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**STUDIES ON THE LOMA PRIETA EARTHQUAKE
No. 1**

**The Shake With Freight:
The Impact of the Loma Prieta Earthquake
On Bay Area Truckers**

Mark Hansen
Jacob Sutter

November 1990

**The University of California
Transportation Center**

University of California
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**The Shake With Freight:
The Impact of the Loma Prieta Earthquake on
Bay Area Truckers**

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November 1990

The University of California Transportation Center
University of California at Berkeley

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The earlier stages of this research were carried out with the assistance of Mike Martello. His efforts on this project are also gratefully acknowledged.

ABSTRACT

The impacts of the Loma Prieta earthquake on Bay Area trucking firms, based on a combination of in-depth interviews and a random survey, are reported. The earthquake's primary impact on truckers derived from the closure of major roadway facilities, which necessitated circuitous routings and increased congestion on the facilities that remained open. The vast majority of truckers rated the impacts from increased congestion and circuitous routings as moderate or severe. Other impacts affecting substantial proportions of truckers involved communication and dispatching efficiency. The most common responses to the earthquake involved rescheduling, rerouting, and acquisition of additional labor. Service adjustments were also fairly common. Overall, truckers' costs increased an average of 7 per cent and while their revenues declined 5 per cent in the four-week period after the earthquake. The variation around these averages was considerable.

Correlations between firm size, use of affected roadway facilities, impact severity, responses, and cost and revenue changes were investigated. Truckers reporting greater use of affected facilities also reported greater impacts. Impact severity, was in turn, correlated with the number of countermeasures taken, as well as cost and revenue changes. Percentage reductions in revenue were also greater for smaller firms. No relationship between the number of countermeasures and cost or revenue changes were observed.

The overall impression is that the impact of the earthquake on Bay Area truckers was substantial, but not debilitating, largely because of the ubiquity of the roadway system and the fact that most firms escaped serious damage to their facilities and equipment. Future efforts to maintain and enhance this resiliency should focus on assuring minimal property damage, enhancing mechanisms for acquiring additional labor on a short-term basis, and improving communications.

I. INTRODUCTION

On October 17, 1989, the San Francisco Bay Area was struck by a strong earthquake centered near Loma Prieta Mountain, south of San Jose. Among the most significant impacts of the Loma Prieta earthquake was extensive damage to the Bay Area road and bridge network. The impact of this damage on passenger travel--particularly commuting--was widely publicized at the time and has since been the object of several studies. This research described in this report concerns the effects of the earthquake on the other crucial urban transport activity: goods movement.

Nationally, it is estimated that 20 per cent of total urban vehicle-miles are made by truck (Tittlemore et al., 1972). It often seems, however, that the extent and importance of the latter is unappreciated by the public, even by transportation planners and policymakers. One reason may be that "freight doesn't vote." Furthermore, while our experience of the performance of passenger transport systems is direct, the consequences of goods transport performance are commingled with a host of other influences that affect the prices we pay for goods and services. Only when the goods movement sector fails to provide the necessary services, or when goods movement activities interfere with passenger transport or with other activities, does the system intrude into the public consciousness.

Thus, inattention to the impact of the Loma Prieta earthquake

on urban goods movement is an indication that basic services were maintained. Had food failed to reach the grocery shelves, had hardware stores been unable to replenish their supplies of flashlights, or had pharmacies run out of medicines, than surely goods movement would have been more competitive with BART crowding and bridge congestion as a source of headlines. The same would have also resulted if trucks had been perceived to greatly exacerbate roadway congestion or threaten roadway safety in the earthquake aftermath.

Even if the urban freight system maintained its basic integrity in the wake of Loma Prieta, important questions remain. First, how severely did the earthquake affect normal trucking operations? Were services maintained through a heroic effort in the face of tremendous adversity, or simply because earthquake impacts were inherently minor? Second, insofar as the earthquake did require adjustments, what were they? Third, what were the "bottom line" consequences of the earthquake on trucker costs and revenues? Finally, what kinds of variation among trucking firms do we see with regard to impact, response, and financial ramifications? These are the kinds of questions that motivated our study.

None of these questions has proved easy to answer. The urban goods movement sector is highly fragmented and competitive. Many of the firms are quite small, with little time or tolerance for the questions of academic researchers. Others, though larger, are extremely protective of the types of information required to fully

answer many of the above questions. Nonetheless, sufficient cooperation was obtained from a sufficient number of trucking firms to develop a reasonably coherent picture of the impact of the earthquake on the urban goods sector, and of how firms within the sector responded to these impacts.

Subsequent sections of this paper present this picture and describe the methods employed to obtain it. In Section II, an exploratory survey undertaken within two months of the earthquake is discussed. Section III describes a survey of a larger, randomly selected, set of truckers conducted during the winter of 1990. Conclusions and recommendations for further research are presented in Section IV.

II. EXPLORATORY STUDY

Within a few weeks of the earthquake, it was decided that some study of its impact on truckers should be carried out. Because of our dearth of experience with this sort of transportation phenomenon, it was decided to begin with an exploratory survey in which a relatively small number of truckers were asked open-ended questions concerning how the earthquake had affected their operations. In light of the exploratory nature of the survey, selection of firms to contact was unsystematic. For-hire truckers were chosen from the Yellow Pages. A number of other firms who were

known or believed to have extensive private trucking operations were also contacted. In all, ten firms--nine of which operated trucks and the one of which, while not a truck operator, made extensive use of trucking services--participated in the exploratory study.

The information generated by the exploratory survey falls into four broad categories. The first category pertains to the ability of the operators to provide needed services in the earthquake aftermath. The second category included information on the adaptations made by truckers. A third category of information concerns the impact of the earthquake on demand for trucking services, while the fourth consists of performance information describing the impact on either overall efficiency or on some determinants of overall efficiency.

Ability to Provide Service

The earthquake did not significantly hamper the ability of most respondents to provide service. In the first place, the vast majority reported no serious damage to their physical plant or equipment. Further, those firms whose routes were affected were generally in a position to hire the additional labor required to maintain services. The majority also had considerable flexibility in rescheduling runs to reflect changed travel conditions. Finally, the temporary nature of the most serious disruption (the closure of the Bay Bridge) allowed truckers to employ strategies (such as

allowing a service backlog to develop) that would not have been sustainable in the longer term.

For the small minority of truck operators who suffered significant damage, the earthquake was far more incapacitating. For example, an auto parts distributor used a handling system involving freight carousel to which the earthquake caused \$2 million worth of damage. While the carousel was inoperative, the distributor could not retrieve parts from it, necessitating that they be sent via Federal Express from other, more distant sources.

Another case in which the earthquake significantly affected freight service offerings was when the service was not a part of the core business. For example, an East Bay lumber company suspended service to San Francisco as a consequence of the Bay Bridge closure. The comparatively minor significance of the San Francisco market, combined with the limited amount of labor hours it was willing to allocate to deliveries, made this response a natural one.

Otherwise, the truckers interviewed indicated that the earthquake created irritants but not barriers to continued operation. Several respondents reported that lack of communications was a problem. Truckers reported lack of information about the accessibility of certain areas of San Francisco, about the ability of clients to receive shipments, and about road conditions. In the case of one firm, the earthquake severed a computer communications link through which regular clients requested services. Finally, two

respondents noted that long-haul truckers were unwilling to take loads to San Francisco because of their uncertainty over conditions in the region.

The increased travel times resulting from the earthquake generally reduced the volume of service that could be provided with a given number of drivers and trucks. For the most part, firms paid overtime or hired additional labor to make up for this. One firm, unable to obtain additional labor, was forced to turn down orders beginning 10 days after the earthquake in order to work off its backlog. Two other operators also reported backlogs, but were able to work them off gradually. This strategy, of course, resulted in many deliveries that were either made behind schedule or scheduled to occur later than they would otherwise have been. One of the firms reporting a backlog stated that the percentage of on-time deliveries slipped from 96-98 per cent to 90-92 per cent.

Adaptations

The most common adaptation--aside from the obvious route adjustments necessitated by facility closures--was the use of additional labor. Five respondents reported that drivers worked additional overtime, while two hired additional drivers. Overtime was preferred over hiring additional drivers for several reasons, including the lack of qualified candidates, the time required to train new drivers, and the difficulty of dividing established routes as compared with simply paying drivers for the additional

hours required to make the usual runs. In the two cases where additional drivers were used, there were extenuating circumstances. A major grocery chain rehired drivers who had previously been laid off, while a home delivery service for retailers was going to need additional "contractors"--the basis on which they employed drivers--for the upcoming holidays.

Three of the firms surveyed did not employ any additional labor after the earthquake, for very different reasons. In one case, additional labor was desired but impossible to obtain. Drivers were already working the legal maximum of 12 hours per day and no acceptable applicants responded when the firm attempted to hire new drivers. Another company was able to avoid using additional labor by changing drivers' workdays from 6 am-6 pm to 12 am-12 pm. The fact that this company used non-union labor may have contributed to its ability to make this adjustment. Finally, as already noted, the East Bay lumber yard solved the problem by suspending transbay deliveries, and making other deliveries earlier in the day.

The increased travel times resulted in some scheduling adaptations. The most common scheduling adjustment, reported by four firms, was earlier dispatch times. In some cases, the earlier times were necessary in order to meet delivery schedules, while in other cases avoiding peak period congestion appears to have been the main motivation. In the former cases, early dispatch was done selectively to meet the needs of specific customers.

Other shifts in scheduling to avoid congestion were reported. The most substantial change was reported by a grocery chain that had previously confined deliveries to the period between 7 am and 7 pm as part of a "good neighbor" policy. After the earthquake, nighttime deliveries were used extensively. More deliveries were also made during the weekend hours. These changes were facilitated by the cooperation of the Teamsters Union, and the fact that most stores being served were open 24 hours a day, 7 days a week. Another company increased the proportion of drivers on the noon to midnight shift. It estimated that 25 per cent of its customers were willing and able to have delivery times changed to the evening period.

Other respondents reported that nighttime delivery would not have been feasible. Reasons varied. Those delivering to businesses cited the need for the business to be open, while those making home deliveries also considered nighttime deliveries to be inappropriate. One firm indicated that adjusting delivery times was difficult because it made many stops on any given route, and cooperation would have had to be secured at each stop.

Two survey participants changed terminal locations in the aftermath of the Earthquake. A company operating in San Jose moved to San Leandro. The move had been planned for the following January, but moved up to the day following the earthquake, because the new terminal had more room, and it was anticipated that additional trucks would be required. In the second case, a large

operator with multiple terminals tried shifting its San Leandro operations to its Santa Clara facility in order to avoid the need for transbay trips. This measure failed to save time or money, largely because of the congestion on Highway 101. Consequently, operations were shifted back to San Leandro.

In light of the higher costs incurred by truckers during the post-earthquake period, rate adjustments would seem to have been a logical response. The results of the interviews suggest otherwise, however. Only two respondents made any reference to rate adjustment as a possible response. A common carrier noted that any rate adjustment would have had to be approved by the California Public Utilities Commission, and that this required hiring a rate consultant to handle the paperwork at a cost of \$1000. Furthermore, this firm indicated that the highly competitive conditions in the industry made them reluctant to raise prices for fear of losing business. Another carrier, who operated on a contract basis and was therefore exempt from PUC regulation, did impose some surcharges to reflect greater distances, but did not charge for extra time resulting from increases in congestion.

Demand

Very few comments were made concerning the impact of the earthquake on demand for trucking service. Demands for certain emergency supplies, such as water, were anticipated and responded to by the grocery chain within hours of the earthquake. Another

respondent noted that, in the two days after the earthquake, business was down about 60 per cent but returned to normal levels a few days later. In another case, the only noted effect on demand was that certain customers changed delivery locations.

Otherwise, demand changes appeared to be small enough that they were either obscured by random variations to which the firms were accustomed, or by the more marked changes in the ability of truckers to handle demand. In any event, aside from the cases just noted, there is no indication of that urban freight demand changed significantly as a result of the earthquake.

Performance

Few of the survey participants were willing to quantify the impact of the earthquake on their overall efficiency or profitability. One firm stated that productivity declined by one-third while the Bay Bridge was closed and 10 per cent after it opened. A second firm indicated that prior to the earthquake, it had averaged 21 stops per route, and that this had dropped to 17-18 afterward. Assuming that times to travel the routes were similar, this implies a 15-20 per cent drop in productivity. Another operator said that payroll was up 20 per cent for the week after the earthquake, and 12 per cent thereafter, but that much of this was the result of paying drivers a nighttime differential, not additional hours. Four other operators, as well as the single non-

operator, reported that the overall performance impact of the earthquake was minimal.

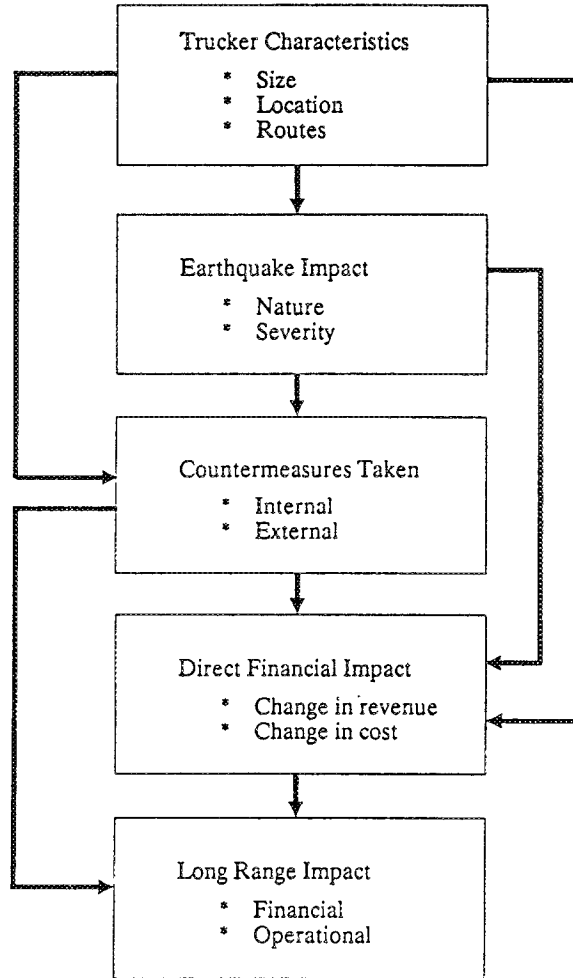
III. SURVEY

Approach

The responses of participants in the exploratory study indicated a fairly wide range of experiences in terms of the nature and severity of earthquake impact. These responses were used to develop a more formal and closed-ended survey for administration to a larger and more representative cross-section of Bay Area truckers.

The conceptual model on which the survey is based is shown in Figure 1. Truck operators are assumed to have a set of characteristics that affect the severity of earthquake impact and their ability to make adaptations to mitigate these impacts. Severity of impact depends on "exposure" of the operator to the damaged and indirectly affected transportation arteries, exposure to property damage based on the location of the operator's terminal, and the other characteristics including size of firm and the nature of its business. The responses of the firm to the earthquake in turn depend on the nature and severity of impacts, its general ability and willingness to respond to changes in its

Figure 1
Conceptual Model



environment, and its ability and willingness to cooperate with outside parties--other truckers, customers, government agencies--when this is necessary to institute the desired changes. The direct financial impact of the earthquake depends on its severity of impact and the effectiveness of the adaptations undertaken in response. Finally, any lasting effects will depend upon financial impact and on adaptive responses that remain in effect even after the specific stimulus for instituting them has ended.

The survey developed from this model is shown in Figure 2. Its sections follow the conceptual framework quite closely. The categories of impact and response included in the survey were based primarily on the information gathered in the exploratory study. Adaptations were divided into two groups, based upon whether they could be undertaken unilaterally or required the cooperation of other parties. (Below, we will term the former "internal countermeasures" and the latter "external countermeasures".) The questions concerning adaptation also asked whether specific responses were still in effect.

The sampling frame for the survey consisted of a list of 327 members of the California Trucking Association (CTA) whose business address was in one of the nine Bay Area counties, or Santa Cruz. The CTA provided a list of 629 firms located in northern California from which the firms located in the 10 counties were identified. Targets for the survey were drawn randomly from this set.

Effects of Bay Area Earthquakes on Urban Goods Movement
 ITS-Project of Prof. Mark H. Hansen (EARTHMS, 01/24/90-Jac)

SURVEY QUESTIONNAIRE

done by the Institute of Transportation Studies at the University of California in Berkeley in cooperation with the California Trucking Association.

Dear Mr. _____
 We would gratefully appreciate if you could fill out this survey for our project on Urban Goods Movement. Thank you very much for trucking in with us.

ITS-Jacob Sutter (415) 642-1694

Company: _____

Trucking Authority: _____

Major Goods Shipped: _____

1) Prior to the earthquake, approximately what proportions of your runs involved

| | none | 0-25% | 25-50% | 50-75% | >75% |
|----------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Bay Bridge | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Cypress structure | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Embarcadero Freeway | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| San Rafael Bridge | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Golden Gate Bridge | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| San Mateo Bridge | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Dumbarton Bridge | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Highway 17 | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Santa Cruz mountains | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

2) Please assess the impact of the earthquake on your operations by marking the answers with little or none 1 moderate 2 severe 3

| | | | |
|----------------------------|--------------------------|---------------------------|--------------------------|
| More circuitous routing | <input type="checkbox"/> | Overloaded phone lines | <input type="checkbox"/> |
| Greater congestion (delay) | <input type="checkbox"/> | Inefficient dispatching | <input type="checkbox"/> |
| Equipment damage | <input type="checkbox"/> | Drop in load size average | <input type="checkbox"/> |
| Loss of customers | <input type="checkbox"/> | | <input type="checkbox"/> |
| Gain of customers | <input type="checkbox"/> | | <input type="checkbox"/> |

3) Below is a list of actions taken by some truck operators in response to the aftermath of the earthquake. Please indicate the actions you took, and whether they are still in effect.

| | Action after EQ | Action still in effect |
|--|--------------------------|--------------------------|
| Rerouted to avoid congestion | <input type="checkbox"/> | <input type="checkbox"/> |
| Rescheduled to avoid congestion | <input type="checkbox"/> | <input type="checkbox"/> |
| Increased use of driver overtime | <input type="checkbox"/> | <input type="checkbox"/> |
| Hired additional drivers | <input type="checkbox"/> | <input type="checkbox"/> |
| Increased truck load through consolidation | <input type="checkbox"/> | <input type="checkbox"/> |
| Reduced frequency of delivery and pickup | <input type="checkbox"/> | <input type="checkbox"/> |
| Stopped service to certain areas | <input type="checkbox"/> | <input type="checkbox"/> |
| Used different trailers and trucks | <input type="checkbox"/> | <input type="checkbox"/> |

4) Did you work closer together with your customers, other carriers, unions, Task Force, Caltrans, local authorities and media to make additional adjustments ?

| | Action after EQ | Action still in effect |
|--|--------------------------|--------------------------|
| Delivered on off-business hours to clients | <input type="checkbox"/> | <input type="checkbox"/> |
| Coordinated deliveries with other carriers | <input type="checkbox"/> | <input type="checkbox"/> |
| Changed working hours agreed by union | <input type="checkbox"/> | <input type="checkbox"/> |
| Got exemption from delivery restriction | <input type="checkbox"/> | <input type="checkbox"/> |
| Had updated information on road conditions | <input type="checkbox"/> | <input type="checkbox"/> |

5) How much was approximately the cost impact on your business because of the earthquake (October 17 until November 18) ? How much are your overtime, fuel and damage costs in four weeks ?

| | Oct. 17 - Nov. 18 | Normal four weeks |
|------------------|-------------------|-------------------|
| Total | \$ | \$ |
| Overtime | \$ | \$ |
| Fuel | \$ | \$ |
| Damage | \$ | \$ |
| Loss of business | \$ | \$ |

Did you recover some of the financial loss and how ?

| | |
|-----------|--------------------------------|
| Total | \$ |
| Surcharge | \$ Insurance \$ |
| New rates | \$ Relief Funds \$ |

6) List anything else which is important to you in regard to the earthquake ? Any additional comments are welcome.

.....

Please send (or fax) the questionnaire to:
 Jacob Sutter, Institute of Transportation Studies,
 108B McLaughlin Hall, Berkeley, CA 94720; FAX (415) 642-1246

Figure 2 - Survey Questionnaire

The design and administration of the survey was strongly influenced by the expectation that obtaining an adequate response rate would be difficult. The experience with the exploratory study indicated that trucking management personnel, while sometimes very cooperative, are generally difficult to reach and have very little time to answer survey questions. In order to maximize the response rate, targeted companies could choose to respond to the survey in three different ways: by mail, phone, or fax. Mail and fax responses were encouraged, because this permitted more thoughtful responses. These options were found to have a lower response rate, however, encouraging more use of the phone option as the survey progressed. Unfortunately, the question concerning financial impact was found to be unworkable in a phone survey format, and was therefore dropped from most phone surveys.

Table 1 summarizes the outcomes of the contacts. Initial phone contact was established with 67 companies, only four of which refused to participate. However, of the 54 companies who agreed to participate either by mail or fax, 26 failed to return the completed survey. Overall, a total of 37 completed surveys were obtained, 27 by mail or fax and 10 by telephone (in one case, a company who failed to return a written survey was subsequently surveyed via telephone). The overall response rate exceeds 50 per cent, which is commonly considered a threshold at which self-selection bias does not undermine the validity of the results (Dillman, 1978).

Table 1
Response Rate Summary

| | Number | Per Cent |
|--|--------|----------|
| Total Contacted | 67 | 100.0 |
| Refused | 4 | 6.0 |
| Failed to Return | 26 | 38.8 |
| Completed Surveys Obtained by Mail or Fax | 27 | 40.3 |
| Completed Surveys Obtained by Phone | 10 | 14.9 |
| Total Completed Surveys | 37 | 55. |

Results

Tables 2 through 6 summarize the truckers' responses to the survey. Tables 2 and 3 present results for Question 1, concerning the level of use of major transportation facilities in the Bay Area, both those damaged by the Earthquake and those that survived intact. Table 1 reveals that the three most heavily used facilities are the Cypress Structure, the Bay Bridge, and Highway 17--all of which were closed after the earthquake. The Cypress Structure is by far the most commonly used, with 13 of the 37 respondents claiming that it is used on more than 50 per cent of their runs. The mean proportion of runs making use of the Cypress structure is 37 per cent. Far fewer truckers reported using the other facilities for 50 per cent or more of their runs. On the other hand, each of the facilities is used by a majority of respondents for at least some of their runs.

The results of Question 1 were used to calculate indexes of exposure for each trucker in the survey. The index was calculated by assigning to each of the possible answers the value at the mid-point of its range (for example, "0-25%" would be assigned a value 12.5%) and summing. The resulting number is an estimate of the number of facilities included in Question 1 that are encountered on an "average" run. Three indexes of exposure were computed in this way: one for facilities severely damaged by the Earthquake (Bay Bridge, Cypress Structure, Embarcadero Freeway, and Highway 17),

Table 2
Facility Usage of Sample Truckers (Per Cent of Runs)

| Facility | 0% | <25% | 25-50% | 50-75% | >75% | Mean % |
|----------------------|----|------|--------|--------|------|--------|
| Bay Bridge | 6 | 16 | 10 | 4 | 1 | 25 |
| Cypress Structure | 4 | 12 | 8 | 8 | 5 | 37 |
| Embarcadero | 12 | 19 | 4 | 2 | 0 | 14 |
| Highway 17 | 11 | 11 | 10 | 4 | 1 | 23 |
| Golden Gate Bridge | 14 | 17 | 5 | 0 | 1 | 17 |
| Dumbarton Bridge | 8 | 21 | 5 | 3 | 0 | 13 |
| San Mateo Bridge | 5 | 18 | 14 | 0 | 0 | 18 |
| San Rafael Bridge | 11 | 20 | 3 | 2 | 1 | 16 |
| Santa Cruz Mountains | 16 | 18 | 2 | 1 | 0 | 10 |

Table 3
Truckers' Exposure to Highway Facilities

| Exposure per Run | Damaged Facilities ¹ | Undamaged Facilities ¹ | Total Facilities |
|------------------|---------------------------------|-----------------------------------|------------------|
| 0.0-0.5 | 10 | 11 | 3 |
| 0.5-1.0 | 10 | 16 | 9 |
| 1.0-1.5 | 11 | 9 | 4 |
| 1.5-2.0 | 5 | 1 | 5 |
| 2.0-2.5 | 1 | 0 | 9 |
| 2.5-3.0 | 0 | 0 | 6 |
| 3.0-3.5 | 0 | 0 | 0 |
| 3.5-4.0 | 0 | 0 | 1 |
| Mean | 1.0 | 0.8 | 1.8 |

Notes

1. Damaged facilities include Bay Bridge, Cypress Structure, Embarcadero Freeway, and Route 17. All others are classified as undamaged.

one for the facilities that were not severely damaged, and one for both damaged and undamaged facilities.

Table 3 shows the results. The average trucker in the sample would have used 1.0 damaged facilities on an average run, as compared with 0.8 of the undamaged facilities. Six of the respondents had average runs on which the average number of damaged facilities used was closer to 2, while 10 had average runs involving less than 0.5 of the damaged facilities.

Table 4 summarizes answers to Question 2, in which the severity of different types of impacts from the earthquake was rated. The disruptions to the roadway network were clearly the most significant of earthquake impact for truckers. Over 75 per cent of respondents rated the impacts from circuitous routing and congestion to be moderate or severe, while all other effects were found to have little or no impact by the majority of respondents. Congestion problems were generally found to be somewhat greater than circuitry problems, with over half of respondents rating them as severe as contrasted with slightly over a third who gave a similar rating to circuitry impacts.

Of the remaining effects, overloaded phone lines and inefficient dispatching were found to have moderate or severe impacts by the largest proportions of respondents. Fourteen cited inefficient dispatching. This may be a consequence of dispatchers' lack of familiarity with the drastically changed travel conditions stemming from the earthquake. Alternatively, some respondent may have

Table 4
Truckers' Assessment Earthquake Impacts

| Impact | Little or No Impact | Moderate Impact | Severe Impact | Mean Impact Rating ¹ |
|-------------------------|---------------------|-----------------|---------------|---------------------------------|
| Circuitous Routing | 8 | 16 | 13 | 2.1 |
| Congestion Delay | 9 | 8 | 20 | 2.3 |
| Equipment Damage | 33 | 2 | 2 | 1.2 |
| Loss of Customers | 36 | 1 | 0 | 1.0 |
| Gain of Customers | 34 | 3 | 0 | 1.1 |
| Overloaded Phone Lines | 22 | 8 | 7 | 1.6 |
| Inefficient Dispatching | 23 | 12 | 2 | 1.4 |
| Reduced Loads | 34 | 2 | 1 | 1.1 |

Notes

1. Computed based on "Little or No Impact" = 1, "Moderate Impact" = 2, and "Severe Impact" = 3.

tended to ascribe the congestion and circuitry problems to the respondents may have tended to ascribe the congestion and circuitry problems to the dispatching process when in fact it was no less efficient than prior to the earthquake. Fifteen respondents rated overloaded phone lines as a moderate or severe earthquake impact. Presumably, this effect was important only in the immediate aftermath. Nonetheless, it is surprising that so many truckers considered overloaded phone lines a significant problem. This reinforces the significance of communications problems found in the exploratory study.

The vast majority of respondents reported little or no impact of the other categories included in Question 2. Four--roughly one in ten--suffered equipment damage. Even smaller minorities were affected by losses or gains of customers, or by reductions in the sizes of loads carried. Clearly, the impacts of the earthquake affected the ability of truckers to serve their customers much more significantly than their customer bases. This is consistent with the results of the exploratory survey.

Table 5 summarizes the internal countermeasures taken by truckers in response to the earthquake, as reported in Question 3. Three actions--rerouting, rescheduling, and increased use of driver overtime--were taken by a majority of respondents. Rerouting was by far the most common, with 33 respondents reporting it. Interpretation of this result is clouded by the question of whether it was actually undertaken to avoid congestion, as the wording of the

Table 5
Truckers' Internal Countermeasures

| Countermeasure | Not Taken | Taken, No Longer in Effect | Taken, Still in Effect |
|------------------------------------|-----------|----------------------------|------------------------|
| Rerouting to Avoid Congestion | 4 | 21 | 12 |
| Rescheduling to Avoid Congestion | 12 | 17 | 8 |
| Increased Driver Overtime | 16 | 14 | 7 |
| Hired Additional Drivers | 32 | 4 | 1 |
| Load Consolidation | 29 | 6 | 2 |
| Reduced Service Frequency | 24 | 9 | 4 |
| Stopped Service to Certain Areas | 23 | 14 | 0 |
| Initiated Service to Certain Areas | 34 | 1 | 2 |
| Used Different Equipment | 34 | 2 | 1 |

Notes:

1. The lower the class, the greater the size.

*Significant at .10 level.

**Significant at .05 level.

***Significant at .01 level.

question was intended to imply, or whether truckers who rerouted simply because of facility closures also reported this countermeasure. Two-thirds of the respondents also reported some re-scheduling to avoid congestion. Again, there is a question of whether respondents who rescheduled simply because their pre-earthquake schedules were no longer viable.

Increased driver overtime and curtailment of service to certain areas are the next most frequently cited countermeasures, with 14--38 per cent--of the respondents citing them. Not surprisingly, the temporary expedient of paying overtime was far more common than hiring additional drivers, a measure taken by only about 14 per cent of those surveyed. Other countermeasures reported by small but non-negligible proportions of respondents include efforts to reduce vehicle-miles through load consolidation (8 reporting) or reducing service frequency (13 reporting). Initiation of service to new areas and use of different equipment were the least common countermeasures, with three respondents citing each.

A question of some importance in this research is whether changes made as a result of the earthquake will persist. The survey was conducted about four months after the reopening of the Bay Bridge, long enough to give some indication of whether countermeasures adopted will be "permanent," but too short to be definitive in this regard, especially in light of the fact that the Cypress structure and Embarcadero Freeway remained closed at this time.

Of the countermeasures included in Question 3, only three remained in effect for a significant number of truckers at the time of the survey. Twelve respondents reported that rerouting continued. Interpretation of this result is again clouded by the ambiguity cited above. Eight of the 25 truckers reporting rescheduling as a countermeasure were continuing to use this strategy, as were seven of the 21 of those who made use of driver overtime. None of the other countermeasures remained in effect for a significant number of the truckers surveyed.

Table 6 summarizes the use of external countermeasures--those requiring the cooperation of others. Of the five such measures included in the survey, only two were used by a significant number of respondents. 14 truckers reported shifting deliveries to off-business hours, and a similar number reported using updated information on road conditions. In both of these cases, the majority of those reporting the countermeasure also reported that it was no longer in effect.

We now consider the answers to Question 5 of the survey, in which respondents were asked to estimate the financial impact of the earthquake on their operation during the subsequent month (that is, up until the reopening of the Bay Bridge). The question was posed as a comparison between cost and revenue results for that particular four-week period and those for an "average month." Also, the question asked for "best estimates" in order to encourage

Table 6
Truckers' External Countermeasures

| Countermeasure | Not Taken | Taken, No Longer in Effect | Taken, Still in Effect |
|--|-----------|----------------------------|------------------------|
| Off-business Hour Deliveries | 23 | 9 | 5 |
| Coordinated Deliveries | 36 | 1 | 0 |
| Changed Working Hours with Union Consent | 34 | 1 | 2 |
| Got Exemption from Delivery Restriction | 34 | 2 | 1 |
| Had Updated Information on Road Conditions | 23 | 10 | 4 |

prompt responses and discourage participants from postponing answering until the matter could be researched.

Usable responses to Question 5 were received on 22 of the 37 surveys. Actually, what is "usable" is a matter of interpretation. In several cases, the response was simply the word "none" scrawled across both columns. Additionally, in some cases, the estimate of total cost impact seemed inconsistent with the itemized (labor, fuel, and other) estimates. Finally, answers were given in different forms: sometimes as a percentage, sometimes as a difference, and sometimes (as requested) as separate dollar estimates for the post-earthquake and average month periods.

To standardize the results to a consistent format, it was decided to put them all on a percentage basis (for example, total cost was x per cent higher than that for an average month). In some cases, this could be done on the basis of the information provided in the survey, while in other cases it was necessary to use trucker financial information available from the California Truckers' Associations and the Public Utility Commission to make the conversion. Any reply that could be reasonably transformed into a percentage basis--including the scrawled "none"--was used.

Recognizing that the values are estimates to begin with, in some cases estimates based on the original estimates, and that the replies to Question 5 sometimes seemed to be internally inconsistent, it is important not to place too much stock in them. With this caveat, Table 7 summarizes the estimates of the impact on

Table 7
Truckers' Estimates of Revenue and Cost Impacts

| Pct. Change from "Normal" 4-Week Period | Cost | Revenue |
|---|------|---------|
| -31 to -50 | 0 | 0 |
| -21 to -30 | 0 | 2 |
| -11 to -20 | 0 | 3 |
| - 6 to -10 | 0 | 1 |
| - 1 to - 5 | 1 | 2 |
| 0 | 9 | 9 |
| 1 to 5 | 4 | 0 |
| 6 to 10 | 4 | 1 |
| 11 to 20 | 1 | 0 |
| 21 to 30 | 2 | 0 |
| 31 to 50 | 1 | 0 |
| Total | 22 | 18 |
| Mean | 7.1 | -5.3 |
| Std. Deviation | 12.1 | 10.2 |
| Std. Error | 2.6 | 2.4 |
| Minimum | - 1 | -30 |
| Maximum | 50 | 10 |

total cost and revenue. Among the 22 respondents for whom a cost impact estimate is available, the average value is 7 per cent. The standard deviation of the estimate is 12.1 per cent, yielding a standard error of the mean of about 2.6. These results suggest that the earthquake increased trucker costs between 4 and 10 per cent on average.

Among the 18 respondents to the revenue question, the average reported impact was -5.3 per cent, with a standard deviation of 10.2 and a standard error of the mean of 2.4. This implies an average revenue impact of between 3 and 8 per cent. Thus, it appears trucker revenue reductions and cost increases had roughly equal impacts upon truckers' operating profits.

Correlation Analysis

The conceptual model depicted in Figure 1 implies the existence of correlations between different variables in the survey data set. Given the nature of the data set, in particular the large number of ordinal variables it includes, non-parametric methods are the most appropriate for measuring these correlations. Also, because the ordinal variables have relatively few categories, it is necessary to use a technique which can handle many "ties" in which many observations have the same value for some variable. The preferred non-parametric correlation measure for such circumstances is Kendall's tau (Blalock, 1979), and it is what we use here.

The first set of correlations we explored were between characteristics of the trucking firms themselves and the exposure to facilities affected by the earthquake. The two trucking firm characteristics considered are firm size and distance from the firm's local base of operations to the epicenter of the earthquake. We hypothesize that firms located closer to the epicenter will have higher levels of exposure. We also hypothesize that larger firms, who tend to serve longer routes, will have lower levels of exposure to Bay Area roadway facilities affected by the earthquake.

The size of the company would ideally be measured by annual revenue, but this data could not be obtained for many of the firms in the survey. Instead, ICC revenue class was used as an indication of size. Three classes, corresponding to annual revenues of over \$5 million, \$1-5 million, and under \$1 million, are defined in the ICC scheme. These are defined as classes I, II, and III, respectively. These same classes define the ordinal variable used for our analysis. When interpreting correlations involving size class, note that a higher class implies a smaller size.

The Kendall rank-order correlations between firm size and distance from the epicenter on the one hand and level of use of major damaged and undamaged roads and bridges on the other are presented in Table 8. Neither of our hypotheses is confirmed. Correlations between size class and exposure are statistically insignificant, while the correlations between distance from epicenter and exposure are marginally significant ($\tau = .22$, $p < .05$).

Table 8
 Kendall's Rank Correlations
 Size Class, Miles to Epicenter, and Exposure

| | Miles to Epicenter | Exposure - Damaged <u>Facilities</u> | Exposure - Undamaged <u>Facilities</u> |
|-------------------------------------|-----------------------|--|--|
| Size Class ¹ | .33*** | -.05 | .14 |
| Miles to Epicenter | | .22** | .19* |
| Exposure - Damaged Facilities | | | .46*** |

Notes:

- 1. The lower the class, the greater the size.
- *Significant at .10 level.
- **Significant at .05 level.
- ***Significant at .01 level.

for damaged facilities; $r = .19$, $p < .10$ for undamaged facilities) but with the opposite sign from what was anticipated. These unanticipated positive correlations may derive from the distance of the earthquake epicenter from the core of the region, where the bulk of roadway facilities included in Question 1 are located.

Statistically significant correlations between distance from epicenter and carrier class ($r = .33$, $p < .01$), and between level of use of damaged and undamaged facilities ($r = .65$, $p < .01$), were obtained. The former result was unexpected, but inspection of the data reveals that larger firms tend to be located south of San Francisco and Oakland, while many of the Class III firms are located north of these cities. This may reflect the greater volume of business in markets connecting the Bay Area with Southern California. The latter correlation implies that truckers who made extensive use of the major highway facilities damaged by the earthquake also relied heavily on the major undamaged highway facilities. In other words, the truckers with the greatest exposure to damaged facilities on the Bay Area freeway system are generally those who make extensive use of that system as a whole. Those with less exposure, on the other hand, presumably use routes involving more local streets and arterials.

We now consider correlations between trucking firm characteristics, level of use of damaged and undamaged facilities, and the firms' assessment of the impact of the earthquake upon their operations. Table 9 summarizes the results, including only those

Table 9
Kendall's Rank Correlations
Impact Severity and its Determinants

| | <u>Circuitors'</u> <u>Ratings</u> | <u>Greater</u> <u>Congestion</u> | <u>Inefficient</u> <u>Dispatching</u> | <u>Overloaded</u> <u>Phone Lines</u> | <u>Total</u> <u>Severity</u> <u>Ratings</u> |
|----------------------------------|--------------------------------------|-------------------------------------|--|---|---|
| Size Class ¹ | .06 | -.07 | .07 | -.14 | -.07 |
| Miles to Epicenter | .24** | .14 | -.01 | -.18* | .08 |
| Exposure-Damaged Facilities | .55*** | .52*** | .32*** | .08 | .48*** |
| Exposure-Undamaged Facilities | .38*** | .44*** | .17** | .22** | .39*** |

Notes:

1. The lower the class, the greater the size.
- *Significant at .10 level.
- **Significant at .10 level.
- ***Significant at .05 level.

impact rated moderate or severe by significant numbers of respondents. Neither firm size nor distance from earthquake epicenter appear to have much influence on impact severity. The only exceptions are the positive correlation ($r=.24$, $p<.05$) between distance to epicenter and routing circuitry and the negative one ($r=-.18$, $p<.10$) between the distance variable and overloaded phone lines. The former result may derive from the correlation between the distance variable and the exposure variables, which in turn (as discussed below) are correlated with impact severity. The correlation between distance and overcrowded phone lines is more likely an indication of a true relationship. Phone traffic density relative to system capacity is expected to be highest in the heavily damaged areas near the epicenter.

Exposure to damaged and undamaged facilities are highly correlated with impact severity, with the correlations involving exposure to damaged facilities generally higher than those involving exposure to undamaged ones. This pattern holds for circuitous routing impact ($r=.55$, $p<.01$ for damaged facilities versus $r=.38$, $p<.01$ for undamaged ones), congestion impact ($r=.52$, $p<.01$ versus $r=.44$, $p<.01$), and the total severity rating obtained by summing the ratings for all the categories ($r=.48$, $p<.01$ versus $r=.39$, $p<.01$). It is reasonable that those firms forced to use new routings for the largest percentage of their runs would experience the most severe impacts. The correlations between impact severity and exposure to undamaged facilities may derive from the

correlations between the two exposure variables. Alternatively, these correlations may indicate that the increased traffic on the undamaged facilities was itself a major source of impact for those truckers making the most extensive use of them.

Table 10 gives the correlations between the different categories of impact for which significant numbers of moderate and severe ratings were obtained. The circuitry and congestion impacts are very highly correlated ($r=.72$, $p<.01$). These two variables are also highly correlated with inefficient dispatching, reflecting the greater demands placed on the dispatching system in the face of severely degraded road conditions. Severity of impact from overloaded phone lines is also correlated with inefficient dispatching, suggesting that the latter was in some cases a consequence of communications problems.

We now turn to relationships involving countermeasures reported by truckers in Questions 3 and 4. Recall that the countermeasures included in Question 3 are those which can be undertaken unilaterally, while the countermeasures in Question 4 require some degree of cooperation between the individual firm and others, either other truckers, labor, customers, or government agencies. We refer the former as internal countermeasures, and the latter as external countermeasures.

We hypothesize that the countermeasures taken will be influenced by (1) the size of the trucking firm (2) the severity of impact of the earthquake on the firm's operations and (3)

Table 10
Kendall's Rank Correlations
Impact Severity by Category

| | <u>Greater Congestion</u> | <u>Inefficient Dispatching</u> | <u>Overloaded Phone Lines</u> |
|----------------------------|-------------------------------|------------------------------------|-----------------------------------|
| Circuitors Ratings | .72*** | .45*** | .29*** |
| Greater Congestion | | .38*** | .13 |
| Inefficient Dispatching | | | .21** |

Notes:

1. The lower the class, the greater the size.
- *Significant at .10 level.
 **Significant at .05 level.
 ***Significant at .01 level.

the proclivity of the firm to respond to these impacts. To test these general relationships, we begin by considering correlations between the total numbers internal and external countermeasures reported undertaken. Table 11 shows the results. No statistically significant correlations relating total countermeasures to trucker size class were found. Apparently, the scale of operation did not influence the ability or desire of truckers to undertake countermeasures. On the other hand, there is a strong relationship between the overall severity of impact (as measured by summing the responses to Question 2) and the number of countermeasures. The relationship is somewhat stronger for the internal measures than for the external ones ($r=.61$ versus $r=.44$, $p<.01$ in both cases), suggesting that the latter were more influenced by exogenous factors such as the ability to secure the required cooperation from other parties.

Finally, the number of internal countermeasures was positively correlated with the number of external ones ($r=.39$, $p<.01$). This is consistent with the hypothesis that firms exhibit a general proclivity toward or against responding to changes in their environment. However, the possibility that this correlation results from the mutual correlations between severity of impact and the two countermeasure variables, rather than from the hypothesized proclivity variable, cannot be ruled out.

Table 12 presents correlations between specific internal countermeasures, severity of specific impacts, and trucker size. As

Table 11
Kendall's Rank Correlations
Size, Severity of Impact and Number of Countermeasures

| | <u>Number of Internal Countermeasures</u> | <u>Number of External Countermeasures⁴</u> |
|--|---|---|
| Size Class ¹ | -.14 | -.05 |
| Total Impact Severity ² | .61*** | .44*** |
| Number of Internal Countermeasures ³ | | .39*** |

Notes:

1. The lower the class, the greater the size.
 2. Sum of severity ratings (1 = little or none, 2 = moderate, 3 = severe) from question 2.
 3. Countermeasures listed in question 3.
 4. Countermeasures listed in question 4.
- *Significant at .10 level.
 **Significant at .04 level.
 ***Significant at .01 level.

Table 12
Kendall's Rank Correlations
Size Class, Impact Severity, and Internal Countermeasures

| | <u>Rerouting</u> | <u>Rescheduling</u> | <u>Driver Overtime</u> | <u>Hired Drivers</u> | <u>Load Condition</u> | <u>Reduced Service Frequency</u> | <u>Stopped Service to Certain Areas</u> |
|-------------------------------|------------------|---------------------|------------------------|----------------------|-----------------------|----------------------------------|---|
| Size Class ¹ | -.24*** | -.08 | .00 | -.11 | -.09 | .00 | -.15 |
| Circuitry Impact | .48*** | .63*** | .71*** | .23*** | .24** | .15 | .16 |
| Congestion Impact | .48*** | .68*** | .61*** | .33*** | .11 | .13 | .18* |
| Inefficient Dispatching | .26*** | .30*** | .45*** | .51*** | .02 | .38*** | .23** |
| Overloaded Phone Lines Impact | .13*** | .22** | .29*** | -.18*** | -.05 | -.39*** | .25* |

Notes:

1. The lower the class, the greater the size.
- *Significant at .10 level.
- **Significant at .10 level.
- ***Significant at .05 level.

before, size appears to have little influence on the nature countermeasures undertaken. The only exception is rerouting, a countermeasure which was less common among small truckers ($r = -.24$, $p < .01$). This could reflect the tendency of smaller firms to have shorter routes and therefore fewer routing alternatives.

The most common internal countermeasures--rerouting, rescheduling, and use of driver overtime--are strongly correlated with the most widely reported impacts: increased circuitry and increased congestion. The use of additional labor through overtime or new hiring was also strongly encouraged when dispatching was inefficient, as was the reduction in frequency of delivery and pickup.

Correlations between severity of specific impacts and the use of widely reported external countermeasures, shown in Table 13, are somewhat weaker than those obtained for the internal countermeasures. Truckers reporting stronger circuitry impacts were more likely to adjust schedules of unionized workers, and to obtain exemptions from delivery restrictions. The use of these countermeasures were less strongly correlated with severity of congestion impact, perhaps because this impact provided a less tangible basis for obtaining the necessary cooperation. Inefficient dispatching is associated with increased use off-business hour delivery times.

Table 13
Kendall's Rank Correlations
Size Class, Impact Severity, and External Countermeasures

| | <u>Off-business Hour Deliveries</u> | <u>Had Updated Road Information</u> |
|-----------------------------------|---|---|
| Size Class ¹ | .00 | -.08 |
| Circuitry Impact | .15 | .28*** |
| Congestion Impact | .15 | .18*** |
| Inefficient Dispatching Impact | .34*** | .23** |
| Overloaded Phone Lines Impact | .09 | .21** |

Notes:

1. The lower the class, the greater the size.

- *Significant at .10 level.
- **Significant at .05 level.
- ***Significant at .01 level.

Regression Analysis of Cost and Revenue Impact

Severity of impact, countermeasures, and firm characteristics are all expected to influence financial impact. In analyzing these effects, it was decided to use multivariate regression in order to have the best chance of isolating the individual effects of the different variables. The dependent variables in the regression analyses were per change in cost and revenue. For independent variables, total impact severity (attained by summing the answers to Question 2), total internal countermeasures (based on Question 3), total external countermeasures (based on Question 4), and size class were used.

The results of the regression analysis are summarized in Table 14. The coefficient on impact severity is positive and marginally significant for the cost model, and negative and highly significant for the revenue model. Thus, it appears that reported impacts did translate into higher costs and reduced revenues. The number of external countermeasures used, and the size class, are also significant (at the .05 level) in the revenue impact regression. Apparently, the more external countermeasures, the more severe the revenue impact. The most straightforward interpretation is that external countermeasures (at least certain ones) has a deleterious effect on business volumes, but it is also possible that it is the conditions prompting these countermeasures, and not the countermeasures themselves, that lead to these negative effects.

Table 14
Regression Analysis of Cost and Revenue Changes

| | Dependent Variable | |
|--------------------------------|--------------------|---------------------|
| | % Change in Cost | % Change in Revenue |
| Total Impact Severity | 2.8* | -2.4** |
| Total Internal Countermeasures | -1.3 | 1.8 |
| Total External Countermeasures | 2.0 | -5.1** |
| Size Class ¹ | 0.2 | -5.9** |
| R-Square (Adj.) | .22 | .68 |
| No. of Observations | 22 | 18 |

Notes:

1. The lower the class, the greater the size.

* Significant at .10 level.

** Significant at .05 level.

***Significant at .01 level.

The negative coefficient on size class implies that the smaller the company (i.e. the greater the size class), the more negative the revenue impact. This is the first and only case in which size differences appear to play a significant role in influencing the impact of the earthquake on truckers. Greater availability of spare equipment and additional labor on the part of larger firms may account for this result. Another reason may be that the large truckers in the sample do a greater share of their business outside of the Bay Area. This theory, however, would imply an association between size and exposure (based on Question 1) when in fact no such association was found (see Table 8).

Neither size class nor the number of countermeasures undertaken were found to be significant in the cost regression. Of the variables considered, only overall impact severity appears to influence how the earthquake affected costs.

These results do not give any indication that truckers who took numerous countermeasures in response to the post-earthquake environment fared better than those who took fewer remedial actions, even when the impact severity is controlled for. This suggests that countermeasures were largely ineffective in limiting the financial impact of the earthquake. This finding must, however, be qualified by the high correlation between impact severity and the number of countermeasures, as well as the relatively small number of observations on which the analysis is based.

An attempt was made to analyze these relationships more fully

by including specific impacts and countermeasures. This turned out to be impossible because of the small number of observations for which the necessary data were available.

IV. CONCLUSIONS AND RECOMMENDATIONS

The transportation disruptions resulting from the Loma Prieta earthquake had substantial impacts on Bay Area truckers. Like other roadway users, they were forced to contend with more circuitous routings and heightened levels of congestion. Unlike others, however, truckers' businesses and livelihoods depend directly on the roadway system. Reducing travel, or shifting to alternative modes, may mean some restructuring of activities and loss of convenience for Bay Area commuters. For Bay Area truckers, on the other hand, these options were either completely impossible or highly detrimental.

Bay Area truckers were thus forced to make other adaptations. In the main, these consisted of using alternate routes and adjusting schedules to avoid congestion and reflect the degraded travel conditions. Increased use of labor--particularly in the form of overtime--was also common. These fairly obvious and direct responses were the primary mechanisms by which the impact of the earthquake was absorbed. More dramatic changes--dropping of service off-hour delivery times, load consolidation--were the exception rather than the rule. Even more rare--indeed virtually non-

existent--were efforts to capture rising costs through rate adjustments.

The incidence of impact and response followed predictable patterns. Truckers with the greatest exposure, as measured by level of use of facilities damaged or indirectly affected by the earthquake, reported the most severe impacts. Likewise, those truckers who reported the most severe impacts also reported the greatest number of countermeasures. Respondents' assessments of impact severity also correlated with their estimates of cost and revenue changes resulting from the earthquake. On the other hand, our results do not support the hypothesis that countermeasures were effective in mitigating the cost and revenue impacts.

These latter provide the main basis for quantifying the impact of the earthquake on Bay Area truckers. Despite the numerous uncertainties surrounding the quality of the individual estimates, they collectively support two conclusions. First, the average cost increase for the month following the earthquake was in the 4-10 per cent range, with a revenue decrease of a similar magnitude. Second, there was wide variation in these impacts. There were indeed firms whose costs jumped by as much as 40 or 50 per cent, but offsetting these were a large number of operators reporting minimal impact. Revenue impact variation was somewhat less, but still substantial.

Aside from exposure, the only variable found to affect the degree of impact is size class, with smaller truck operators tending to experience greater revenue reductions (no such trend was

found for costs). Given the large number of reports of inefficient dispatching as a moderate to severe impact, the quality of the dispatching system may be another such variable, although how such quality might be measured is not apparent. There may well be other variables that influenced the ability of truckers to cope in the post-earthquake period. Partly from oversight, and partly from tight constraints on the length of the survey, other factors that may have been relevant in this context were not addressed.

The persistence of some of the reported countermeasures over the several months between the reopening of the Bay Bridge and the time of the survey suggests that they may be adopted on a permanent basis. The earthquake may have forced operators to experiment with innovations viewed as too risky or unpromising beforehand, some of which were found sufficiently effective to "stick." Or, the innovations could have been long intended, but prior to the earthquake blocked by organizational inertia. In any event, it appears that the earthquake did serve as a catalyst for change, some of which will be of permanent benefit.

Are there lessons from all of this that can help us plan for the "big one"? While the benefits of seismic upgrading for bridge and highway facilities may be evident without this study, perhaps it adds some further weight in their favor. Beyond this, planning efforts should probably focus on supplies of the two commodities that Bay Area truckers found in shortest supply in the earthquake aftermath: labor and information. The availability of a reserve

corps of drivers could prove valuable to firms who would otherwise face the unpleasant choice between reducing operations and hiring unqualified individuals. The ability to grant temporary exemptions to legal maximums for daily and weekly driver hours could also be useful in this regard. With regard to information, the need is twofold. First, information flow within the Bay Area is required to help truck operators determine the local road and accessibility conditions. Information flow between the affected area and truckers outside of it must be improved so that shipments into the area are not unnecessarily disrupted by driver fears and uncertainties.

These suggestions notwithstanding, Bay Area truckers demonstrated an impressive ability to function when faced with a drastically degraded roadway infrastructure. This ability reflects an underlying strength of the technology--its use of an ubiquitous guideway system with a high degree of route redundancy--and of an industry accustomed to the strong demands of a competitive marketplace. Barring the obvious threats posed by widespread damage to plant and equipment, the urban goods sector can be expected to show similar resilience in future calamities.

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