Transport-Related Impacts of the Northridge Earthquake

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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.

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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		Chi-square	Probability*
	Yes	No		
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)

Not employed 32.5	Percent employed 67.5		
	Missed no work 32.7	Missed work 67.3	
		Missed no full days 3.7	Missed full days 96.3
		Missed no partial days 66.4	Missed partial days 33.6
		Missed only full or only partial days 70.5	Missed full days and partial days 29.5

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.

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