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# ECONOMIC IMPACT OF LIFELINE DISRUPTION IN THE JANUARY 17, 1995 HANSHIN-AWAJI EARTHQUAKE

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## ABSTRACT

Lifeline failures in the January 17, 1995 Hanshin-Awaji earthquake disrupted the economy of the Kobe region with a severity previously unexperienced in any modern urban area. The potential for such catastrophic lifeline failures in a major seismic event also exists in the U.S.; however, recent disaster experiences in the U.S. do not provide a sufficient basis for estimating the likely economic loss in such events. This paper examines the economic impact of the Hanshin-Awaji earthquake on the region in general, and the losses induced by lifeline disruption in particular. It begins with a brief survey of damage, disruption, and economic recovery in the disaster. A model for evaluating the economic impact of multiple lifeline disruption is then developed and estimated with data from the first 10 weeks after the disaster. The relative contributions of different types of damage or disruption to economic impact are evaluated. The significance of damage to the Port of Kobe is then discussed with regard to both short-run and long-run impact. Results can potentially be applied to supporting mitigation and disaster recovery decisions in the U.S.

## KEYWORDS

economic, impact, loss, recovery, Hanshin-Awaji earthquake, Kobe, lifeline, port

## INTRODUCTION

The Hanshin-Awaji earthquake that struck Japan on January 17, 1995 represents one of the most severe urban earthquake disasters ever experienced in an industrialized nation. The earthquake devastated the port city of Kobe, an urban center of some 1.5 million people, as well as several other neighboring cities within a narrow, densely populated strip of land some 3 km wide located between the Rokko Mountains and Osaka Bay. Over 6,300 people were killed, 41,000 injured, and 500,000 displaced from their homes by this disaster (Goltz 1996). Property damage exceeded 100 billion dollars.

From an economic impact point of view, the significance of this earthquake lies not only in the magnitude of the losses but also in the occurrence of many phenomena not experienced in recent moderate U.S. disasters. The Port of Kobe was almost completely shut down as a result of the earthquake. For certain industries, geographic concentration caused extreme vulnerability to loss. In addition, the massive, sustained disruption of virtually all of the major lifelines was unprecedented and produced substantial business interruption losses.

This paper examines the economic impact of the earthquake on the region in general, and the losses caused by lifeline disruption in particular. Lifelines are broadly defined here to include not only the major utilities, but also highway, railway, and port transportation systems. Data were collected primarily during two visits to Japan in May and July, 1995. Following a discussion of damage, disruption, and recovery in the disaster, the economic impact of lifeline service disruption is examined. A model based on data for the first 10 weeks after the disaster is presented, and the longer term impact of port disruption is considered.

## DAMAGE, DISRUPTION AND RECOVERY

### Direct Damage

Physical damage in the Hanshin-Awaji earthquake has been estimated at over 10 trillion yen, virtually all of which occurred in Hyogo Prefecture. This amounts to roughly $100 billion, or five times the direct damage in the January 17, 1994 Northridge earthquake. Table 1 shows that about four-sevenths of this damage (59 percent) pertained to buildings, while two-sevenths (28 percent) accrued to infrastructure and the remainder to other property. The Port of Kobe alone suffered over 10 billion dollars worth of damage. On a per capita basis, damage in the Hanshin and Northridge earthquakes represents approximately $18,100 and $2,300 per person in Hyogo Prefecture and Los Angeles County, respectively.

**Table 1. Direct Damage in the Hanshin-Awaji Earthquake[(a)]**

| Damage type | Damage Cost<br>Billion yen | Damage Cost<br>Billion dollars[(b)] | Percent |
|---|---|---|---|
| *Buildings* | *5,899* | *59.0* | *59 %* |
| Residential | 2,104 | 21.0 | |
| Nonresidential | 3,794 | 37.9 | |
| *Infrastructure* | *2,845* | *28.4* | *28 %* |
| Port | 1,040 | 10.4 | |
| Highways | 600 | 6.0 | |
| Railways | 353 | 3.5 | |
| Other | 852 | 8.5 | |
| *Other property* | *1,263* | *12.6* | *13 %* |
| TOTAL | 10,007 | 100.1 | 100 % |

notes: (a) source: Hyogo Prefectural Government
(b) using exchange rate of 100 yen = 1 dollar

Lifeline damage and disruption in the earthquake was severe. Major disruption was suffered to electric power, water and natural gas services, as well as to highway, railway, and port transportation accessibility. Three major expressways in the region, including the Hanshin Expressway, suffered extensive bridge damage and were closed, causing severe congestion on adjacent surface streets and virtual paralysis of the region in the first two to three weeks following the disaster. Restoration proceeded most quickly for telecommunications, followed by electricity, water, gas, and transportation in that order. Including temporary repairs for emergency restoration, complete recovery of service took about one week for electricity and two months for water and gas. Ten weeks were required to restore commuter rail service between Kobe and Osaka on the first of three major lines. Route 5 of the Hanshin Expressway reopened for traffic 6 months after the earthquake, while Route 3 of the Expressway is anticipated to remain closed until fall, 1996.

Generally speaking, the central and western wards of Kobe City suffered the greatest lifeline damage. In addition, the restoration of lifeline service also proceeded from areas of least damage inward to areas of greatest damage. For example, five weeks after the earthquake, the heavily impacted Nagata Ward of Kobe City had water restored to only about 60 percent of homes and businesses while service had been completely restored to Takarazuka, a less heavily impacted city to the east of Kobe.

## Economic Impact and Recovery

The economic impact of the Hanshin-Awaji earthquake is still being felt, and full recovery will require many more months, if not years. Information available as of this writing provide some indication of the magnitude and complexity of this impact. In the first few weeks after the earthquake, economic activity in the impacted region was extremely low. For example, in February, department store sales in Kobe City were only 10 percent of the same month in the previous year (Kobe City Government 1995). Table 2 shows the extent of impact and recovery several months after the disaster according to a variety of measures.

**Table 2. Economic Impact and Recovery[a]**

| Index[b] | Month / Year (months after disaster) | Percent of Month in Previous Year |
|---|---|---|
| *Economic Functionality* | | |
| Businesses operational | 7/95 ( 6 months) | 64 % |
| Synthetic shoe manufacturers operational | 11/95 (10 months) | 97 % |
| Tourist attractions opened (Kobe city) | 12/95 (11 months) | 83 % |
| Hotels opened (Kobe city) | 12/95 (11 months) | 91 % |
| *Production Levels* | | |
| Department store sales (Kobe city) | 11/95 (10 months) | 65 % |
| Container cargo through Kobe Port | 11/95 (10 months) | 71 % |
| Synthetic shoe manufacturers | 11/95 (10 months) | 50 % |
| *Employment* | | |
| Persons on unemployment assistance | 10/95 ( 9 months) | 121 % |
| Workers at Kobe Port | 11/95 (10 months) | 87 % |
| *Reconstruction* | | |
| Housing starts | 7/95 ( 6 months) | 96 % |
| " " | 11/95 (10 months) | 170 % |

note: (a) source: Nikkei Weekly, 1/15/96.
(b) assumed to pertain to total impacted region except where otherwise noted.

Although these figures are not comprehensive, they do indicate several interesting patterns. In terms of economic functionality, six months after the earthquake, slightly less than two-thirds of businesses had reopened. Toward the end of the year, other measures show that functional recovery appears to be nearing completion. On the other hand, production levels appear to be recovering more slowly. This is starkly illustrated by the case of the synthetic shoes manufacturing industry which suffered severe damage from shaking and fire following earthquake. Ten months after the disaster, the industry association reported that fully 97 percent of the manufacturers had reopened, but business volume remained at only 50 percent of the previous year. Industry leaders attribute this in part to a loss of market share over the recovery period (Nikkei Weekly 1/15/95). While this industry may represent an extreme case, other reports also indicate that business activity may require more than a year to fully recover. One survey conducted at the end of March found that only 74 percent of businesses expected sales to return to normal within a year (*White Paper*, 1995). In addition, table 2 shows that unemployment, at 21 percent above normal, remains serious.

Reconstruction demand will constitute an important element of the economic recovery. To the extent that disaster assistance funds come from outside the region, this will provide a net positive boost to the regional economy. What is interesting to note, however, is the lag time between the occurrence of the disaster and full-fledged reconstruction activity. Housing starts six months after the earthquake were still below levels in the previous year. This is consistent with the author's personal observations that while debris removal had largely been accomplished six months after the earthquake, many residential lots remained cleared and little rebuilding could be seen. The delay is attributable in part to low levels of earthquake insurance, city reconstruction planning time, and other financial and legal constraints. Housing reconstruction did, however, pick up in the latter half of the year. Ten months after the earthquake, housing starts reached 70 percent above previous year levels.

## IMPACT OF LIFELINE SERVICE DISRUPTION

### Lifeline Impact Model

As mentioned above, the extent of lifeline disruption in this disaster greatly exceeded that experienced in recent U.S. earthquakes. Analysis was conducted to investigate the short-run impact of this lifeline disruption on regional economic activity. The objectives of this analysis were: (1) to evaluate the contribution of lifeline disruption to the total direct and indirect regional economic loss; (2) to compare the impact across different types of lifelines; and (3) to develop a viable methodology for estimating lifeline disruption impact in other urban earthquake disasters. The methodological approach consisted of developing a multivariate regression model to explain post-earthquake reductions in economic activity as a function of losses in various lifeline services. The model controls for factors other than lifeline disruption that also reduce economic activity. The approach captures two important dimensions of the economic impact: the geographic variation within the impacted region in terms of initial damage as well as subsequent lifeline restoration, and contrasts in the restoration time required for different lifelines.

The scope of the analysis was largely determined by the availability of data. The analysis is conducted on a weekly basis and is limited to 10 weeks following the earthquake. Since sufficient economic data are as yet unavailable, electric power consumption was used as a proxy for economic activity. Because electric power not fully restored until one week after the earthquake, the first week's observations are excluded from the analysis. The study region comprises Kobe City and 5 neighboring cities (Ashiya, Nishinomiya, Takarazuka, Itami and Amagasaki) which were significantly impacted by the earthquake. The region is divided into 6 electric power service areas according to local utility company definitions.

The analytical model explains economic activity as a function of lifeline service availability, controlling for other earthquake-related damage. The latter is approximated by the availability of undamaged structures or buildings in a particular area. All variables are expressed as a percent of normal levels. The general format of the model is as follows:

$$E_{s,t} = \alpha + \beta_1 G_{s,t} + \beta_2 W_{s,t} + \beta_3 S_s + \beta_4 P_{s,t} + \beta_5 T_{s,t} + \varepsilon \qquad (1)$$

The variables $E$, $G$, $W$, $S$, $P$, and $T$ respectively measure the percentage availability of electricity, gas, water, structures, port, and surface transportation in area $s$ at time $t$; $\alpha$ and the $\beta$'s are coefficients to be estimated, while $\varepsilon$ is the error term. Data for electricity are seasonally adjusted. Structures availability is assumed to be invariant over time since very few new buildings were constructed in the first 10 weeks after the earthquake. The port variable is measured as the percent of total shipping berths that were operational. Transportation availability consists of the percent of rail and highway routes into an area that were open at the time.

Alternative specifications of the basic model in equation (1) were also examined. These include a combined gas and water variable (*GW*) and several alternative port and general transportation variables. For example, a port variable reflecting both port facility restoration and transportation accessibility conditions in area *s* (*PH*) and one considering only container cargo facilities (*P2*) were also attempted. For general transportation, separate variables for highways (*H*) and railways (*R*), as well as for these two modes weighted by direction (*HW* and *RW*) were also considered.

Data required to implement equation (1) were mostly gathered in two trips to Japan in May and July 1995. This information was obtained from many different sources in a variety of formats. In general, direct data were available for electricity, gas, water, and port services from the operating agencies. Structural damage data were obtained from Architectural Institute of Japan (1995). Transportation indices were calculated based on a series of newspaper articles and maps. Except for electricity, most of the data was available on a city or city ward basis. Mapping wards/cities into electric service areas (ESAs) was performed by weighting the data by population information from the Japanese Census.

Data on electric power consumption, the dependent variable (*E*), gives a sense of the magnitude and variation of total impact in the study region. In the second week after the disaster, after electricity had been fully restored, consumption in the 6 ESAs ranged from under 40 percent of normal to almost 95 percent. Ten weeks after the earthquake, power consumption was still about 65 percent in the most heavily impacted area.

Results for selected specifications of the model are shown in table 3. In specification 1, the preferred model, the combined gas and water variable (*GW*) is used and the port variable is eliminated. With 50 degrees of freedom, the explanatory power of this preferred model is quite high, as indicated by the adjusted $R^2$ value of 0.76. An F-test indicates the model is significant at the 1 percent level and all of the estimated coefficients are significant at least at the 10 percent level. Because all of the variables are expressed in equivalent terms (as percentages of normal levels), the estimated coefficients can be compared directly to determine the relative influence of the different contributors to economic loss. Thus in specification 1, building damage (*S*) is shown to have by far the greatest impact on loss, followed by transportation disruption and then loss of gas/water service. This finding is consistent with expectation and observations after the earthquake. To interpret the coefficients literally, a 10 percent increase in structures availability is associated with a 12 percent increase in economic activity while a similar change for transportation access entails a 2.8 percent economic gain and for gas/water, a 0.8 percent increase.

**Table 3. Regression Results**

| Specification | 1 (preferred) | 2 (original) | 3 (transport disaggregated) |
|---|---|---|---|
| Constant | -.43 ** | -.26 | -.30 |
| Gas (G) | | .07 | |
| Water (W) | | .14 | |
| Gas & Water (GW) | .08 * | | .004 |
| Structures (S) | 1.20 *** | .99 *** | .95 *** |
| Transportation (T) | .28 *** | .30 *** | |
| Highways (H) | | | .15 *** |
| Railways (R) | | | .33 *** |
| Port (P) | | -.33 | |
| adjusted $R^2$ | .76 | .77 | .80 |
| F-statistic | 56.52 *** | 35.85 *** | 54.44 *** |

note: significance levels are indicated for the 1% (***), 5% (**) and 10% (*) levels.

Specification 2 represents the original model as shown in equation 1. Here, gas and water are modeled separately and the port variable is included. Results indicate that water disruption has greater impact than gas; however, neither coefficient is significant at the 10 percent level. This probably arises in part from estimation problems due to multicollinearity, which is indicated by a correlation coefficient of .84 between the two variables. The coefficient for port service, on the other hand, is estimated with an implausible negative coefficient, albeit at a low significance level. Other variants on the specification of port restoration produced similar results. One likely explanation is that the disruption of port services cannot be geographically associated with subareas in the straightforward manner of, say, building damage or water service disruption. Port impact is likely to have important indirect economic consequences related to the types of industries in each subarea and inter-industry relationships in the region as a whole. It is also possible that in the first 10 weeks after the disaster, port disruption did not have measurable impact over and above the losses attributable to building damage and water, gas, and transportation disruption.

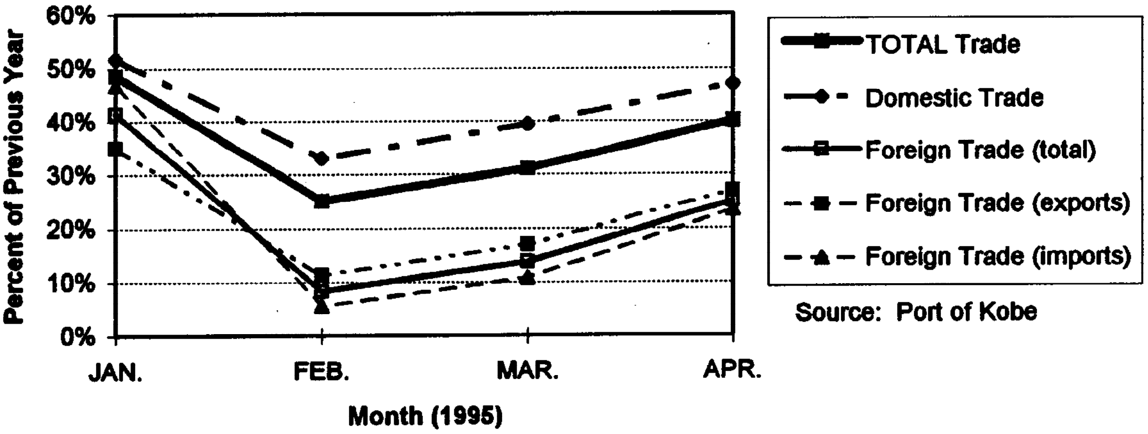
In specification 3, the transportation variable is disaggregated to consider the impact of highways and railways separately. This distinction was expected to be significant because in the impacted region, rail represents the primary mode of commuter travel while roads handle most of the goods traffic. Additionally, substitution between the two modes is imperfect. Results show that railway disruption had a greater impact than highways. The gas/water variable is not significant, but again this may be attributable to its high collinearity with the railway variable. As with the other specifications, the model has high explanatory power.

## Port Disruption

Regional economic impact resulting from the damage and disruption at the Port of Kobe, while not well-captured by the preceding model, is likely to be both substantial and complex. In contrast to the other lifelines, restoration of function is projected to require 2 years. The combination of long restoration time and importance to the regional economy indicates that port disruption could potentially induce significant long-run impacts, as well as short-run losses. Such massive disruption to a major port in a developed country is unprecedented and could potentially provide many valuable lessons for other cities in seismically active regions around the Pacific Rim.

Before the earthquake, the Port of Kobe played a major role in the regional as well as national economy. The largest port in Japan, it ranked sixth among container ports in the world. The Port accounted for approximately 10 percent of the nation's import and export trade and handled 30 percent of Japan's container cargo throughput. It served an especially important role for the economy of western Japan: roughly 65 percent of imports and exports for the Kinki region, which includes Hyogo Prefecture, and the adjacent Chugoku region was handled at Kobe. The Port of Kobe also accounted for 80 percent of exports from the neighboring Shikoku region (Port of Kobe 1994).

The disruption of port activity in the first few months after the earthquake provides some measure of the associated economic loss in the short run. Figure 1 shows monthly volume of cargo traffic at the Port from January to April, 1995 as a percentage of the corresponding month in the previous year. Total trade in January 1995 was roughly half that in January 1994 and is consistent with the observation that the Port was virtually closed after the earthquake struck on the 17th of the month. By April, total trade amounted to only 40 percent of the previous year. Figure 1 also shows that domestic trade is recovering more quickly than foreign trade, and with regard to foreign trade, exports are recovering slightly more than imports. These recovery patterns are consistent with the restoration pace of port facilities over this period. While some shipping berths were restored on a provisional basis within a few days of the earthquake, the first berth for handling container cargo was not reopened until March 20th, two months later. The loss of trade volume indicates the loss of output for those businesses and industries directly involved in Port activity.



Source: Port of Kobe

**Figure 1. Volume of Cargo Traffic Through the Port of Kobe, January-April 1995**

The impact on other area businesses that are indirectly dependent upon Port functions, however, is mitigated by the possibility of diverting cargo traffic to alternative ports. This route substitution would often entail higher surface hauling costs and longer transportation times. Kobe's loss in this event benefited other regions to which the trade was diverted. At the national level, the impact of the port damage in the months following the earthquake was thus much smaller than the losses imposed on the Kobe region itself. Following the earthquake, the press provided much anecdotal evidence of cargo traffic diversion and often indicated that competitor ports in South Korea and Taiwan were capturing some of Kobe's market share in container cargo shipping. Some evidence of the actual magnitudes and patterns of this diversion is available from a survey by the Ministry of Transportation (1995) covering the two-week period immediately following the earthquake. The survey included 11 of the major shipping firms that accounted for 80 percent of activity at Kobe. The diversion of container cargo from Kobe to other ports is shown in table 4.

**Table 4. Diversion of Container Cargo from Kobe Port** [(a)]

| Cargo Diverted to Port of: | Volume Diverted (TEU)[(b)] | Percent of Total Diversion |
|---|---|---|
| Yokohama, Japan | 10,792 | 46.7 % |
| Tokyo, Japan | 4,775 | 20.7 % |
| Osaka, Japan | 4,470 | 19.3 % |
| Nagoya, Japan | 1,417 | 6.1 % |
| Hakata, Japan | 828 | 3.6 % |
| Pusan, S. Korea | 661 | 2.9 % |
| Other | 164 | 0.7 % |
| TOTAL | 23,108 | 100.0 % |

notes: (a) source: Ministry of Transportation; based on survey of 11 shipping firms for 1/17/95-1/31/95.
(b) TEU=ton equivalent unit.

Table 4 shows that the main beneficiaries of the diversion were domestic ports. Pusan in South Korea, the only foreign port identified, received less than 3 percent of the cargo diverted. Almost half of the container cargo was rerouted to Yokohama, with Tokyo and Osaka ports together accounting for another 40 percent. Other sources report that for the domestic ports listed in table 4, after the earthquake, the increase in container cargo ranged from 9 to 73 percent of their normal volume. (Port of Kobe 1995)

Whether or not the losses will be sustained in the long run, that is after physical restoration of Port facilities is completed, is as yet uncertain. It is possible that with prolonged service disruption, the Port of Kobe may permanently lose customers and market share to its competitors. This may be especially relevant in the case of imports to Japan. As shown in figure 4, imports took the hardest hit and have shown the slowest recovery, despite having performed better than exports before the earthquake (according to the January statistics).

Recent pre-earthquake trends also indicate that long-run loss may be a realistic scenario. Experience from other disasters has shown that these events typically accelerate rather than reverse pre-earthquake long-term trends. Table 5 shows that Kobe's prominence as a major port has experienced some decline in recent years. Although year-to-year fluctuations do occur, the data for 1991 and 1993 are indicative of recent trends. Between these two years, Pusan, South Korea displaced Kobe as the 5th largest container port in the world. Traffic also declined in terms of both number of ships and cargo volume. The decline has been more pronounced for coastal ships and domestic trade than for ocean-going ships and foreign trade. The diversion of traffic to other domestic ports may therefore provide an impetus to Kobe's further decline.

**Table 5. Kobe Port Activity and Ranking, 1991-93**[(a)]

| | 1991 | 1993 | Change |
|---|---|---|---|
| *World Ranking, by container cargo handled* | *5th* | *6th* | |
| *Ships (number)* | *91,676* | *83,359* | *- 9 %* |
| Ocean-going ships | 11,392 | 10,935 | - 4 % |
| Coastal ships | 80,284 | 72,424 | - 10 % |
| *Cargo handled (freight tons)* | *174,100,929* | *168,693,868* | *- 3 %* |
| Foreign trade | 53,726,710 | 53,507,855 | - 0 % |
| Domestic trade | 120,374,219 | 115,186,013 | - 4 % |

note: (a) source: Port of Kobe

On the other hand, it is also possible that the Port's long-run competitive position may be enhanced by the capital investment in terms of reconstruction and facility expansions, as well as operational changes such as the reductions in facility charges and increase to a 24-hour container handling schedule after the disaster.

## CONCLUSIONS

The Great Hanshin-Awaji disaster provides an important opportunity for learning about the impact of earthquakes on urban economies. In particular, the massive disruption of lifeline services was unprecedented and caused substantial direct and indirect economic loss to the Kobe region. Using data from the first 10 weeks after the earthquake, a model was developed to study the impacts of disruption to water, gas, highway and railroad transportation, and the Port, as well as other factors represented by damage to buildings. While building damage was found to have the greatest impact, transportation disruption was also highly significant and gas/water outage influenced economic loss to a lesser degree. The model exhibited high explanatory power and general robustness. Although port disruption was not found to be influential in this approach, further exploration suggested that it may entail long-term loss to the region. The lifeline disruption impact model provides a flexible framework that can potentially be applied elsewhere to support decision-making on lifeline vulnerability mitigation, post-disaster restoration prioritization, and recovery planning.

Findings suggest several areas for further research. As data become available, the lifeline impact model should be recalibrated with direct measures of economic activity such as sales volume. The electricity consumption proxy may, for example, turn out to reflect business functionality more closely than production levels, which may lag behind. The positive impact of debris removal and reconstruction activity should also be considered. Finally, the insights gained from experience in this disaster should be applied to improve the state of the art of economic impact analysis for disasters in the U.S.

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