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.

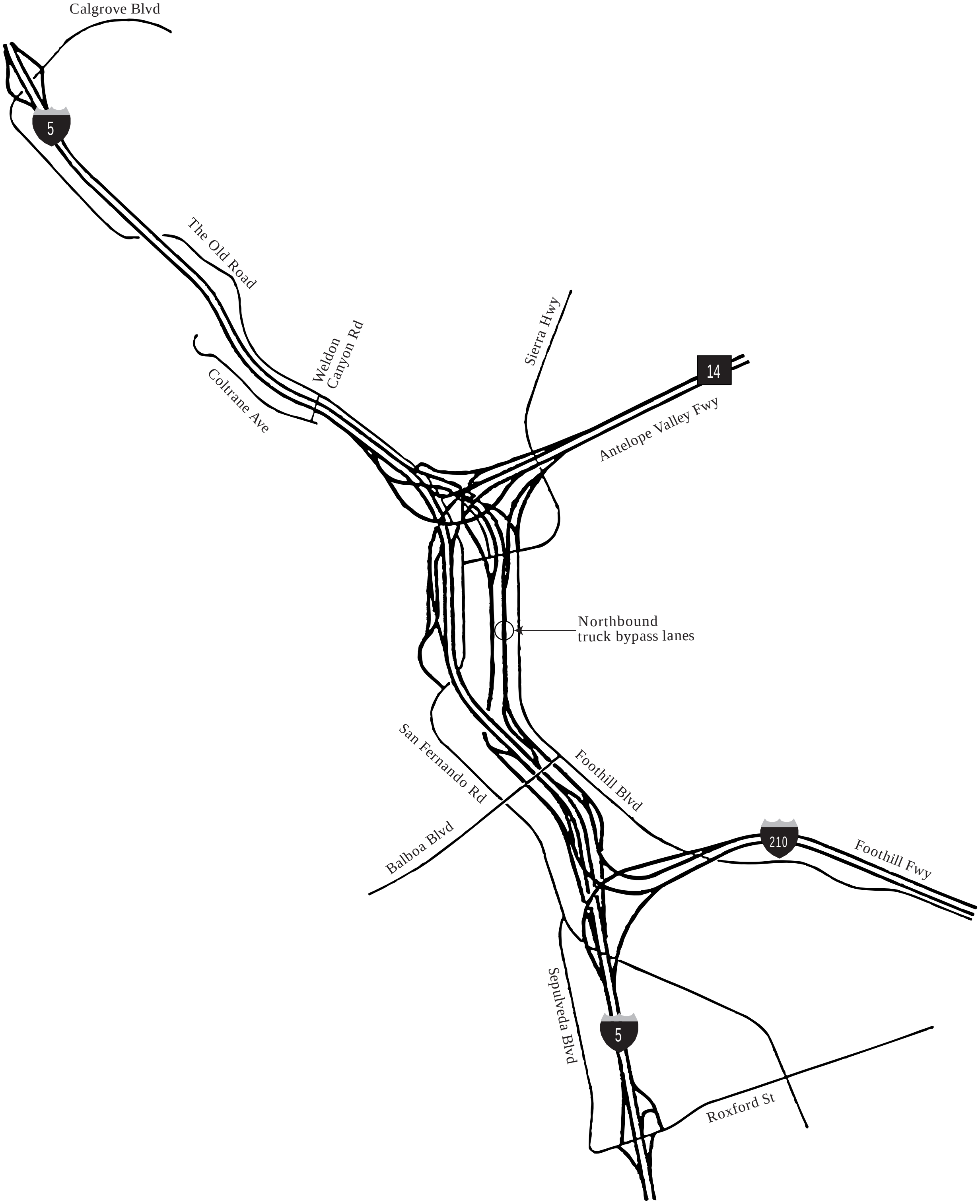
Public Transit Service Expansion

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.

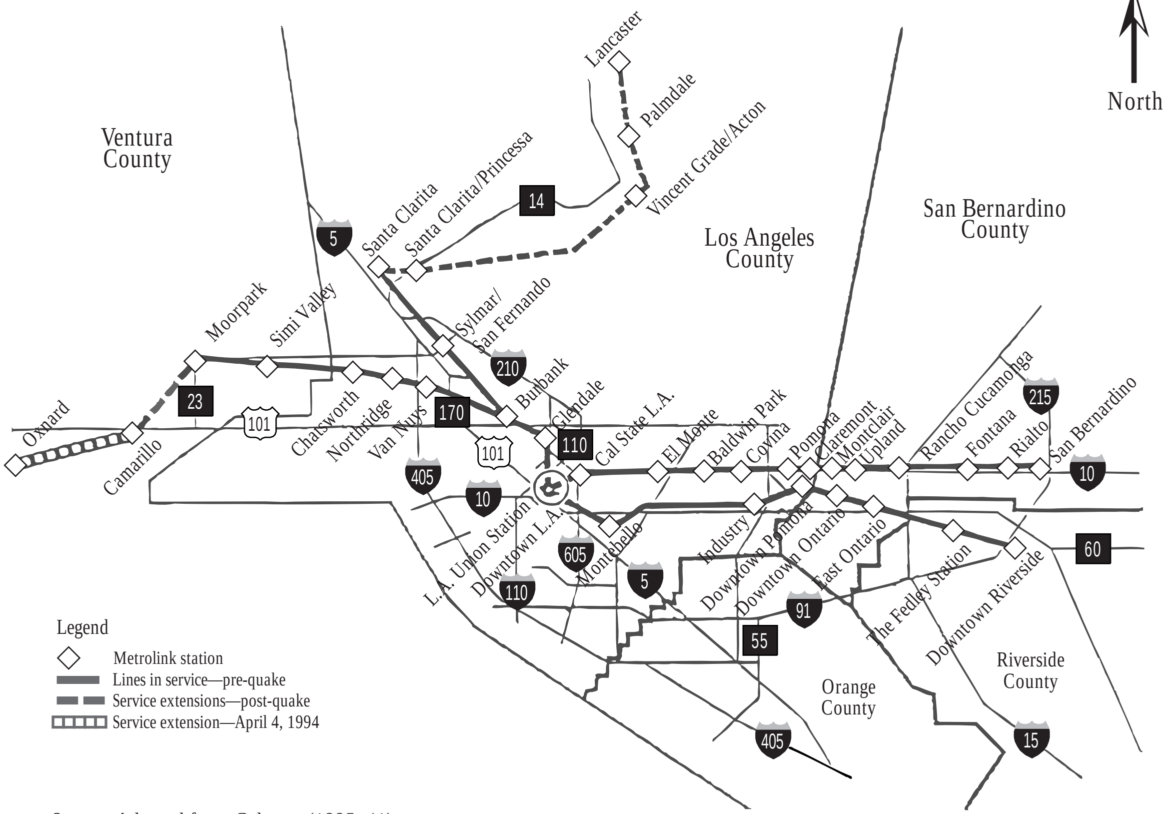
Commuter bus services were not expanded until April 1994. Three new express routes from the northern Los Angeles County cities of Lancaster and Palmdale to employment centers in Van Nuys, the Los Angeles International Airport area, and the west Los Angeles area were provided, and the existing service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

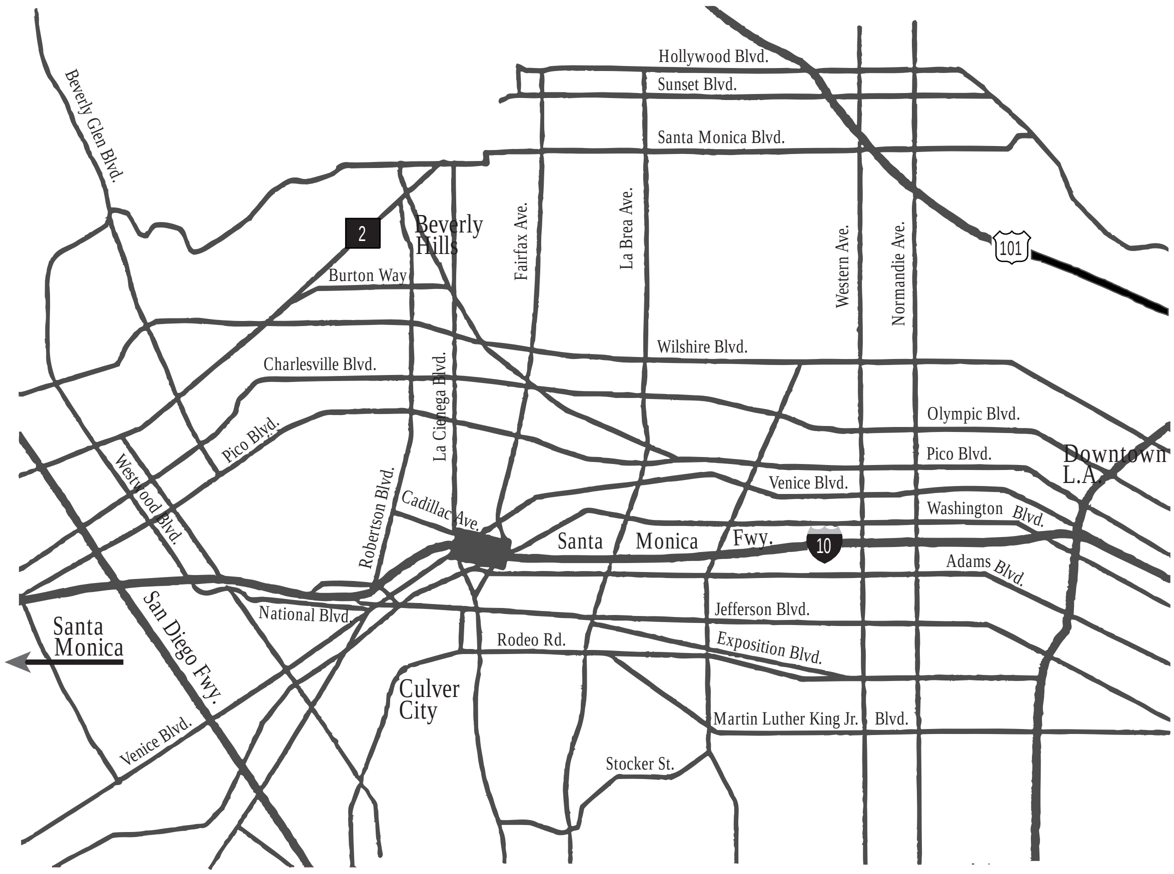
The I-10 (Santa Monica Freeway) is known as "the world's busiest freeway." Caltrans data show that average weekday traffic volumes on the eight-lane facility were about 310,000 in the vicinity of the damage. Just to the east, the freeway has 10 lanes, and an average daily volume over 400,000 (Caltrans 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).

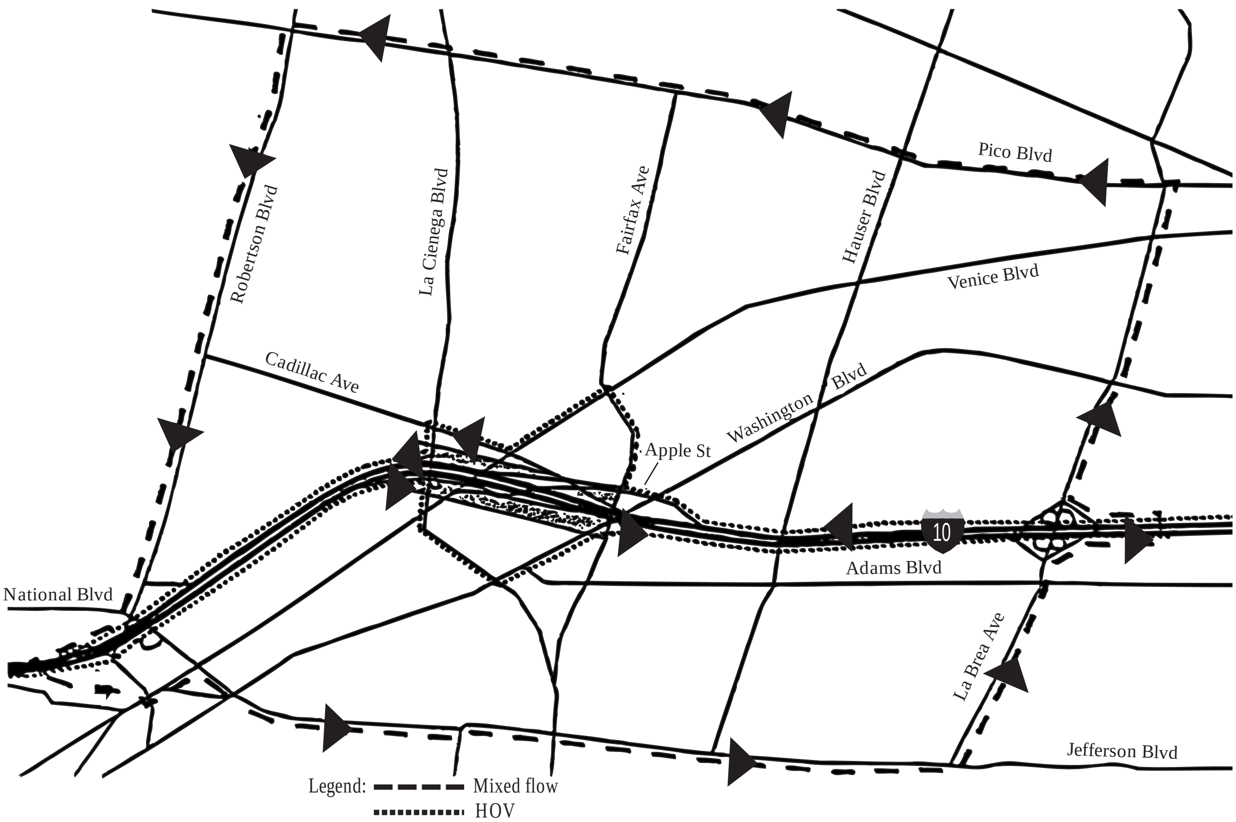
use signalization strategies to increase through capacity on the major detour arterials.

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.

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.

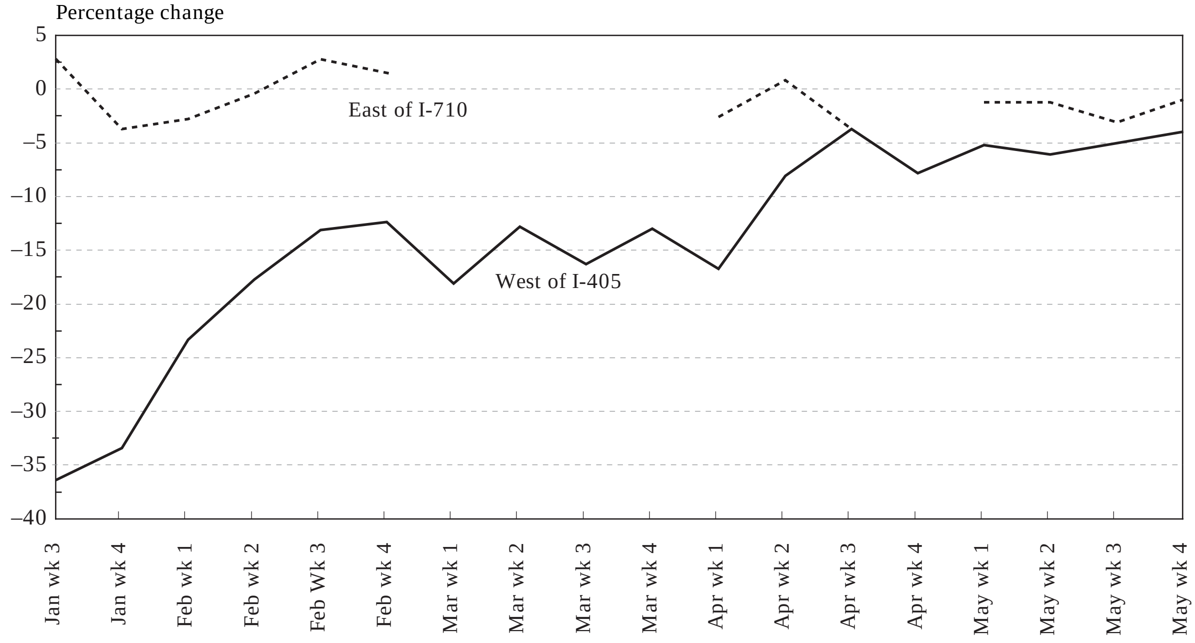
In considering shifts in mode or schedule, however, we must take into account total travel volume. For example, a decline in transit patronage after the earthquake may reflect a decline in overall travel demand, rather than a decline in transit share; it is quite possible that the transit share increased, 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

[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.

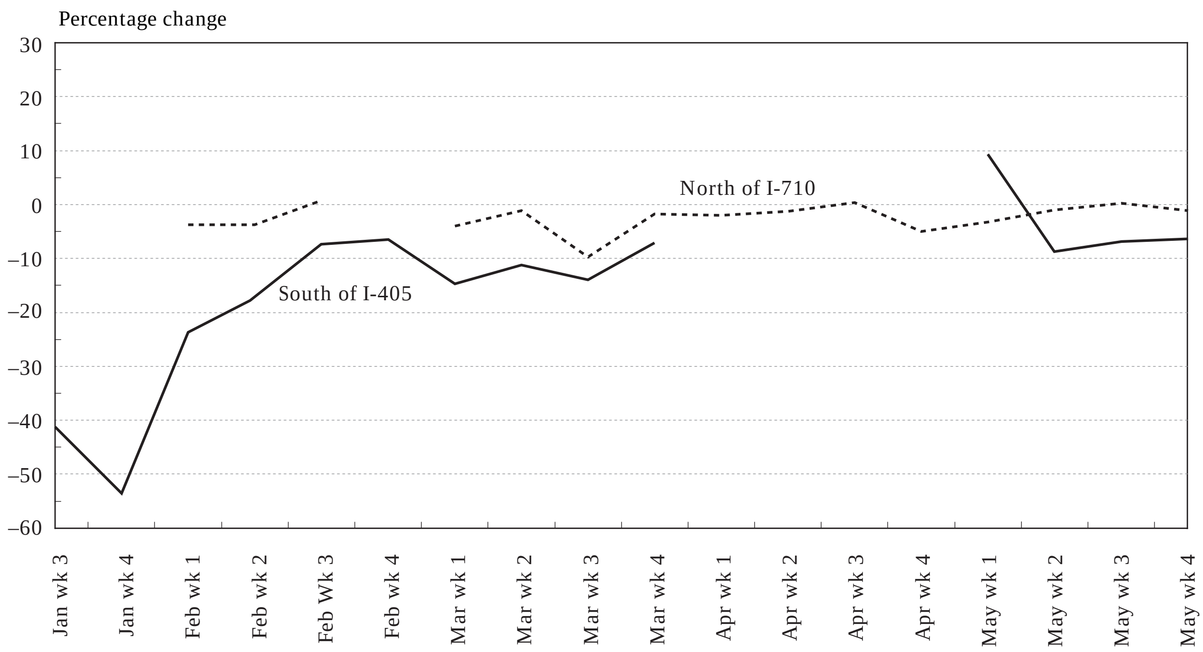
[2] As noted previously, historical freeway traffic volume data are available for selected count stations, but historical arterial traffic data are extremely limited. Route-level transit ridership data are also limited.

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.

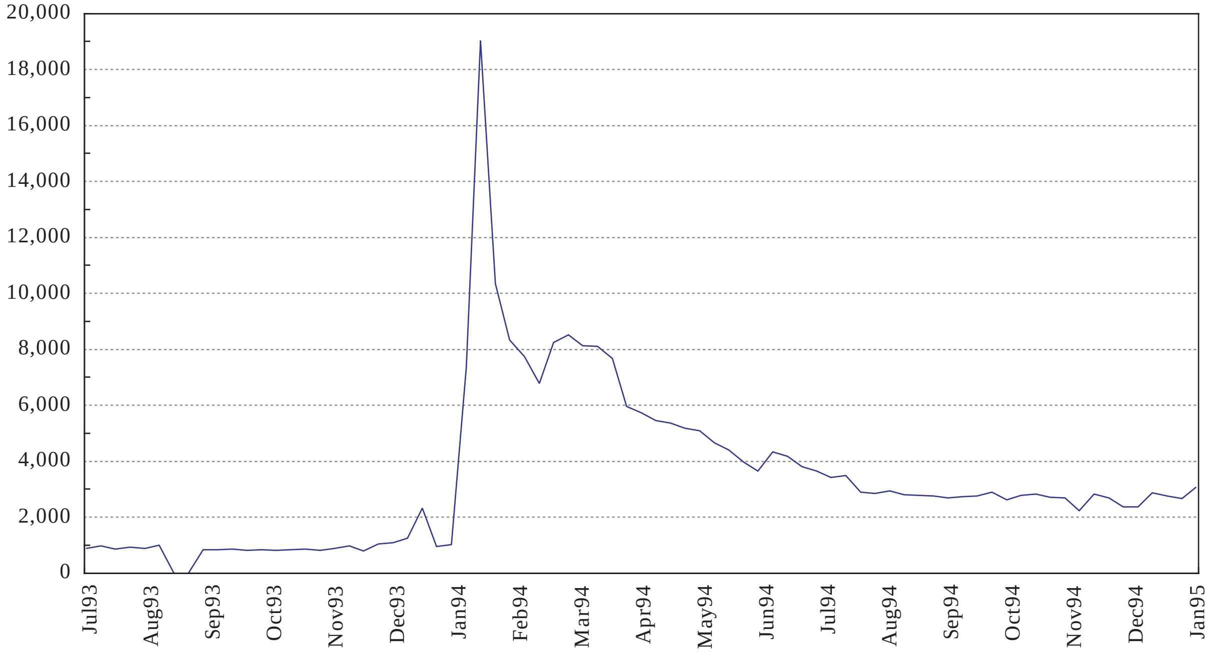
Given the extremely limited alternatives available to I-5 corridor commuters, Metrolink's failure to retain most of its new ridership under such conditions merits discussion. First, initial demand overwhelmed the system. News reports described parking shortages, trains too crowded to board, and lengthy 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.

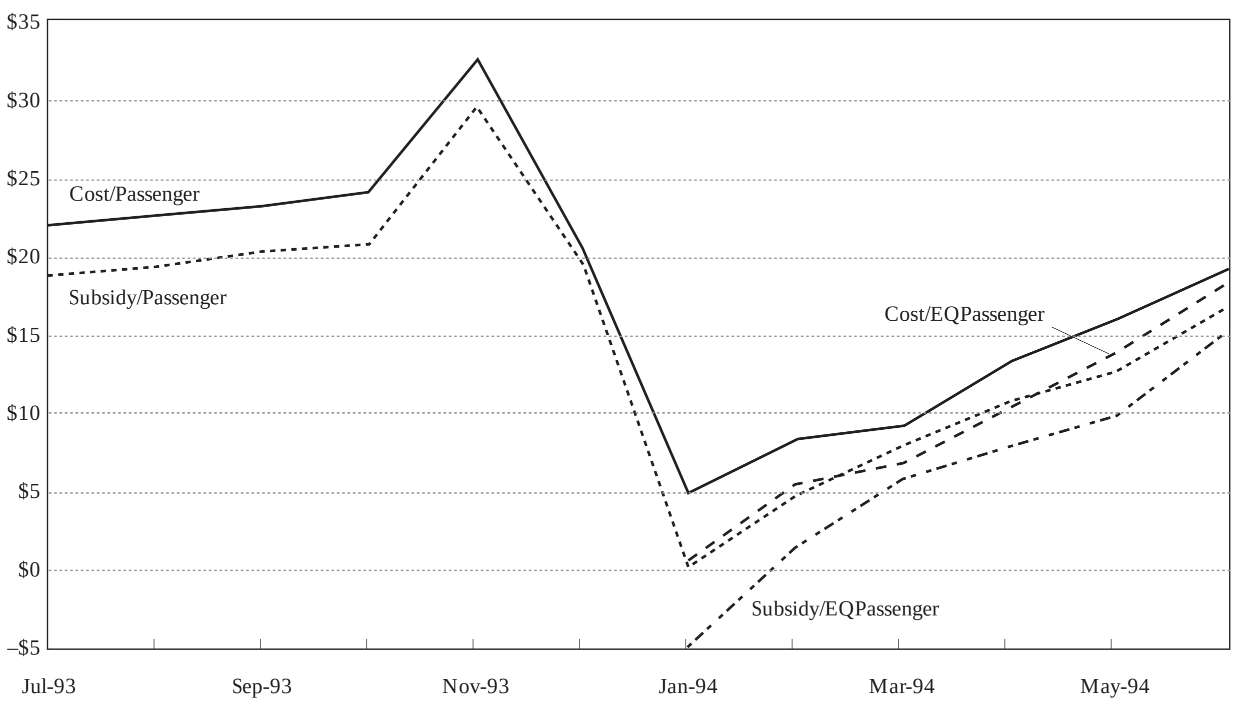
We used the cost and passenger revenue data provided by Metrolink to generate cost and subsidy per passenger for each month in FY 1993–94. Figure 8 shows cost and subsidy per passenger for total monthly passengers and for the additional passengers (and additional emergency service). Throughout the recovery 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.

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