paper.

Transportation Damage Caused by the Northridge Earthquake

The Northridge earthquake damaged or destroyed bridges, ramps, roadways, and interchanges on 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). See map and overview on pages iv–vi.

While all four freeway damage locations caused major disruptions to the ground transportation network, two are especially notable. Damage to the SR-14/I-5 interchange and damage further north on I-5 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 earthquake's highway damage 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 that 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). The substantial damage to this heavily traveled freeway was the focus of much policy discussion and media attention in the days immediately following the earthquake (Zamichow 1994).

Notably, the transportation damage from the Northridge earthquake was confined almost exclusively to the street and highway network. The major airports in the region and the ports of Los Angeles and Long Beach sustained no significant damage (Willson 1998). Similarly, both the freight

[1] The study by Tierney, which is based on a survey of firms affected by the Northridge earthquake, is most similar to this paper. While Tierney's work was aimed at assessing business impacts, this paper gives more detailed information on the link between business impacts and transportation damage.

and passenger rail systems in the region were almost untouched. For example, all Metrolink commuter rail lines in the region were in full service within three days after the earthquake[2] (Gardner Consulting Partners 1995). There was some damage to a crude oil pipeline, which required a shift to truck shipments, but that was minor in the context of the regional transportation system (Willson 1998). Overall, it is safe to assume that disruptions to goods movements and transit systems were primarily due to the damage to the street and road network, most importantly the highway damage described above.

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 for each damaged corridor (Barton-Aschman and Associates 1994). The travel delays were measured relative to pre-earthquake travel times, and thus represent the incremental increase in travel times due to earthquake damage.[3] Most of the delay data are for weekday peak periods (6:00 a.m. to 9:00 a.m. and 3:00 p.m. to 6:00 p.m.), although there is some limited information about off-peak delays for specific corridors.

The peak-period delays for SR-14 and I-5 often exceeded an hour in the weeks immediately following the earthquake. By March 1994, once detours for both the SR-14 and I-5 damage had been implemented, peak-period delays along those corridors dropped to approximately 15 minutes. Off-peak travel time data showed no delay for the SR-14 corridor in March 1994 (Barton-Aschman and Associates 1994).

For the I-10 corridor in West Los Angeles, peak-period delays often exceeded 20 minutes, but fluctuated greatly during the first month following the earthquake. By the beginning of March 1994, delays on the I-10 corridor stabilized at 10 to 15 minutes until the freeway repair was completed on April 11, 1994. The limited data for off-peak travel along the I-10 corridor suggest that the off-peak delay was similar to the peak-period delay (Barton-Aschman and Associates 1994).

Along SR-118, peak-period delays initially ranged from 10 to 35 minutes. After a detour was implemented on local streets (on February 21, 1994), peak-period delays dropped to approximately five minutes. The available data show no travel time delay during the off-peak period for the SR-118 corridor (Barton-Aschman and Associates 1994).

Overall, the disruption to the highway network was substantial but short-lived for the corridors discussed above. Many damaged freeways were repaired within months of the Northridge earthquake, and travel delays (relative to pre-earthquake travel times) were only a few minutes for most corridors by March 1994. Given the large but transitory impact on the Los Angeles area highway system, how were businesses affected by the transportation damage?

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).

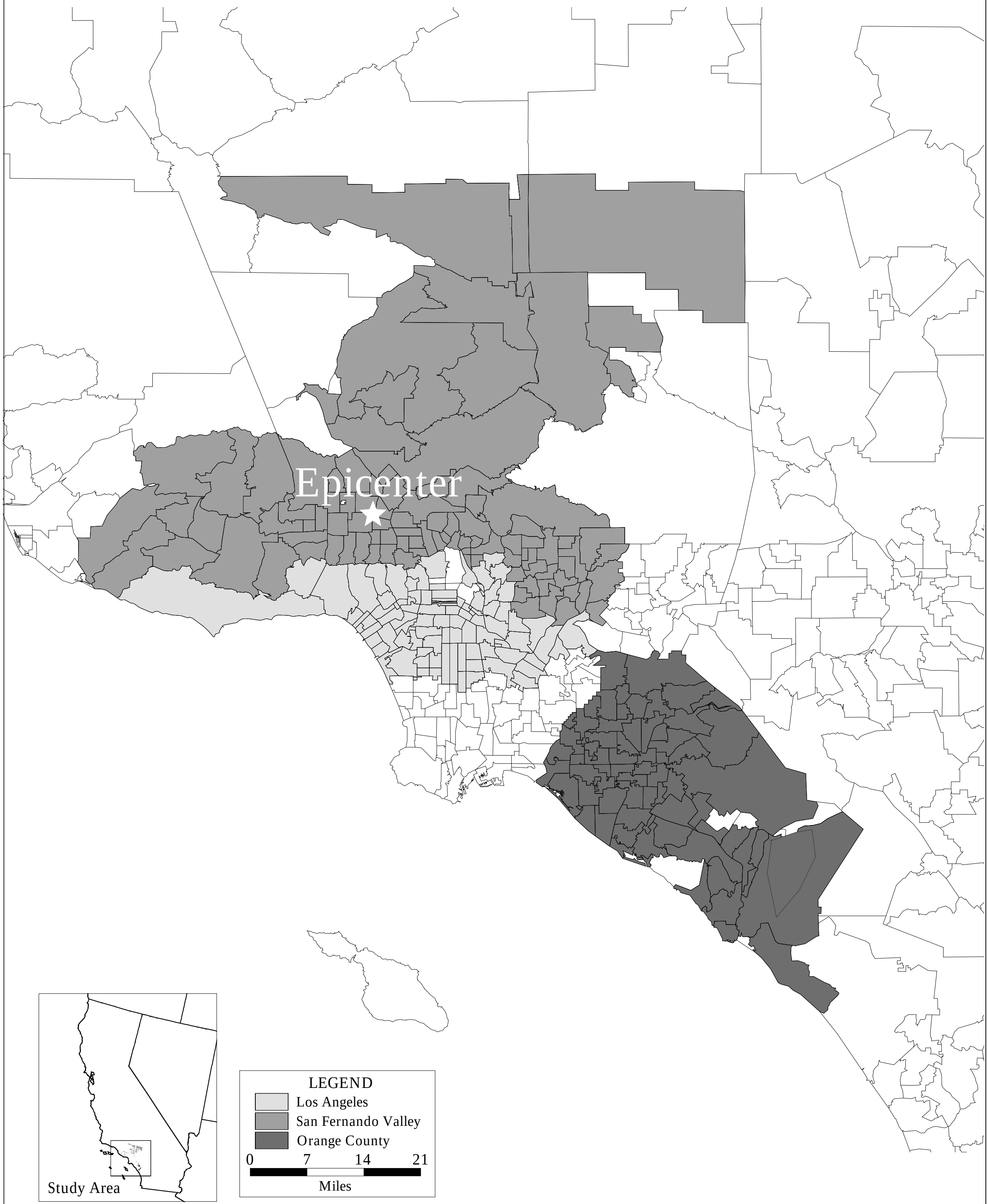
Geographic Areas

The 2,250 firms were drawn from three areas in the Los Angeles region, as shown on map 1. The area labeled "San Fernando Valley" includes the

[2] If anything, mass transit service was improved in the immediate aftermath of the earthquake. The Metrolink commuter rail line was extended to Palmdale and Lancaster to help alleviate the bottleneck caused by the damage on I-5 and SR-14 (Barton-Aschman and Associates 1994). Bus systems added emergency service and new shuttle services were established to connect Metrolink or Amtrak stations with major employment centers (Ardekani and Shah 1995).

[3] Specifically, travel time delays were measured relative to assumed pre-earthquake travel speeds in all corridors of 55 mph, with the exception of an assumed pre-earthquake speed of 45 mph in the I-10 corridor (Barton-Aschman and Associates 1994). If anything, actual pre-earthquake peak period travel times might have been slower than the assumed speeds, such that the travel delays, if they are inaccurate, overestimate the magnitude of the earthquake's impact on the transportation system.

MAP 1 Geographic Areas



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). "Los Angeles" 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.[4] Orange County, while in the same consolidated metropolitan area as Los Angeles, was more than 50 miles from the epicenter and was much less affected by the earthquake. Orange County was included to provide a sample of firms that were in the same regional economy, but relatively distant from the epicenter. Note that, for purposes of this paper, the Orange County firms were not used as a counter-factual to attempt to answer what would have happened without an earthquake. The survey asked firms to estimate the extent of earthquake impacts, and the study design relied on the ability of firms to make those inferences. Orange County was included in the sample to provide greater variation in earthquake effects and in particular to allow an examination of how earthquake losses and transportation impacts varied with distance from both the epicenter and the highway damage.

Industry Groups

Manufacturing, retail, and wholesale firms were surveyed in all three study areas. Several factors were important in choosing these industry groups. Because the focus of the study was on the link between transportation damage and business losses, we chose industry groups based on an *a priori* assessment of how intensively those sectors relied on the ground transportation network for their day-to-day business activities. The retail and manufacturing sectors obviously depend on the transportation system to move goods and provide access to customers. Similarly, manufacturing firms depend on transportation access to ship their output.

In order to get a sufficiently large within-industry sample with a limited budget, some business sectors had to be excluded from the survey. 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 movement and shipping impacts due to the earthquake. Other industry groups, such as construction, services, and financial, insurance, and real estate (FIRE), were excluded because a large number of firms in those sectors might have experienced large losses or gains due to the earthquake, which might be unrelated to transportation. There was some concern that it would be difficult to discern the link between transportation and business losses for firms that either experienced net gains (as some construction firms might have) or for firms that experienced large losses not due to the highway damage (as might have been the case for firms linked to the insurance industry).

Overall, the goal of the project was not to sample all business sectors in the Los Angeles region, but to study three sectors that are important in their own right. Those three sectors (manufacturing, retail, and wholesale) account for approximately 40% of the firms in the Los Angeles metropolitan area.

Survey Methodology

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-

[4] More specifically, the study area boundaries were drawn as follows. The combined "San Fernando Valley" and "Los Angeles City" areas are 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. The study includes eastern Ventura County, because it is economically and geographically part of the San Fernando Valley area. Within the sampled regions—Los Angeles, Orange, and Ventura Counties—the three areas shown on map 1 are defined by zip codes as follows: the San Fernando Valley area includes firms with zip codes from 91000 through 91999 plus zip codes larger than 93000; the Los Angeles city area includes firms with zip codes between 90000 and 90999; and the Orange County area includes firms with zip codes between 92000 and 92999.

respondents were mailed a followup on November 15, 1994, and our research team began to contact nonrespondents by telephone in early December 1994. Telephone followup was completed in January 1995.

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.

Selection Bias

Issues regarding selection bias typically can be addressed in three ways. First, it is common practice to consider the survey response rate, and to be more cautious when interpreting from surveys with low response rates. Second, one can examine whether the characteristics of survey respondents suggest some selection bias. Third, one can interpret the results in ways that allow for possible selection bias.

In terms of the first criterion, response rate, this research compares favorably with past surveys of firms. Tierney (1995) obtained a 23% response rate when surveying firms following the Northridge earthquake. More generally, several recent surveys of business populations have generated response rates similar to the 27% obtained in this study.[5] Having said that, surveys of firms bring special difficulties which, even in the best of circumstances, often result in lower response rates than for household surveys (Hansen et al 1983). For that reason, we carefully analyzed the most important source of bias for this research—whether response rates were influenced by the earthquake's effects.

Specifically, we examined whether the undeliverable and response rates within study area zip codes were related to the intensity of the ground shaking and the severity of the building damage caused by the earthquake.[6] Such a relationship might suggest that firms returned surveys based in part on their exposure to the earthquake's effects. Zip codes were grouped based on the four criteria listed below.[7]

1. *High Peak Ground Acceleration (PGA) Zip Codes:* All zip codes with average 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 criterion.

2. *High Modified Mercalli Intensity (MMI) Zip Codes:* All zip codes where ground shaking, measured by MMI, was greater than or equal to VIII. Thirty-six zip codes met that criterion.

3. *High Building Damage Zip Codes:* All zip codes where at least 25% of the building stock was inspected by local building authorities. Of the 263 zip codes, 16 met this criterion.

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 criterion.

Given the four criteria outlined above, two-sample t-tests were used to examine whether response and undeliverable rates were significantly different in zip codes 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

[5] Kalafatis and Tsogas (1994) surveyed furniture manufacturers, and obtained response rates that 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%.

[6] Recall that 216 surveys could not be delivered to the address in the Dun and Bradstreet database. It is conceivable that the undeliverable rate was influenced by the earthquake, e.g., if firms near the epicenter ceased operations due to earthquake damage. For that reason, the relationship between undeliverable rates and the intensity of ground shaking and building damage was examined.

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

building damage.[8] (For the test results, see Boarnet 1995, Section 3, 31–41.) Overall, there is no evidence that firms either received or chose to return a survey based on their exposure to the earthquake's effects. This suggests that the most important source of bias, the earthquake itself, was likely not a major factor in determining which firms returned surveys.

The last point to consider is how the representativeness of the sample might influence the interpretation of the results. While exposure to severe earthquake effects does not appear to be an important source of bias, other characteristics did influence the response rates. Comparing businesses that returned surveys with the underlying population of 2,250 firms showed that retail firms were significantly underrepresented among respondents, manufacturing firms were significantly overrepresented, and firms in Ventura County were significantly overrepresented (Boarnet 1995).

The differences in response rates across industry groups suggest that inferences within an industry might be more reliable than inferences drawn from the entire sample. Yet the pattern of results (reported in the next section) is generally the same across the three industry groups, such that the differential response of the retail and manufacturing firms is not likely to crucially affect the inferences and conclusions reported in this paper. The response rate in Ventura County is an even smaller concern, since the overwhelming majority of firms in the population were from Los Angeles and Orange Counties.[9] The response rates in those two counties are representative of the proportion of firms in the underlying population.

[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 were 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.

RESULTS

Business Impacts

Table 1 gives information on the firms that stated that the earthquake caused them to lose money. (These are firms who responded "yes" to the question, "Did the Northridge earthquake cause your business to lose money?") Of the 559 firms that responded, 194 (35%) stated that the earthquake caused them to lose money. As table 1 shows, 25% of manufacturing firms reported earthquake business losses, 48% of retail firms said the earthquake caused losses, and 37% of wholesale firms reported business losses. The difference between the proportion of retail and manufacturing firms reporting losses is statistically significant at the 5% level. (The t-statistic is 4.28 with 59 degrees of freedom.) Similarly, the gap between the proportion of wholesale and the proportion of manufacturing firms that reported earthquake losses is also significant at the 5% level. (The t-statistic is 2.60 with 59 degrees of freedom.)

Of the 194 firms that reported earthquake losses, 170 estimated the total value of their losses.[10] The average self-reported loss was $85,026. The

[9] Of the 2,250 firms surveyed, 79 were in Ventura County.

[10] The survey asked firms to estimate "total business losses from the earthquake." Thus, the estimates likely represent total business losses at the time that the survey was administered (in fall 1994).

Table 1 Earthquake Business Losses, by Firm Type

Firm type	Number reporting earthquake-related business loss	Number completing survey	Percentage reporting earthquake-related business loss	Earthquake loss as percentage of 1993 sales[1]
Total	194	559	34.70	6.61
Manufacturing	59	232	25.43	4.45
Retail	61	127	48.03	7.26
Wholesale	74	200	37.00	8.06

[1] Reported only for the 194 firms that stated they had a business loss due to the earthquake. Data exclude three firms that reported earthquake losses that exceeded 1993 sales.

standard deviation of the loss was $225,602. The large standard deviation is due to a small number of outliers who reported very large losses.[11]

The last column of table 1 shows self-reported earthquake losses as a percentage of 1993 sales for those firms with 1993 sales data.[12] Manufacturing firms reported self-assessed losses averaging 4.45% of 1993 sales, retail firms reported losses averaging 7.26% of 1993 sales, and wholesale firms reported losses averaging 8.06% of 1993 sales. These inter-industry differences in losses as a percentage of sales are not statistically significant at the 5% level. (The two-sample test statistic for comparing losses as a percentage of sales for manufacturing and retail firms is 1.32. The two-sample test statistic for manufacturing and wholesale firms is 1.44. Both tests have 58 degrees of freedom.)

Manufacturing firms appear to be less affected than retail firms, at least in terms of the probability of reporting an earthquake loss.[13] It is not entirely clear why this is so. The manufacturing firms in the study are larger (on average) than the retail and wholesale firms, but probit regressions that predict the incidence of loss based on firm size (employees and sales) and firm type (retail and wholesale dummy variables) give insignificant coefficients for the size variables (Boarnet 1995, 43).

It is possible that the variations in the probability of an earthquake loss across firm types reflect a difference in earthquake vulnerability across firm types. Alternatively, it could be that the Northridge earthquake was centered in an area (the San Fernando Valley) that had a disproportionate number of retail and wholesale firms. Of the respondent firms with address information that could be matched to a geographic information system, 28% of the manufacturing firms were within a 20-mile radius of the epicenter, while 38% of retail respondents were within 20 miles of the epicenter, and 29% of wholesale respondents were within 20 miles of the epicenter. Thus, it might be that manufacturing firms reported a lower incidence of earthquake losses because those firms were further from the epicenter.

Business Losses and Transportation Damage

Firms that reported an earthquake-related business loss were asked whether they attributed any of that loss to the transportation damage resulting from the earthquake.[14] The responses are summarized in table 2.

Of the 194 firms that reported an earthquake business loss, 83 attributed some portion of that loss to transportation. Conditional on having an earthquake loss, the proportion of retail firms linking some portion of the loss to transportation (50.82%) is larger than the proportion of manufacturing firms attributing some loss to transportation damage (28.81%) at the 5% level. (The t-statistic for the difference between the sample proportions is 2.53 with 59 degrees of freedom.) Similarly, the proportion of wholesale firms that attributed some loss to transportation damage (47.39%) is larger than the proportion of manufacturing firms (28.81%), and the difference is again significant at the 5% level. (The t-statistic is 2.25 with 59 degrees of freedom.)

When focusing on transportation-related business losses, manufacturing firms appear to be less affected than retail or wholesale firms. This is similar to the pattern for overall business losses reported in table 1. Again, it is not clear whether manufacturing firms were less affected by the highway damage due to the nature of those firms, or

[11] Of the 559 firms that completed the survey, 58 (10%) stated that the earthquake caused business gains. The average self-reported gain, excluding two extreme outliers, was $52,234 with a standard deviation of $119,051.

[12] The Dun and Bradstreet database included information on 1993 sales revenue for most, but not all, firms.

[13] Because of the differential response rates across firm types discussed earlier, one might wonder whether this result is due to selection bias. While that is possible, note that the most obvious source of bias is not consistent with the results that were discussed above. Manufacturing firms were more likely to return surveys. If firms that were more affected by the earthquake (and thus more sensitized to the importance of the study) were more likely to return surveys, manufacturing firms would presumably have experienced more earthquake losses, rather than the lower incidence of loss reflected in the responses summarized in table 1.

[14] To not influence the results, firms were not informed of specific damage locations. The question asked whether firms could attribute any business losses to transportation damage from the earthquake. The survey specified that transportation damage included "road and highway damage, detours, closures, increased traffic due to road closures elsewhere, etc."

Table 2 Firms that Stated that Some Earthquake Loss was Due to Transportation, by Firm Type

Firm type	Number stating some loss due to transportation damage	Number reporting an earthquake-related loss	Percentage stating some loss due to transportation damage[1]	Average estimated percentage of total earthquake loss due to transportation damage
Total	83	194	42.78	38.96
Manufacturing	17	59	28.81	30.63
Retail	31	61	50.82	36.20
Wholesale	35	74	47.39	45.63

[1] Conditional on reporting an earthquake-related business loss.

whether retail and wholesale firms were more affected simply because more of those firms were closer to the epicenter and the highway damage.

Firms that attributed some loss to transportation damage were asked to estimate how much of their loss was due to this damage. The survey relied on firm self-assessments of transportation impacts. The questions did not identify specific transportation impacts or suggest how the damage might have been related to business losses. Instead, firms were left to their own judgment in assessing the highway damage and its impact on their business. This strategy had important advantages. Most notably, because the questionnaire did not ask detailed cost and revenue data, the survey could be completed quickly and easily.[15] Pre-tests had suggested that this was crucial in increasing the response rate.

Among firms that believed that transportation played a role in their business loss, the average response was that 39% of the total loss was due to transportation damage. This varied by firm type, and table 2 shows that retail and wholesale firms attributed a higher portion of their loss to transportation than did manufacturing firms. Yet the differences across industries in the fraction of loss attributed to transportation are not statistically significant at the 5% level.

The results in table 2 suggest that transportation played a reasonably important role in business losses from the Northridge earthquake. At least in the self-assessed data reported here, the fact that 43% of all firms with a loss attributed some loss to transportation, and that the average estimate for a transportation loss was 39% of all losses, both suggest that transportation damage was an important factor in earthquake business losses. Another way to illustrate this point is to compare firms' assessment of the effect of the transportation damage with their assessment of other earthquake effects.

Table 3 reports firm assessments of the severity of 10 different possible effects of the Northridge earthquake. Firms were asked to rate each effect on a scale from 1 to 5, with "1" meaning the effect was "no problem" and "5" meaning the effect was a "very severe problem." Note that the top four effects (or impacts) listed in table 3 are related to transportation. The other six impacts are arguably not related to transportation. Average scores for all

[15] Cost and revenue questions were asked, but those questions were left to the end of the survey. Many firms chose not to answer those questions. The information on firms' assessments of damages is thus much more reliable.

Table 3 Severity of Earthquake-Related Effects

	Average score on 1–5 scale[1]	Percentage 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 and materials	1.32	3.96
Inventory loss or damage	1.56	9.31
Repair/cleanup (not included in building damage)	1.70	10.84
Seismic retrofit (not included in above)	1.21	2.34

[1] On a 1 to 5 scale, 1 indicates no problem and 5 indicates a very severe problem.

respondent firms are shown in table 3. Table 3 also shows the percentage of firms that gave each impact a severity rating of "4" or "5."

Table 3 illustrates two points. First, the earthquake impacts were moderate in the context of the entire region. Despite the publicity and large dollar value losses to property, the average severity ratings for all earthquake-related impacts were rated less than 2. Second, transportation appears to be as important as any other factor listed in table 3. The two earthquake effects with the highest average severity are "shipping delays to business location" and "shipping delays from business location." Overall, the severity ratings suggest an important role for transportation in the business losses that resulted from the earthquake. This is consistent with the information from the self-reported loss estimates reported earlier.

Table 4 gives severity ratings by geographic area, and table 5 gives severity ratings by firm type. The basic pattern is the same as that in table 3. Note that, in table 4, firms in the San Fernando Valley area gave all impacts higher ratings. This is expected given that the epicenter and many of the locations with the most damage were in the San Fernando Valley area. Also note that, in table 5, retail and wholesale firms generally gave higher severity rankings to the four transportation impacts than did manufacturing firms. This confirms the pattern from tables 1 and 2; retail and wholesale firms appear to be either more sensitive to the transportation disruptions or were more heavily affected by the highway damage caused by the Northridge earthquake.[16]

While the survey asked firms to assess what portion of their loss was due to transportation damage, the questionnaire did not ask firms to apportion transportation losses into a portion due to shipping versus other uses of the road system. Yet, tables 3 through 5 can give some insight into the role of shipping versus employee and customer access in transportation-related business losses. All categories of firms cited problems with employee and customer access, which, in terms of average severity, were almost as important as the shipping delays. The overall message is that transportation disruptions were not restricted to freight movement, but extended to other types of accessibility provided by the highway system.

[16] Severity rankings were also examined for only those firms that reported an earthquake loss, firms that reported a transportation-related business loss, firms in zip codes where PGA exceeded 0.5, firms in zip codes with MMI greater than or equal to VIII, firms in zip codes where at least 10% of the building stock was inspected, and firms in zip codes where at least 25% of the building stock was inspected. For all these groups, the severity ratings show the same general pattern in terms of the assessment of transportation impacts relative to the nontransportation impacts. Of course, severity rankings in the areas with intense ground shaking and large amounts of building damage were higher than for other areas. See Boarnet (1995) for details.

Table 4 Severity of Earthquake-Related Effects, by Geographic Area

	Average score			Percentage of firms with 4 or 5 score[1]		
Effect	Los Angeles City	Orange County	San Fernando Valley	Los Angeles City	Orange County	San Fernando Valley
Customer access to business location	1.56	1.20	1.72	7.69	2.72	14.61
Employee access to business location	1.68	1.24	1.84	7.77	3.38	14.27
Shipping delay to business location	1.91	1.68	2.19	10.53	4.76	19.10
Shipping delay from business location	1.71	1.28	2.10	7.73	3.45	18.08
Building damage	1.38	1.14	1.57	2.86	2.72	7.82
Utility cut-offs	1.69	1.16	2.11	11.00	3.40	17.13
Higher prices/costs for goods and materials	1.39	1.16	1.38	3.85	2.05	5.68
Inventory loss or damage	1.53	1.16	1.92	8.10	2.60	16.20
Repair/cleanup (not included in building damage)	1.67	1.18	2.18	8.10	2.74	20.67
Seismic retrofit (not included in above)	1.15	1.15	1.33	1.00	2.74	3.59

[1] On a 1 to 5 scale, 1 indicates no problem and 5 indicates a very severe problem.

Table 5 Severity of Earthquake-Related Effects, by Firm Type

Effect	Average score: Manufacturing	Retail	Wholesale	Percentage of firms with 4 or 5 score[1]: Manufacturing	Retail	Wholesale
Customer access to business location	1.35	1.73	1.58	5.91	12.71	9.23
Employee access to business location	1.48	1.67	1.69	5.88	9.48	11.92
Shipping delay to business location	1.82	2.09	1.99	9.87	13.56	12.95
Shipping delay from business location	1.66	1.57	1.88	9.55	7.76	11.92
Building damage	1.29	1.53	1.38	2.24	5.88	6.19
Utility cut-offs	1.62	1.79	1.70	8.48	15.25	11.28
Higher prices/costs for goods and materials	1.25	1.44	1.34	2.25	4.31	5.73
Inventory loss or damage	1.37	2.11	1.42	4.93	22.31	6.22
Repair/cleanup (not included in building damage)	1.58	2.29	1.49	6.28	27.12	6.19
Seismic retrofit (not included in above)	1.12	1.42	1.19	0.47	5.50	2.65

[1] On a 1 to 5 scale, 1 indicates no problem and 5 indicates a very severe problem.

Another way to get insight into this issue is to examine how firms both perceived and responded to changes in their employees' commutes. Table 6 summarizes firm responses to a question that asked whether ". . . some employees required longer commute times to get to work."[17] The responses are tabulated by geographic area in table 6.[18]

Close to 40% of the firms in both the San Fernando Valley and the Los Angeles City areas stated that their employees had longer commute times after the earthquake. When firms were asked to assess how quickly employee commutes returned to pre-earthquake conditions, the median response was one month for the entire sample. For firms in the San Fernando Valley area, the median assessment of how quickly employee commutes returned to normal was two months.

Table 7 shows the percentage of firms who used each of three possible policies to respond to their employees' commuting problems following the Northridge earthquake.[19] Neither ridesharing nor

Table 7 Policies To Mitigate Disruptions to Employee Commuting, by Geographic Area (In percent)

Geographic area	Arranged ridesharing, vanpools, and carpools	Encourage use of public transportation	Allow changed work hours
Total	7.33	10.91	19.14
Los Angeles City	9.13	15.98	18.72
Orange County	3.36	3.36	10.07
San Fernando Valley	8.38	10.99	26.70

Table 6 Firms that Stated that Their Employees had Longer Commutes, by Geographic Area

Geographic area	Number stating that employees had longer commutes	Number completing survey	Percentage with employees with longer commutes
Total	176	559	31.48
Los Angeles City	81	219	36.97
Orange County	19	149	12.75
San Fernando Valley	76	191	39.79

[17] Note that the focus here is on assessing how firms were affected by commuting disruptions. For that reason, it was appropriate to ask firms about their assessments of employee commutes.

[18] There were no statistically significant differences across industry groups in the proportion of firms stating that their employees had longer commutes.

[19] These are the firms that responded "yes" when asked: "During the time immediately following the earthquake, did your firm implement any of the following policies?" The three possible choices were "arrange ridesharing, vanpools, or carpools," "encourage employees to use public transportation," and "allow employees to change their work hours to avoid traffic." Firms were allowed to answer "yes" to any or all of the three policies.

public transportation were widely popular, and the incidence of both policies was lower than the percentage of firms that stated that their employees endured longer commutes. The most common policy was allowing employees to change their work hours. This was used by 19% of all respondent firms, and 27% of firms in the San Fernando Valley area.

Distance Decay and Transportation Losses

Common sense dictates that many earthquake impacts are most severe nearest the epicenter. While soil conditions, building quality and age, and other factors also influence earthquake damage, proximity to the epicenter is a key factor in earthquake impacts. Suarez-Villa and Walrod (1996) document that, for advanced electronics manufacturing firms in the Los Angeles area, those within five miles of the epicenter experienced the greatest disruption in terms of workdays lost due to the Northridge earthquake.

For the manufacturing, retail, and wholesale firms surveyed here, 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 significantly explained by distance from the epicenter and severe ground shaking. (For results, see Boarnet 1995.) Given that, how do transportation-related business losses correspond to distance from the epicenter and the location of major freeway damage?

Table 8 gives probit regressions for the probability of reporting that some business losses were due to transportation damage, conditional on reporting any earthquake loss. Before discussing the regression results, note that the distance decay pattern for transportation damage (or any earthquake-related effect) might be nonlinear. Distance might only be an important predictor of severity close to the epicenter. This is especially important given the inclusion of Orange County firms, all of which are reasonably distant (over 40 miles) from the epicenter and somewhat unaffected by the earthquake.

For that reason, the effect of distance was modeled using a threshold. The regressions in table 8 include a variable that measures distance (in miles) from the epicenter, and the distance variable interacted with a dummy variable that equals 1 if the firm is within 20 miles of the epicenter. This allows the distance decay pattern to differ within and outside of a 20-mile threshold. The 20-mile threshold was chosen based on a visual examination of the distance decay pattern for lost workdays for the survey respondents. Threshold distances of 5 and 10 miles were also tested, and the results were never qualitatively different from those shown in table 8. Similarly, other nonlinear representations for the distance decay were examined, including

Table 8 Probit Regressions for Stating that Some Loss was Due to Transportation[1]

Independent variable	All firms	Manufacturing firms	Retail firms	Wholesale firms
Retail dummy	0.541			
	(0.264)			
Wholesale dummy	0.513			
	(0.251)			
Distance from epicenter	6.7×10^{-4}	-7.6×10^{-3}	–0.009	0.010
	(7.1×10^{-3})	(0.014)	(0.015)	(0.010)
Distance* 20-mile dummy[2]	1.9×10^{-3}	–0.034	8.5×10^{-4}	0.017
	(1.7×10^{-2})	(0.038)	(0.031)	(0.026)
Constant	–0.615	–0.288	0.125	–0.408
	(0.274)	(0.418)	(0.479)	(0.368)
Number of observations	165	47	52	66
Log(L)	–109.34	–27.28	–35.76	–45.12

[1] Conditional on reporting an earthquake business loss. Standard errors are in parentheses.

[2] Distance from epicenter multiplied by a dummy variable that equals 1 if the firm is within 20 miles of the epicenter.

using distance and its square as independent variables, and again the results were qualitatively the same as in table 8.[20]

Note that no distance variable is statistically significant in table 8. This result holds whether all firms are pooled or for each firm type separately. The distance variables were also insignificant when the model in table 8 was estimated using both logit and ordinary least squares estimation. Robust standard errors were used for the least squares estimates to avoid heteroskedasticity problems, which are caused by estimating limited dependent variables models with least squares. The model in table 8 was also specified using straight-line distance from each of the four freeway damage locations, and again the distance variables were statistically insignificant.[21]

Unlike other earthquake-related effects, the incidence of transportation losses is not significantly related to distance from either the epicenter or the freeway damage. The dense transportation network in Los Angeles (and most other cities) provides travelers with different routes to get to the same location. Depending on a particular firm's needs, travel patterns, and location, the freeway damage may or may not have posed a serious problem. Factors such as how the transportation system is used and the availability of alternate routes might be poorly correlated with distance from both the epicenter and freeway damage. Overall, while it is sensible to expect most earthquake impacts to decay with distance, that same pattern does not appear for transportation losses. The complexity of the transportation system, and the interaction between any one firm's needs and the highway network, creates a pattern where the transportation-related losses are more geographically dispersed than for other earthquake effects.[22]

SUMMARY AND CONCLUSION

The evidence above suggests that the Northridge earthquake was a relatively moderate event, both in terms of the size of business losses relative to sales and in terms of the average severity ratings summarized in tables 3 through 5. Having said that, transportation damage appears to be roughly as important as any other source of loss, including structural damage and other lifeline disruptions. It is possible that retail and wholesale firms are more vulnerable to transportation losses compared with manufacturing firms, but this result could also be due to a higher proportion of retail (and to some extent wholesale) firms near the epicenter and the damaged highways.

Possibly the most important fact to come from this analysis is the lack of any relationship between distance from the transportation damage and business losses. While both common sense and experience suggest that earthquake impacts will be most severe near the epicenter, transportation-related business losses are an exception, at least in the case of the Northridge earthquake. Distance to a damaged freeway or the epicenter was not a good predictor of whether a firm experienced a transportation-related business loss. The incidence of loss depends not only on the spatial distribution of highway damage, but on how individual firms use the highway network. Firms that were distant from the highway damage but depended heavily on access through those corridors might have been more heavily affected than firms that were closer to the damage but relied less on those freeways. Future research might examine in more detail how dependence on the highway network varies across different types of firms, and how that creates variation in vulnerability to earthquake disruptions or other major transportation damage.

There are relatively few opportunities to observe transportation disruptions of the magnitude caused by the Northridge earthquake. The results

[20] The results are the same if Orange County firms are excluded from the analysis and if distance is represented linearly rather than with a threshold effect. Results are available upon request.

[21] Complete test results are available upon request.

[22] One might be tempted to test the distance decay relationship using travel time delays rather than distance from the epicenter or freeway damage. Yet, time delay captures only part of the complexity of the transportation system. A firm might be near a large bottleneck but relatively unaffected if they rarely use the congested transportation artery. Similarly, a firm that depends on shipping goods through a distant but congested damage location might be heavily affected by the freeway damage. Lacking more detailed information on how firms use the transportation system, it was not possible to incorporate the available travel delay data into a more sophisticated model of transportation-related business losses.

of this study demonstrate that manufacturing, retail, and wholesale businesses believed that transportation damage played an important role in their overall losses. This highlights the link between transportation systems and the functioning of the regional economy, and also emphasizes the role that transportation systems might play in economic recovery from major disasters. Future research might examine more closely how particular firms differ in their ability to adapt to major transportation disruptions, and how that information can be used to limit the economic consequences of large-scale transportation damage.

ACKNOWLEDGMENTS

This research was funded by the Bureau of Transportation Statistics of the U.S. Department of Transportation. David Greene and two anonymous referees provided helpful comments on an earlier draft. I have also benefited from the very able research assistance of Eugene Jae Kim throughout this project. Dan Barkley, Richard Crepeau, Gayla Smutny, Inha Yoon, Alistair Wallbaum, and Wallace Walrod also provided assistance with the survey of firms and related tasks. Ruey-Min Wang provided assistance with early versions of the map, and Mike Myers and Steve Lewis of the Bureau of Transportation Statistics produced the final map.

REFERENCES

Applied Technology Council. 1991. *Seismic Vulnerability and Impact of Disruption of Lifelines in the Coterminous United States.* Redwood City, CA.

Ardekani, S.A. and A.K. Shah. 1995. Post-Quake Transportation Operations Following the 1994 Northridge Earthquake, presented at the Transportation Research Board 74th Annual Meeting, Jan. 22, 1995, Washington, DC.

Bare, G. and N. Steinman. 1995. The Effects of the January 17, 1994, Northridge Earthquake on Travel Behavior in the Santa Monica Freeway (I-10) Corridor, presented at the Transportation Research Board 74th Annual Meeting, Jan. 22, 1995, Washington, DC. Caltrans District 7, Barton-Aschman and Associates, Inc.

Barton-Aschman and Associates, Inc. 1994. *Northridge Earthquake Recovery, Interim Report #1.* Los Angeles, CA: California Department of Transportation District 7.

Boarnet, M.G. 1995. Economic Impacts of the Northridge Earthquake's Transportation Damage: Results from a Survey of Firms, final report to the U.S. Department of Transportation, Federal Highway Administration.

Chang, S.E. and W.J. Taylor. 1995. *Urban Economic Impact of Transportation Disruption: Evidence from the January 17, 1995, Hyogo-Ken Nambu Earthquake*, presented at the 14th Pacific Regional Science Conference, Taipei, China. Irvine, CA: EQE International.

Chawla, S.K. and R. Nataraajan. 1994. Does the Name of the Sender Affect Industrial Mail Response? *Industrial Marketing Management* 23:111–115.

Childers, T.L. and O.C. Ferrell. 1979. Response Rates and Perceived Questionnaire Length in Mail Surveys. *Journal of Marketing Research* 16:429–431.

Dillman, D.A. 1978. *Mail and Telephone Surveys: The Total Design Method.* New York, NY: John Wiley and Sons.

Dowrick, D.J. and D.A. Rhoades. 1993. Damage Costs for Commercial and Industrial Property as a Function of Intensity in the 1987 Edgecumbe Earthquake. *Earthquake Engineering and Structural Dynamics* 22:869–884.

EQE International. 1994. *The January 17, 1994, Northridge, California Earthquake.* San Francisco, CA.

EQE International and Office of Emergency Services. 1995. *The Northridge Earthquake of January 17, 1994: Report of Data Collection and Analysis, Part A: Damage and Inventory Data,* Report on EQE Project Number 36386.02. Irvine, CA: EQE International.

Gardner Consulting Partners. 1995. Los Angeles Earthquake Study: An Analysis of the 1994 Northridge Quake on Metrolink Commuter Rail Ridership, prepared for the U.S. Department of Transportation, Federal Transit Administration. August.

Giuliano, G. and K.A. Small. 1991. Subcenters in the Los Angeles Region. *Regional Science and Urban Economics* 21:163–182.

Gordon, P. and H.W. Richardson. 1995. The Business Interruption Effects of the Northridge Earthquake, University of Southern California Lusk Center Research Institute, Research Report No. LCRI-95-01.

Hansen, R.A., C. Tinney, and W. Rudelius. 1983. Increase Response to Industrial Surveys. *Industrial Marketing Management* 12:165–169.

Kalafatis, S.P. and M.H. Tsogas. 1994. Impact of the Inclusion of an Article as an Incentive in Industrial Mail Surveys. *Industrial Marketing Management* 23:137–143.

Kroll, C.A., J.D. Landis, Q. Shen, and S. Stryker. 1991. Economic Impacts of the Loma Prieta Earthquake: A Focus on Small Business, University of California–Berkeley, Center for Real Estate and Urban Economics, Working Paper 91-187.

National Research Council. 1992. *The Economic Consequences of a Catastrophic Earthquake*. Washington, DC: National Academy Press.

Suarez-Villa, L. and W. Walrod. 1996. Lessons from the Northridge Earthquake: The Transportation-Intensive High Technology Industries of the Los Angeles Basin. Department of Urban and Regional Planning, University of California, Irvine. Mimeo. December.

Tierney, K. 1995. Impacts of Recent U.S. Disasters on Business: The 1993 Midwest Floods and the 1994 Northridge Earthquake, presented at the National Center for Earthquake Engineering Research Conference on Economic Consequences of Earthquakes, New York, Sept. 12–13, 1995. Disaster Research Center, University of Delaware, Newark.

Willson, R. 1998. Impacts and Responses: Goods Movement After the Northridge Earthquake. *Journal of Transportation and Statistics* 1:2.

Zamichow, N. and H. Chu. 1994. Metrolink Ridership Falls as Road Detours Open. *The Los Angeles Times*, Feb. 3, 1994, A-18.

Zamichow, N. 1994. Riordan Presents Traffic Plan. *The Los Angeles Times*, Jan. 24, 1994, A-1 and A-28.

An Assessment of Transportation Issues Under Exceptional Conditions: The Case of the Mass Media and the Northridge Earthquake

JANE GOULD

London Business School

ABSTRACT

This study explores how the mass media covered transportation issues following the 1994 Northridge earthquake. The mass media were a vital channel for travel information, and they provided considerable information to the public about the safety of travel, alternative routes, and new travel modes. Using a methodology known as content analysis, it was found that the broadcast media also presented considerable detail and imagery about devastation to the transportation system at large. This study concludes that an alternative to the commercial mass media may be useful, since the implication from this research is that a vital part of disaster recovery rests in the dissemination of balanced transportation news and stories.

INTRODUCTION

The media are often relied on as a source of travel information, and they can become *the* primary source after an incident or natural disaster disrupts normal travel activity. Following the 1994 Northridge earthquake, the mass media became a vital

Dr. Jane Gould, London Business School, Regents Park, London NW1 4SA, England. Email: jgould@lbs.lon.ac.uk.

channel of transportation news, literally overnight. An opinion poll taken five days after the earthquake showed that the need for travel information was paramount in Los Angeles. Respondents indicated that "finding alternative routes to work and long traffic delays," was the third most serious problem, after "the need to restore electricity," and "cope with stress" (*The Los Angeles Times* 1994).

Under normal conditions, information is recognized as playing a vital role in managing urban transportation activities. In simulations, researchers have examined the impact of information on network performance (Arnott et al 1991; Khattak et al 1994; Jayakrishnan et al 1994). Other researchers have studied the media as a source of information and considered the characteristics of radio traffic bulletins and their likely impact on travel behavior (Dudek et al 1971; Daniels et al 1976; Abdel-Aty et al 1995; Polydoropoulou et al 1995). One research program has looked specifically at the content of messages as a factor (Ball-Rokeach and Schaffer 1995), and others have studied reliance on traffic bulletins during bad weather using survey research (Khattak and De Palma 1997). Radio has been tested as a means to convey timely information about the availability of parking (Khattak and Polak 1993). Teletext, which is used in France, is a source for queries about mass transit routes and connections (Morrison 1996). In addition, broadcast television is growing as a source of ongoing travel news and other information (Hartgen and Casey 1990).

Despite general recognition by transportation planners that media channels play a vital role, there has been little investigation of their role during a crisis or disaster. Exceptions are the recent overhaul of the Emergency Broadcast System in the United States and the Open TALK emergency alert in the United Kingdom, where potential applications include the evacuation of areas, and clearing roads for passage by emergency vehicles (*The New York Times* 1993; *The Daily Telegraph 1996*). While these systems may be in operation moments before or after a crisis, it is conventional broadcasting that is likely to then take over, and reach most people.

For example, during the Northridge earthquake, news about the damage was first communicated by conventional, over-the-air radio channels. Within a half hour of the main tremor, there were unconfirmed stories over the radio that major sections of the Santa Monica freeway (I-10) had collapsed (Torous 1995). By daybreak, aerial cameras were transmitting pictures of the freeway damage to television viewers. It is believed that helicopter-based television reporters arrived at the scene of the freeway damage before transportation officials. For nearly two weeks after the earthquake, the mass media were the primary source of travel information for the public. However, much of the travel information that they used was provided by the California Department of Transportation, and the timeliness and accuracy of the information probably reinforced in the public mind that transportation officials were in control of the situation (e.g., USDOT et al 1995).

This paper is devoted to: a) developing an understanding of the quantity and type of information about transportation available in the media during this critical post-earthquake period; and b) assessing whether the media spotlighted longer term transportation priorities and needs. This research is focused on the *content* of the mass media, and describes how characteristics of transportation stories changed over time.

The organization of this paper is chronological. The first secion describes the period just after the earthquake. For example, what type of travel stories were presented during the crisis, and did they help to restore order? The next section examines information over the next six weeks: as travel conditions normalized, did the media continue to provide travel news and stories? Finally, the paper explores coverage of longer term transportation issues. Conclusions are also presented in the final section.

METHODOLOGY AND SAMPLE

In this research we look specifically at message content, using a methodology known as content analysis. Content analysis is frequently used in the social sciences to describe a message system, or serve as a basis for other inferences (Holsti 1969). In this research, we both describe the environment of media stories and then make inferences about likely decisionmaking and travel behaviors.

The data is based on a universe of stories in three different media. We do not sample stories because news events are not distributed randomly and we make inferences based on cumulative coverage. The broadcast data come from several sources: tapes of evening broadcasts on CBS network television from January 17 to January 25; text transcripts from other network programming; taped video of broadcasting on an NBC affiliate TV station in Los Angeles for January 18 through January 22, 1994; and special Metrolink footage. In the case of radio programming, written transcripts were examined for eight major stations in Los Angeles for January 18 through February 28, 1994.

The analysis of the print media is based on more than 900 news stories in *The Los Angeles Times* between January and September 1994. Stories in San Francisco papers following the Loma Prieta earthquake were also examined. A computerized content analysis was made of *The Los Angeles Times* using 28 categories, with key words such as trains, road repair, Caltrans, and seismic retrofitting. Other analyses, including the study of seismic issues in the press and the broadcast stories, were conducted by trained coders, using instruments that were designed for this study. The coding instruments and full procedures are reported in Torous (1995).

MEDIA COVERAGE IMMEDIATELY AFTER THE EARTHQUAKE

Media researchers frequently study a window 24 to 48 hours after a disaster because of its critical importance (e.g., Wenger 1980; Walters et al 1993). The audience for news is very large, since people are faced with great uncertainty and need to acquire information. For example, on the morning after the Northridge earthquake, nearly 80% said they used broadcast media—television or radio—as their most important source of information (Bourque 1997). Despite power outages, television broadcasts were widely available and there were no signal disruptions in nearby Orange County.

We wished to describe the characteristics of transportation stories during the first 48 hours of coverage, and were guided by issues raised by Smith (1992). Smith, who is a journalist, studied media coverage following the Loma Prieta earthquake. He observed that the frequency of video footage about transportation damages was shown disproportionately. Using content analysis, he described "excess" attention paid to the collapse of the I-880 freeway and the Bay Bridge. His inference is that these transportation landmarks were visually interesting, so journalists chose to depict them as "symbols" of the overall devastation.

Since many people died in the I-880 freeway collapse, it could be argued that it was the loss of life that led to extended media coverage. A priori, we did not expect transportation stories to receive a high level of media attention, since there was only one direct traffic fatality after the Northridge earthquake.

Working from a tape archive of daytime programming for a local (Los Angeles) television station, two coders independently classified each local news story per its major theme. The intercoder reliability was above 80%. During 6½ hours of programming on January 17, it was found that pictures about the damaged freeways were presented in 31% of the television news stories. Table 1 lists the amount of attention given to different topics: 18% of the televised stories were directly about the downed freeways or road conditions. Another 13% of the coverage occurred when a visual of the freeway collapse was shown, but the narration, or voice over, was not about transporta-

TABLE 1 Coverage of News Stories on Local Television

Topic	Percentage of stories (9 a.m.–3 p.m.)
Recovery of bodies from Northridge Meadow Apartments	19
Transportation pictures (seared freeways or interchanges)	18
Transportation "overlay" (picture only, story is not transportation-related)	13
Gas line breaks and fires	11
Rescue of janitor from collapsed parking garage	8
Aftershocks occurring (in real time)	8
Red Cross and other medical	8
Other topic or uncoded	15

tion. These "transportation overlays" took place when the newscaster spoke about a different issue (e.g., the closure of schools), but the picture on TV still showed freeway damages. Television producers might have used transportation overlays because more relevant stock footage was not available, or, as Smith has suggested, a transportation visual was more interesting to them and was a dramatic symbol of the crisis at large.

Table 1 shows that considerable broadcast time went to a category called "rescue of janitor" (8%). This concerned the rescue of a janitor trapped under parking garage rubble by digging through concrete debris. Since the stories showed that parking structures were unsafe, this could be construed as additional transportation coverage. The most frequently cited event was the Northridge Meadow tragedy, where the collapse of the apartment building resulted in many fatalities.

Based on the frequency analysis, there is some evidence to support Smith's assertion that transportation damage can become a visual image for overall damage. On January 17, television viewers saw pictures over and over again that showed massive devastation to the transportation network. This coverage occurred despite the absence of transportation-related fatalities.

We do not know how these visual images influenced individual travel decisions, but communications research has found that initial images are so potent that they will be recalled even when there is conflicting information at a later time (Wenger 1980). One possible outcome is that constant repetition leads people to overestimate the extent of damages. Wenger has dubbed this the "Dresden Syndrome," since media users come to believe that entire communities have been wiped out, rather than just discrete areas.

In the context of the Northridge earthquake, this may have led commuters to anticipate heavy damage throughout Los Angeles' 616 miles of freeways. This may have reduced trip-taking, and there is evidence that many travel trips were curtailed over the first few weeks (Yee et al 1995).

However, people may have also curtailed trip-taking because they were busy at home with the cleanup and aftermath of the earthquake. A different outcome from the extensive coverage is that it focused the attention of both the public and policymakers on the need to provide massive resources for infrastructure repair. Smith (1992) postulated that attention by the news media can accelerate aid from out-of-town policymakers who first learn about the magnitude of damage from television.

We extended our content analysis of television to January 18, the second day after the earthquake. Again, intercoder reliability was found to be above 80%. Analysis indicated a sharp contrast to the coverage of the previous day. By mid-morning, pictures were broadcast of transportation workers clearing rubble from the I-10 freeway collapse so that demolition efforts could begin. In fact, all television aerial coverage of the damaged sites was preempted so that wrecking crews could position their equipment, which was airlifted by helicopters.

Again, we make inferences about the impact this coverage had on individual travel decisions. This prompt and organized effort by transportation officials may have deflected further television coverage of the damages and helped to restore public confidence. It may also have helped to balance the negative imagery shown redundantly during the first day. Both of these are likely outcomes since mass media coverage serves many functions including the regeneration of the community (Walters and Hornig 1993; Walters et al 1989).

MEDIA COVERAGE ONE TO SIX WEEKS LATER

Communications research indicates that after initial media attention to a disaster, there is a precipitous drop in the number and frequency of stories (Singer and Endreny 1993). We found a similar pattern for nationally televised news, as the number of stories about the earthquake declined by nearly one-half after January 20, the third day of coverage (Torous 1995). This might be attributed to several factors, including the development of more "newsworthy" stories elsewhere, the cost of keeping a camera crew on the site, the cessation of emergency conditions, and a general decline in reader/viewer attention.

While national media coverage may drop off quickly, the resolution of transportation issues is likely to take some time. For drivers, the need to find new routes, explore new travel options, or adjust the time of travel can continue over weeks and months. A content analysis coded for the presence of specific route or mode information, such as maps, detours, or timetables. The analysis verified that in the local mass media—radio, television, and newspapers—there was extensive travel information and it continued over many weeks. Table 2 shows the type of travel information that was broadcast on television news during the first week. Almost 60% of the news stories about transportation had specific information to help travelers.

Among the mass media, *The Los Angeles Times* had the longest and most complete coverage of route information, as they were not constrained by the space and time of broadcast channels. Radio coverage provided numerous traffic reports, as well as news stories about the status of road reconstruction and new bus and train operations. Most of the travel reports on radio, and in the other media, were based on information that was initially sourced by the California Department of Transportation (Caltrans). They held daily press briefings commencing on the third day after the earthquake.

One of the most unique aspects of news coverage in the weeks after the earthquake was the attention paid by all three media to stories about train service. The frequency of stories mentioning buses, trains, carpools and high-occupancy vehicle lanes was compared across radio, television, and newspapers. All of these topics sharply declined in frequency after the earthquake, with the exception of stories about Metrolink service. The attention to Metrolink is particularly interesting, since the scale of operations for the freeway system and Metrolink is so immensely different. However, media attention could convey the sense that Metrolink was a solution.

According to interviews conducted with Metrolink officials, two issues helped to keep the train service in the media spotlight: one was the frequent opening of new train stations and expanded service, and the second was the perceived newsworthiness of commuter train service to Los Angeles. Metrolink had been in operation for about 15 months before the earthquake, but had not been widely publicized. Since the earthquake provided an opportunity for many people to learn about its service, we were interested to test whether earthquake-related publicity was associated with new ridership.

TABLE 2 Travel Information on Television News: January 17–22

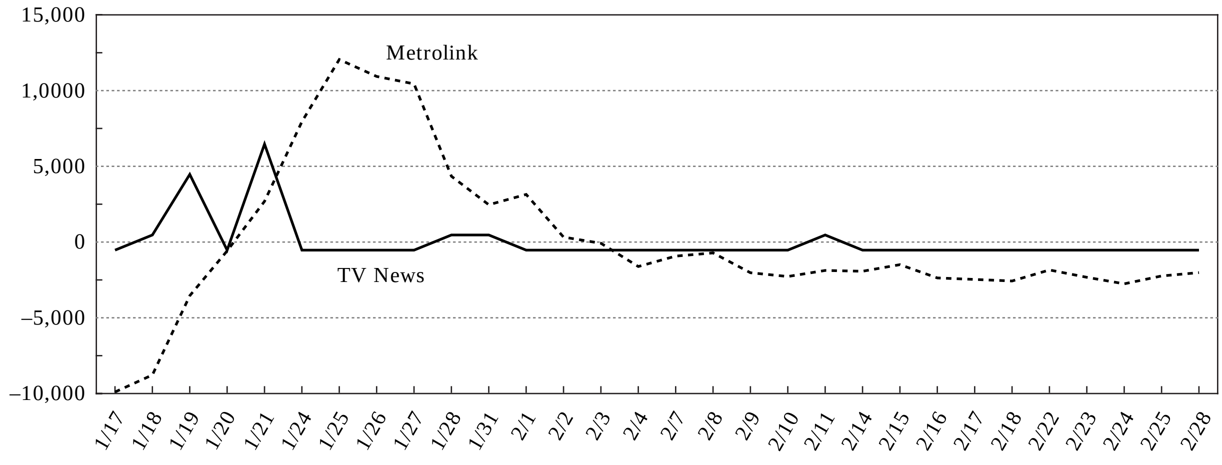
Message advisory	Percent
Verbal advice on closed roads and detours	60
Stay at home—do not travel	15
Vehicular travel is slow/dangerous	11
Travel time is slow/congestion	4
Other	11

To examine this we conducted a lagged time series analysis between media coverage and train ridership on the Santa Clarita line of Metrolink. Data from radio was not available for this analysis, and our results underestimate the media effects since drivers delayed by congestion would be receptive to radio broadcasts about an alternative mode. For this investigation, we used the stories about Metrolink carried on one local television station and by *The Los Angeles Times*, for a six week period (January 17 through February 28, 1994). We verified that content presented on other local television stations was similar.

Figure 1 shows the association between the frequency of television news coverage and daily Metrolink ridership. It can be seen that an increase in television coverage precedes the gain in Metrolink ridership immediately following the earthquake, and again at the end of January. After this, there was very limited coverage of Metrolink on television, but even brief coverage in early February appears to be associated with an increase in Metrolink ridership. The time lag between television coverage and ridership varies between two and five days. That is, after broadcast on television, ridership increased over the subsequent period. The direction of the lag clearly favors television news coverage predicting ridership. In table 3, it can be seen that five of the lagged relationships are statistically significant at the 5% level.

Newspapers lack television's ability to convey pictorial content that is simple, direct, and instructive. On the other hand, newspapers can present longer stories and more analysis and interpretation. To test their role, we examined the relationship between the frequency of newspaper coverage

FIGURE 1 Time Series of Metrolink Ridership (Santa Clarita Line) and Occurrence of Television News Stories



Note: The data in each series have been standardized to have a zero mean, and the media data are scaled by 1,000. Since train service was not offered on weekends, weekend media coverage was treated as a Friday occurrence.

TABLE 3 Lagged Correlation Coefficients of Television and Newspaper Stories

Lag	–7	–6	–5	–4	–3	–2	–1	0	+1	+2	+3	+4	+5	+6	+7
Television	–0.14	0.01	0.18	–0.29	–0.22	–0.26	–0.21	–0.01	0.23	0.46	0.55	0.65	0.42	0.39	0.33
Newspaper	0.08	0.16	0.31	0.38	0.38	0.35	0.43	0.56	0.52	0.52	0.35	0.17	0.00	–0.22	–0.30

Key: boldface ≤ 0.05

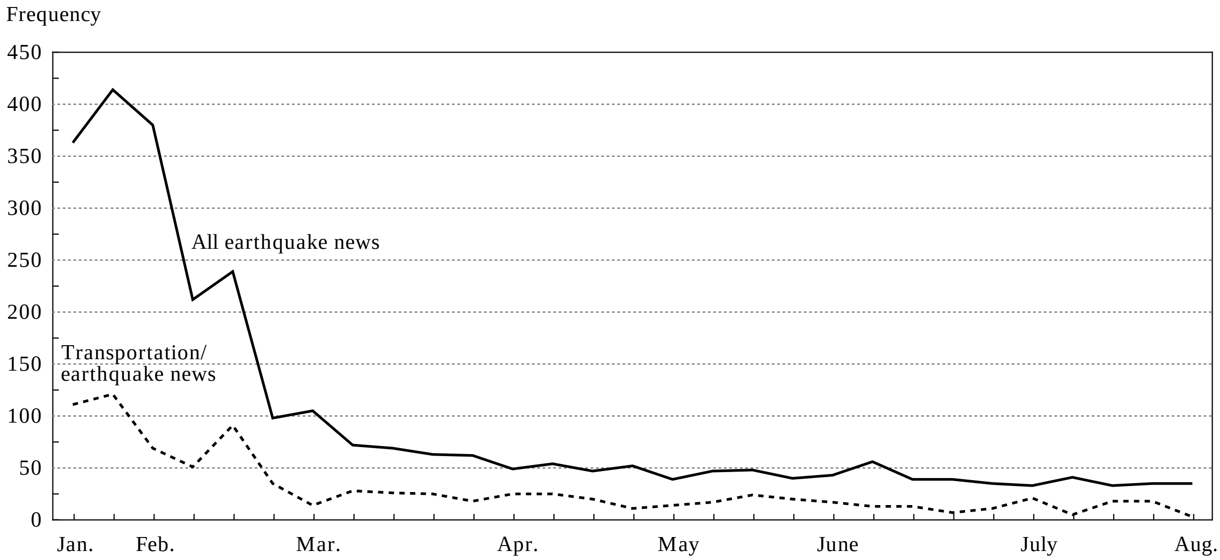
and Metrolink ridership. Table 3 shows the magnitude of the lagged correlation coefficients. For newspapers, there is some increase in ridership on the first and second day *after* stories appear, but there is also a "reverse" association—an increase in Metrolink ridership is associated with a subsequent increase in news stories. Editors probably judged new train ridership to be a newsworthy issue, and there were headlines and pictures of busy trains.

From ridership data, we know that the initially high levels of Metrolink use fell once commuting conditions normalized. It appears that the mass media, and television in particular, may have had an initial role in acquainting people with the service and encouraging trial use. Commuters probably first learned about this alternative mode of travel from television, and televised pictures also conveyed helpful information about the location of new stations, boarding procedures, and so forth.

LONGER TERM MEDIA COVERAGE

According to an interview with a local radio traffic service, it took between four and six weeks after the earthquake for road travel to stabilize (Metro Traffic News Service 1994). After the initial surge of media coverage, and special attention to Metrolink, was there sustained attention to transportation issues? We were able to investigate this through content analysis, as *The Los Angeles Times* maintains an archived database of all stories. Unfortunately, we were not able to obtain detailed longitudinal data for other media. Using a computerized content analysis of the full text, individual stories were classified by occurrences of key words (Torous 1995). Figure 2 shows that transportation issues closely parallel other reporting about the earthquake. Initially, transportation issues were mentioned in about 25% of the earthquake stories, but over time the proportion of transportation stories gained. The recovery of the transportation network stayed on the media agenda while other concerns, like emergency shelter,

FIGURE 2 Frequency of All Stories in *The Los Angeles Times* About the Earthquake and Those Specifically About Transportation and Road Repair



medical care, and food, were resolved within weeks. The reopening of freeway exchanges in May and July 1994 is associated with temporary increases in news coverage.

Through the computerized content analysis, individual stories were examined in terms of positive or negative effect. Among stories on rebuilding and reopening roadways, there was supportive coverage. Negative factors were seldom mentioned, such as noise pollution, dissent about rebuilding, or the cost. In newspaper editorials, Caltrans was praised for awarding contracts with financial incentives for early completion.

There was one topic where analysis showed that press coverage was more equivocal for transportation policy. Seismic repair and seismic safety were continuing topics of discussion beginning with a front-page analysis on January 18. Between January and July 1, 1994, there were a total of 66 stories in the local newspaper. A separate analysis found that the issue coverage could be distinguished across two time periods. During the first six weeks after the earthquake, the press was seen to be neutral about the cause of the seismic collapse. Following this, stories and editorials were prone to cite delays from party politics and an unresponsive state government. A content analysis coded the "sources" said to be responsible for the seismic failures (see table 4). In June 1994, voters in California defeated a bond measure to allocate new funds for seismic repair. Since the measure was statewide, its defeat cannot be linked to opinions expressed by a single source (e.g., *The Los Angeles Times*). Nonetheless, it would be useful to study how this issue was treated by other media, and the broadcast channels in particular.

RECOMMENDATIONS AND CONCLUSIONS

This study has explored media coverage about transportation across three different time periods following the Northridge earthquake. The content, or messages, within the media have been the particular focus. Where appropriate, we have tried to make inferences about likely impacts on travel behaviors and activity.

The combined analyses point to the media as a potent influence. The presentation of transportation-related stories is of considerable importance to the public, emergency workers, and transportation planners alike. Stories in the media can take two general formats. One format is fairly straightforward, for example, official travel advisories and route information. Following a disaster, transportation officials provide and package travel advisories for the news media. Daily press conferences between transportation authorities and the media are used to disseminate much of this information.

The second format of travel information is not as widely understood. Smith (1992) suggests that it

TABLE 4 Agencies and Issues Cited by Newspaper Reporting

	Percentage of occurrences	
	1/17–2/28/94 (n=33)	3/1–6/30/94 (n=33)
Agency to blame or at fault		
Caltrans	36	36
Employee union	9	3
State Legislature	12	12
Governor	6	33
Other	6	3
Policy that is blamed or at fault		
State budget constraints	3	9
Competition with other state programs	6	3
Competition with other transportation programs	6	12
Caltrans priorities (new v. old)	17	9
Competition with Bay area retrofits	3	9
Caltrans delays in completing retrofits	15	—
Poor administration or supervision of retrofit	6	12
Inadequate assessment of structures	3	12
Seismic standards not strict enough	—	3
Bureaucratic constraints on contracting	15	12
Public safety compromised by politics	18	36

Note: Multiple codes were allowed per story.

is construed from the storytelling needs of journalists. Ongoing news coverage can contain numerous pictures and references to the transportation system. For example, no one anticipated that pictures of downed freeways and seared interchanges would represent more than 30% of the visual coverage on television on January 17. These are images and content that transportation officials do not control.

We found that on the first day of the earthquake news about transportation damage "overwhelmed" the media agenda. Initial pictures showed uncountable devastation, but on the second day other aspects like quick reaction and demolition and removal by transportation authorities emphasized a positive response. The arrival of demolition equipment by helicopters was a newsworthy event, and may have helped to counter the initial imagery of overwhelming destruction.

For nearly six weeks after the disaster, the media presented a steady amount of news about travel, including route information, road conditions, and travel timetables. We found a particular emphasis on news of Metrolink train service, and there was some indication that televised stories were associated with a temporary increase in ridership, while recognizing that other factors also led people to use the train (see Giuliano 1996).

A careful mix of informational text and visual route maps might help the public, and lead them to make different decisions about mode choice, departure time, route choice, and diversions. An alternative to the commercial mass media may be useful, since the implication from this research is that a vital part of disaster recovery rests in the dissemination of balanced transportation news and stories.

ACKNOWLEDGMENTS

Special thanks are expressed to Gerald Gould and Lyn Long, who provided research assistance. Appreciation is also expressed to transportation officials in Los Angeles, including Marge Tiritelli of Caltrans, Steve Chesser of the MTA, and Peter Hidalgo of Metrolink. A number of news agencies provided data, including KNBC of Burbank, California, the Nexis research service, the *The Los Angeles Times* Poll, the Vanderbilt Television News Archive, and AVR Services. Research support was provided by the Bureau of Transportation Statistics Northridge Earthquake Grant. All errors of omission or interpretation are those of the author.

REFERENCES

Abdel-Aty, M., K. Vaughn, R. Kitamura, P. Jovanis, and F. Mannering. 1995. Models of Commuter's Information Use and Route Choice: Initial Results Based on Southern California Commuter Route Choice Survey. *Transportation Research Record* 1453:46–55.

Arnott, R., A. DePalma, and R. Lindsey. 1991. Does Providing Information to Drivers Reduce Traffic Congestion? *Transportation Research A* 25, no. 5:309–318.

Ball-Rokeach, S. and A. Schaffer. 1994. A Content Analysis of Radio Traffic Reports, conference paper for Program on Maximizing the Injury Prevention Potential of Radio Traffic Reports. Annenberg School for Communications, University of Southern California.

Bourque, L. 1997. Community Response to the January 17, 1994, Northridge Earthquake, Final Report to the National Science Foundation, CMS-9411982. January.

The Daily Telegraph. 1996. Avoiding Flood of Tears. 24 September. p. 2. Available from Connected@Telegraph.co.uk.

Daniels, E., M. Levin, and J. McDermott. 1976. Improving Commercial Radio Traffic Reports in the Chicago Area. *Transportation Research Record* 600:52–57.

Dudek, C., C. Messer, and H. Jones. 1971. Study of Design Consideration for Real-Time Freeway Information Systems. *Highway Research Record* 363:1–10.

Giuliano, G. 1996. Traveler Responses in the Wake of Major Transportation Damage, presentation at UCLA Extension Public Policy Program Conference: Restoring Mobility and Economic Vitality Following Major Urban Earthquakes, 25–26 April, Los Angeles, CA.

Hartgen, D. and M. Casey. 1990. Television Media Campaigns To Encourage Changes in Urban Travel Behavior: A Case Study. *Transportation Research Record* 1285:30–39.

Hidalgo, P. Metrolink Public Affairs Department, Los Angeles, CA. 1995. Personal interview. February.

Holsti, O. 1969. *Content Analysis for the Social Sciences and Humanities*. Reading, MA: Addison Wesley Publishing Co.

Jayakrishnan, R., H. Mahmassani, and T. Hu. 1994. An Evaluation Tool for Advanced Traffic Information and Management Systems in Urban Networks. *Transportation Research C* 2:129– 147.

Khattak, A., H. Al-Deek, and P. Thananjeyan. 1994. A Combined Traveler Behavior and Transportation System Performance Model with ATIS, Partners for Advanced Transit and Highways (PATH), Research Report UCB-ITS-PRR-94-14. Institute of Transportation Studies, University of California, Berkeley.

Khattak, A. and A. De Palma. 1997. The Impact of Adverse Weather Conditions on the Propensity To Change Travel Decisions: A Survey of Brussels Commuters. *Transportation Research A* 31: 181–203.

Khattak, A. and J. Polak. 1993. Effect of Parking Information on Travelers' Knowledge and Behavior. *Transportation* 20:373–393.

The Los Angeles Times. 1994. Survey #329: Northridge Earthquake Aftermath Poll, Los Angeles County. 22 and 23 January.

Morrison, A. 1996. Alternative Information Technologies for the Provision of Spatial Information to Public Transport Passengers in France, Germany, and Spain. *Transport Review* 16:243– 271.

The New York Times. 1993. Technology, Warning of Disasters, Digitally. Section 3, p. 9. 7 November.

Metro Traffic News Service, Los Angeles, CA. 1994. Personal visit. December.

Polydoropoulou, A., M. Ben-Akiva, and I. Kaysi. 1995. Influence of Traffic Information on Drivers' Route Choice Behavior. *Transportation Research Record* 1453:56–65.

Singer, E. and P. Endreny. 1993. *Reporting on Risk*. New York, NY: Russell Sage Foundation.

Smith, C. 1992. *Media and Apocalypse*. Westport, CT: Greenwood Press.

Tiritelli, M., District 7 California Department of Transportation, Public Affairs Department, Los Angeles, CA. 1995. Personal interview. February.

Torous, J. 1995. Twenty Seconds that Shook the Agenda: An Assessment of Transportation Issues in the Mass Media Following the Northridge Earthquake, prepared for the Bureau of Transportation Statistics, U.S. Department of Transportation. University of California, Los Angeles, Consolidated Earthquake Impact Research Project.

U.S. Department of Transportation, Federal Highway Administration; Caltrans; Industry Task Force. 1995. The Lessons Learned from the Northridge Earthquake.

Walters, L. and S. Hornig. 1993. Faces in the News: Network Television News Coverage of Hurricane Hugo and the Loma Prieta Earthquake. *Journal of Broadcasting and Electronic Media*, Spring, 219–232.

Walters, L., L. Wilkins, and T. Walters. 1989. *Bad Tidings: Communication and Catastrophe*. Hillsdale, NH: Lawrence Erlbaum Publishers.

Wenger, D. 1980. A Few Empirical Observations Concerning the Relationship Between the Mass Media and Disaster Knowledge: A Research Report, in *Disasters and the Mass Media: Proceedings of the Committee on Disasters and the Mass Media Workshop*. Washington, DC: National Academy of Sciences.

Yee, A., S. Leung, and L. Wesemann. 1995. The 1994 Northridge Earthquake: A Transportation Impact Overview, presentation at the 1995 Transportation Research Board Annual Meetings, Washington, DC.

JOURNAL OF TRANSPORTATION AND STATISTICS

Guidelines for Manuscript Submission ▾ Instructions to Authors

After retaining a copy for your files, submit two double-spaced copies of your manuscript to:

Marsha Fenn, Managing Editor
Journal of Transportation and Statistics
Bureau of Transportation Statistics
US Department of Transportation
Room 3430
400 7th Street SW
Washington DC 20590

As the manuscripts are subject to peer review, submission of a paper indicates the author's intention to publish in the *Journal of Transportation and Statistics*. Simultaneous submission of a manuscript to other journals is unacceptable. Previously published manuscripts, whether in an exact or approximate form, cannot be accepted. Check with the editor if in doubt.

All manuscripts must be typewritten and double-spaced with a 1" margin on all sides. Double-space all material, including quotations, the abstract, and any notes. All figures and tables should appear at the end of the paper, and each should be on a separate page. Include the figure name and filename on the bottom of the page.

Cover page. This page should include the title of the manuscript, the author's name, mailing and email addresses, and telephone number. The following page should contain a one-paragraph abstract of the manuscript of about 100 words. The abstract should include the title of the manuscript, briefly describe the contents of the paper, and explain the research method and results. The abstract should not contain any abbreviations or acronyms.

Graphic elements. Make sure that figures and tables are called out in the text. The title of your article, along with the figure or table number, should be written on the bottom of the page. All figures and tables should appear at the end of the paper, and each should be on a separate page.

Figures need to be on high-quality paper, no more than 8½" x 11" in size, in black ink. Complicated graphics are to be avoided, and print should be large enough to allow for considerable reduction.

References. The reference style follows the *Chicago Manual of Style*. In the text, include the author, year, and page number. For example: Road dust also accounted for over 30 percent of emissions of very fine particles—those measuring 2.5 microns or smaller. (Barnard 1996, 17). Complete references must appear at the end of your manuscript. Include enough information in your reference so that the reader can find the document or contact its author. References should be alphabetized by authors' last names. When an author has more than one publication, place the oldest one first. Include the place of publication and publisher for books, and volume, month, or issue, and pages for journals. Examples of various types of references follow:

Gordon, R. 1990. *The Measurement of Durable Goods Prices.* Chicago, IL: University of Chicago Press.
in the text: (Gordon 1990)

Kargon, R.H., ed. 1974. *Maturing of American Science.* Washington, DC: American Association for the Advancement of Science.
in the text: (Kargon 1974)

Michaelis, L., D. Bleviss, J.-P. Orfeuil, and R. Pischinger. 1996. *Mitigation Options in the Transportation Sector. Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis, Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by R.T. Watson, M.C. Zinyowera, and R.H. Moss. Cambridge, England: Cambridge University Press.
in the text: (Michaelis et al. 1996)

National Academy of Sciences (NAS), Committee on National Statistics. 1985. *Sharing Research Data.* Washington, DC: National Academy Press.
in the text: (NAS 1985)

Yates, C. 1992. Eurocontrol Comes of Age. *Jane's Airport Review* 4:3.
in the text: (Yates 1992)

Papers selected for publication in the journal. An electronic copy of the manuscript must be submitted on a 3½" diskette, along with two paper copies of the article. Make sure the hard copy corresponds to the electronic copy. Label the diskette with your name, the date, and the title of your paper. Please specify what software was used, including the release number (e.g., Word 6.0 for Windows). Send a list of filenames. Please keep a copy of the electronic file.

Send separate files for each table, figure, and the text. Do not imbed tables and figures in the text files. Indicate the approximate placement of each figure and table in the text.

Once the page proofs of your manuscript are returned to you, you will be required to return them to the Managing Editor within 48 hours. If the proofs are not returned, we will assume the article is correct as is.

BUREAU OF TRANSPORTATION STATISTICS PRODUCT ORDER FORM

Orders may be placed by:

mail	BTS Product Distribution Center Room 3430 400 7th Street SW Washington DC 20590
phone	202.366.DATA
fax	202.366.3640
email	orders@bts.gov

Orders for future products will be mailed upon availability.

FORMAT		PRODUCT
CD-ROM	Print	
	❑	Airport Activity Statistics of Certificated Air Carriers, Summary Tables, 1996
		American Travel Survey, 1995
❑		*Microdata CD-ROM: Household Trip and Person Trip Data Files* (SAS format—1 CD)
❑		*Microdata CD-ROM: Person Trip File, Household Trip Data File* (ASCII format—2 CDs)
❑		*Microdata CD-ROM: Demographic File*
	❑	*State Profiles* please write state desired ____________________
	❑	*United States Profile*
❑		Census Transportation Planning Package 1990 (statewide) please write state required ____________________
❑		Census Transportation Planning Package 1990 (urban) please write metropolitan area required ____________________
		Commodity Flow Survey 1993
❑		*National Transportation Analysis Region (NTAR)*
	❑	*United States Highlights*
	❑	*State Freight Transportation Profiles* please write state desired ____________________
❑		*State Report*
	❑	*State Summaries*
	❑	Directory of Transportation Data Sources 1996
	❑	Federal, State, and Local Transportation Financial Statistics, FY 1982–1994
	❑	Implications of Continuous Measurement for the Uses of Census Data in Transportation Planning
	❑	International Travel and Tourism 1997
	❑	Internet Starter Kit, Update 1997
	❑	Journal of Transportation and Statistics, Volume I Number I, January 1998
❑		LRS in GIS 1998
	❑	Map of Major U.S. Transportation Facilities 1997
	❑	Map of Transportation in North America 1998

FORMAT CD-ROM	Print	PRODUCT
❑		National Transportation Atlas Databases 1997 please note ❑ DOS or ❑ UNIX
	❑	National Transportation Statistics 1993
	❑	National Transportation Statistics specify year ❑ 1997 ❑ 1996 ❑ 1995
❑		Nationwide Personal Transportation Survey, 1983 and 1990
	❑	Pocket Guide to Transportation
❑		Rail Waybill Data: 1988–1992
	❑	Telephone Contacts for Users of Federal Transportation Statistics, 1998
❑		TIGER/Line Files, 1995 please write in state required __________
❑		Traffic Safety Data: 1988–1994
	❑	Transportation Acronym Guide 1996
❑		Transportation Data Sampler-3 1996
	❑	Transportation Expressions 1996
	❑	Transportation in the United States: A Review, 1997
	❑	Transportation Receipts and Outlays in the Federal Budget: FY 1977–1994
❑		Transportation Safety 1997
	❑	Transportation Statistics Annual Report specify year ❑ 1997 ❑ 1996 ❑ 1995
	❑	Transportation Statistics Beyond ISTEA: Critical Gaps and Strategic Responses, 1998
		TranStats
	❑	*Truck Movements in America*
	❑	*Federal Gas Tax: Household Expenditures, 1965–1995*
	❑	*Truck Shipments Across the Woodrow Wilson Bridge: Value and Tonnage in 1993*
	❑	*The Economic Importance of Transportation Services: Highlights of the Transportation Satellite Accounts, 1998*
❑		Travel Demand Forecasting 1997
	❑	Welfare Reform and Access to Jobs in Boston 1998

Customer name and title ________________________

Organization ________________________

Address ________________________

City/state/country/zip code ________________________

Telephone and fax numbers ________________________

Email address ________________________

JOURNAL OF TRANSPORTATION AND STATISTICS

Volume I Number 2
May 1998
ISSN 1094-8848

CONTENTS

GENEVIEVE GIULIANO + JACQUELINE GOLOB
Impacts of the Northridge Earthquake on Transit and Highway Use

PETER GORDON, HARRY W RICHARDSON + BILL DAVIS
Transport-Related Impacts of the Northridge Earthquake

RICHARD WILLSON
Impacts and Responses: Goods Movement After the Northridge Earthquake

MARLON G BOARNET
Business Losses, Transportation Damage, and the Northridge Earthquake

JANE GOULD
An Assessment of Transportation Issues Under Exceptional Conditions: The Case of the Mass Media and the Northridge Earthquake