ESTIMATION OF INDIRECT LOSSES CAUSED BY DISRUPTION OF LIFELINE SERVICE

A Pilot Study of the Memphis Light, Gas and Water System

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ABSTRACT

A general methodology for estimating the indirect losses caused by a disruption of lifeline service is presented This methodology is different from previous approaches in that it attempts to incorporate local data on lifeline usage patterns and detailed information on regional economics into the analysis Although the analysis is presented using natural gas as the pilot system, the methodology is general enough to have application for other lifeline systems Since the conduct of this study is part of a larger National Center for Earthquake Engineering Research (NCEER) effort that involves multiple investigators, parts of the analysis are still being performed Therefore, what is presented in this paper is a snapshot of the analysis with particular focus on model development Models for natural gas usage, economic productivity and natural gas outage are presented. In order to provide the reader with some understanding of how the results of the analysis will feed into the overall loss assessment procedure, a general discussion of the methodology is presented along with a discussion of future activities This study is part of the Urban Seismic Risk Project that is being sponsored in whole by the NCEER

INTRODUCTION

The past performance of many lifeline systems has demonstrated that these systems can be highly vulnerable to disruptions during natural disasters and that economic losses associated with their disruption may far exceed the cost to repair the damaged system Even with this recognition, few studies have attempted to quantify these indirect losses The most notable study was performed for the Applied Technology Council (ATC-25. 1992) in an assessment of national lifeline vulnerabilities Even at this coarse scale, the ATC study identified the significance of lifeline dependencies and suggested that in a major earthquake, business interruption losses could be as much as three times the repair costs for the system The current study attempts to improve upon the methodology developed in the ATC-25 study by developing more refined models of lifeline usage and economic output

From many respects, the approach used to model the economic integrity of a region is based on empirical models derived from an examination of local and state economic data To our knowledge, little information exists on the requirements of businesses for lifeline services As part of a larger National Center for Earthquake Engineering (NCEER) effort, the Disaster Research Center (DRC) of the University of Delaware is conducting a survey of Memphis businesses to assess the importance of various lifeline systems to these businesses As part of this survey, questions regarding the length of time that a business can operate without a specific lifeline service are being asked This information will be essential in completing the current study which attempts to quantify the economic impact on a region that suffers some level of lifeline disruption

In addition to the survey above, various other empirical models have been developed that quantify the level of gas usage by customer type, and the economic productivity associated with various sectors of the economy Although economic models exist (e g., input-output) that can relate changes in economic output to changes in various economic sectors, this type of approach cannot consider in detail the influence of lifeline loss or availability The drawback of the current approach is that a more comprehensive dataset is required to execute the methodology

This paper presents an interim report of the analysis. Because this effort is part of a larger study being performed for NCEER (Project title· Urban Seismic Risk), some parts of the analysis are being performed by other members of NCEER It is expected that all parts of the analysis will be completed by the end of 1994. At that time, a complete summary of expected indirect losses can be reported on In the meantime, this paper presents our final gas usage and economic models

METHODOLOGY

The methodology for assessing direct and indirect economic losses due to earthquake-induced utility disruption is shown in Figure 1 Although this study deals specifically with a natural gas utility, the methodology, as shown, can be generalized to apply to many other urban utility networks, such as water, power and telecommunications

For the purpose of demonstrating the methodology, an assessment of losses related to the disruption of natural gas service provided by Memphis Light, Gas and Water (MLGW) in the event of a large earthquake in the New Madrid Seismic Zone (NMSZ) is being made MLGW serves Shelby County, Tennessee, which includes the city of Memphis

The first step in the loss assessment is the seismic hazard analysis This includes the development of earthquake scenarios, and estimates of Modified Mercalli intensity and liquefaction potential For this study, seismic hazard analyses performed by Hwang et al (1991) have been utilized

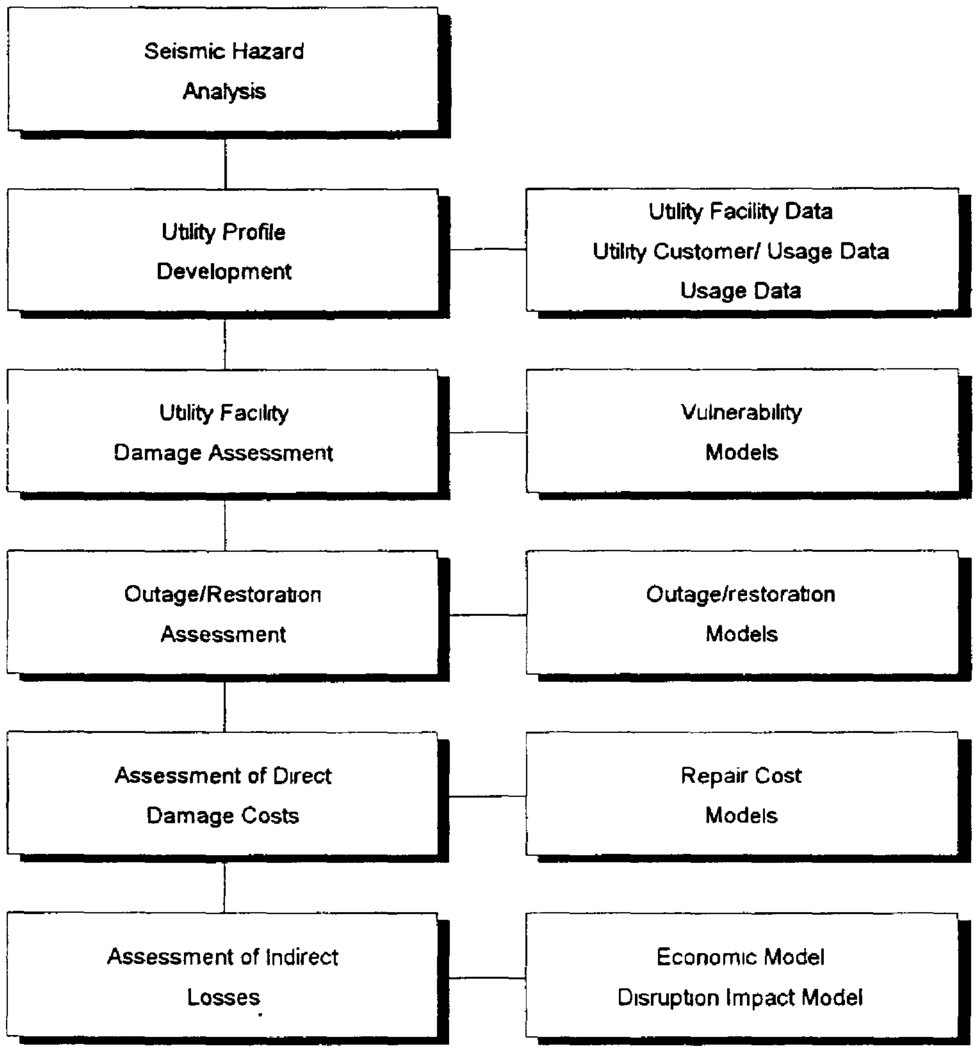


Figure 1
Methodology for the Assessment of Direct and Indirect Losses Due to Earthquake-Induced Utility Disruption In An Urban Enviroment

The next major step is the development of a utility profile. This profile includes data on utility facilities, such as pipeline and storage facility specifications, and pipeline system maps, including the locations of compressor stations Additional data required for the analysis includes customer and gas usage data, such as the number of residential, commercial and industrial customers, average annual quantities of gas sold, and annual revenues Regional data on natural gas usage patterns are available through various national organizations, while MLGW customer and facility data have been collected by

Hwang and others at the Center for Earthquake Research and Information (CERI) at Memphis State University

The facility damage assessment for this study was performed by various NCEER investigators, this effort was coordinated by Professor M Shinozuka of Princeton University Preliminary results of their damage assessment of the MLGW transmission system have been made available for use in this study.

The fourth step in the loss analysis procedure is the outage and restoration assessment This outage assessment takes the results of the damage analysis as input, and applies restoration models to determine the length of time that various utility service areas and customers will be without service, or operating at reduced service levels

Following the outage assessment, the estimation of losses due to direct damage is performed These direct losses include both the cost of facility repair, such as pipeline repair or replacement, as well as revenue lost by the utility as a result of service interruption. The first cost is estimated through the use of generalized repair cost models, while the second cost is estimated from annual customer revenues.

The final step in the methodology is the assessment of indirect losses, or loss of regional economic productivity as a result of the loss of utility service These losses may be estimated in dollars, and as a percent of gross state product (GSP). Two models are required for the implementation of this step, models of the region's economic activity in terms of percent of GSP, and disruption impact models which relate decline in economic activity to reduced utility service The final model used in this study, the impact disruption model, may be refined following completion of the related NCEER study by Prof Kathleen Tierney of the Disaster Research Center in Delaware, which includes the survey of businesses in the Memphis area to develop a more detailed business profile, including an assessment of utility dependence

Natural Gas Usage Data

Data on regional and national natural gas utilization are available from two sources the American Gas Association (AGA) and the Department of Energy's Energy Information Administration (DOE/EIA). The American Gas Association annually publishes "Gas Facts", a statistical record of the gas utility industry "Gas Facts" contains data on energy reserves, natural gas supply, underground storage, energy consumption, customers, sales, revenues and prices Relevant data is presented for the U S as a whole, for census divisions, and for individual states "The Natural Gas Annual", published by DOE/EIA, presents similar information, and includes a set of summary statistics for each state. In addition to data on natural gas deliveries by utilities, the DOE/EIA statistics include natural gas purchased directly from producers and delivered to end users through transportation agreements with pipeline companies These "transportation volumes" or "deliveries for the accounts of others" are, by definition, not included in the gas industry figures presented by theAGA While damage to the pipeline companies will impact these transportation volumes and deliveries, this study is concerned with the impact of natural gas utility disruption on an urban area, and therefore, the AGA statistics are utilized here

Specific data on local natural gas usage for Shelby County is presented in Table 1 This data includes number of customers, consumption, revenue and supply (MLGW, 1991) This data will be combined with outage estimates to determine the percent of impacted households and commercial and industrial enterprises, and the subsequent economic impact, as well as the resulting loss of revenue for the utility. Other data, such as consumption data, are important to complete the overall picture of regional natural gas usage

Table 1. Natural Gas Data for Shelby County, Tennessee (1990)

Measure	Res	Comm	Industr	Elec. Gen.	Other	Total
Customers	245,600	18,600[a]	400[b]	-	-	264,600
Annual Consumption[c] (mil BTUs)	81 6	694 8	89,296 0	-	-	-
Annual Sales[c] (Tril BTUs)	20 0	12 9	31 6	-	-	64 5
Annual Revenue[c] (1000 $)	88,389	46,508	24 245	-	-	159,142
Average Price[c] ($/mil BTU)	4 41	3 60	0 77	-	-	-

Notes

a) MLGW "general services" customers are assumed to represent mostly commercial customers

b) MLGW "demand" customers are assumed to represent mostly industrial customers

c) Derived from 1991 consumption data from MLGW (1992)

In developing average daily revenues per customer for each user group, it is important to consider seasonal fluctuations in natural gas usage An examination of U.S. quarterly sales volumes (AGA, 1991) for a five-year period (1986-1990) reveals a consistent pattern of greater usage in the winter months (1st and 4th quarters, October through March) than in summer months (2nd and 3rd quarters, April through September) The extent of this fluctuations varies among the different user groups, as follows

- o Residential Users
  - summer usage accounts for ~25% of annual sales by volume
  - winter usage accounts for ~75% of annual sales by volume

- o Commercial Users
  - summer usage accounts for ~30% of annual sales by volume
  - winter usage accounts for ~70% of annual sales by volume
- o Industrial Users
  - seasonal fluctuation in usage is negligible

It is assumed that these national figures, representing typical seasonal fluctuation patterns, are sufficient to capture the average seasonal vanation in the current study area This information has been used to calculate two average daily sales volume figures from total annual sales for each user group - one for summer and one for winter. From the average daily sales figures, average price data allows calculation of average daily revenues, which, when combined with customer data, yields average daily revenues per customer Table 2 lists seasonal average daily revenues per customer derived for Shelby County

Table 2. Average Daily Revenue per Gas Utility Customer for Natural Gas Sales in Shelby County, Tennessee (Dollars)

Customer Group	Winter	Summer
Residential	$1 48	$0.49
Commercial	$9 63	$4.10
Industrial	$188 16	$187 13

Economic Models

Various data on the national and state economies are collected and published by the U.S Department of Commerce, Economics and Statistics Administration, Bureau of Economic Analysis (BEA) and the Bureau of the Census (BOC) Economic censuses are performed by the BOC every five years, most recently in 1987 (published in 1990) Data is collected on vanous sectors of the economy· Manufacturers, Wholesale Trade, Retail Trade, Service Industries, Mineral Industries, Construction Industries, and Transportation Industries Other economic data are published monthly by the BEA under the auspices of the "Survey of Current Busmess"

Data relevant to this study are those that provide an indicat10n of the relative productivity of various business sectors, as defined by the Standard Industrial Classification (SIC). Two such economic indicators are value added and gross state product Although value added has been used in previous indirect earthquake loss studies (ATC-25, 1991, Dames and Moore, 1991), it is by definition, an industrial measure and is not applicable to the trade and service industries that constitute a significant portion of the economy of an urbanized area. For this reason, gross state product was used

Gross state product (GSP) is defined as the market value of goods and services produced by labor and property in a State, and is collected for industry categories according to SIC code GSP is the state counterpart of the national gross domestic product (GDP) The GSP is organized into 13 major economic sector groups according to SIC codes Table 3 presents 1989 GSP figures for the State of Tennessee, and for the U S. as a whole

Table 3. 1989 Gross State Product (Millions of Dollars)

SIC Division	SIC Major Groups	Tennessee	United States
A	Farms	1,426	88,587
A	Agricultural Services, Forestry and Fisheries	312	24,896
B	Mining	354	80,254
C	Construction	4,013	247,721
D	Manufacturing	22,161	965,997
E	Transportation and Public Utilities	7,326	460,863
F	Wholesale Trade	6,271	339,468
G	Retail Trade	9,903	485,979
H	F.I R.E	13,981	896,652
I	Services	15,494	970,539
J	State and Local Govt	6,772	413,123
-	Fed. Civilian Govt	3,716	125,481
-	Fed Military	537	65,111
	TOTAL	92,267	5,164,671

While GSP data reflects economic activity for all sectors of the economy relevant to this urban analysis, it does so for the State of Tennessee as a whole To utilize this data for one county within the state, Shelby County, some means of extracting Shelby County's share of the state's economic activity must be developed

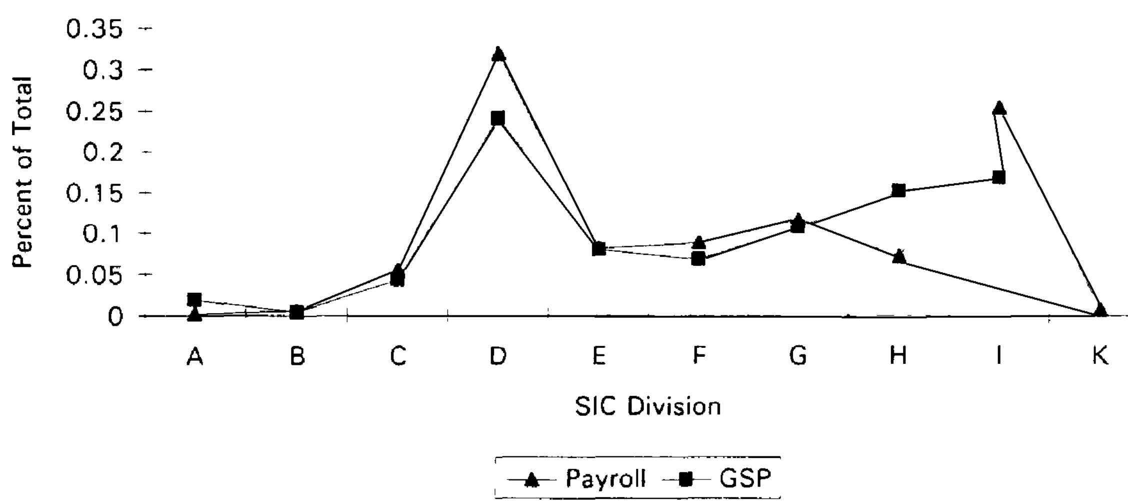
The approach for deriving estimates of county contributions to GSP was to compare economic indicators for the County to those of the State, and to identify any differences that are important to capture in the resulting model County Business Patterns 1989, published for each State by the Bureau of the Census (1991), presents estimates of employment, payroll and number of establishments by detailed industry category Table 4 presents summary statistics for Tennessee and Shelby County As shown in the table, Shelby County accounts for about 22% of the state's payroll, 20% of the state's employees and 18% of the state's business establishments The number of businesses (19,888) compares favorably with the total number of MLGW commercial and industrial customers (19,000)

Table 4. 1989 Business Patterns for Tennessee and Shelby County (Source: County Business Patterns, 1989; Tennessee, BOC, 1991)		
Measure	**Tennessee**	**Shelby County**
No of Establishments	112,337	19,888
No. of Employees	1,829,371	364,349
Annual Payroll ($1,000)	34,792,660	7,620,976

To determine which economic indicator was the most appropriate for use in estimating Shelby County's contribution to GSP, we compared industry contribution to GSP to various state economic indicators, by industry. Figure 2 shows a comparison of industry contribution to 1989 GSP and annual payroll for the State of Tennessee by SIC group The comparison shows that as a percent of total contribution, annual payroll represents a reasonable indicator of the GSP when compared with each of the different SIC divisions Comparisons for SIC divisions H (F I R E) and I (Services) show the largest discrepancies Other comparisons were made using information on number of establishments and number of employees as possible indicators However, the correlations with GSP were not as good as that presented using annual payroll

Table 5 shows Shelby County's contribution to Tennessee's GSP as estimated from annual payroll data As the table indicates, Shelby County's share of the GSP is estimated at $20 8 billion The amount of GSP on a per day basis is estimated at $57 1 million Also indicated in Table 6 is the share of GSP per day, per establishment

Figure 2 - Comparison of Industry Contribution to 1989 GSP and Annual Payroll for the State of Tennessee by SIC group



To utilize the economic data described here in the assessment of indirect economic impacts of natural gas disruption, the economic activity of each industry group needs to be assigned to a customer category Two basic business customer types exist within the State of Tennessee, and Shelby County - Commercial and Industrial. Using the information presented in this section, as well as the previous section on gas usage, the following average daily GSP per establishment ($/day/est) have been established

	Shelby Co.	State of Tenn.
Commercial	2,640	1,820
Industrial	7,150	8,510

This data may be combined with outage estimates to quantify loss of economic productivity due to natural gas disruption

Table 5. Shelby County's Contribution to Tennessee GSP

SIC Division	Share of GSP (million $)	Share of GSP per day (million $)	Share of GSP per day, per establishment[a] ($)
A	399	1 1	5,630
B	5	0 01	1,150
C	871	2 4	1,610
D	2,629	7 2	7,220
E	3,084	8 4	9,230
F	2,014	5 5	2,690
G	2,183	6 0	1,230
H	3,539	9 7	5,410
I	3,709	10 2	1,570
J	1,483	4 1	--[b]
Other[c]	932	2 6	--[b]
TOTAL	20,848	57 1	

Notes

a) Calculated using the 1989 estimates of the number of establishments by SIC for Shelby County (County Business Patterns, 1989, Tennessee, BOC, 1991)

b) No estimates for the number of government and military establishments are available

c) Federal government, military

FUTURE ACTIVITIES

Two major activities will place in the next research period vulnerability assessment and estimation of indirect losses In order to perform the seismic vulnerability asssessment, the results from the damage analysis being performed by Professors Hwang and Shinozuka will be utilized This analysis is based on assessing the seismic vulnerability of major natural gas transmission pipelines that serve the Memphis area. The scenario used in this assessment is a magnitude 8+ earthquake in the New Madrid Seismic Zone. Although this analysis will not identify where specific pipeline breaks will occur, it will provide an assessment of probable outage areas. Based on this analysis and on an assessment of potential shaking intensity levels in the Memphis area, the current project team will determine what the likely impact will be on distribution pipelines. As is evident from past California earthquakes, natural gas distribution pipelines may also be vulnerable to earthquake, even if located outside the immediate epicentral area For purposes of demonstrating the current methodology, the project team will estimate the number of repairs that may result from the NMSZ scenario and the time for repair (both partial and full restoration) Based on this analysis, we will apply these outage times to the economic models discussed previously to estimate the likely loss of productivity caused by a disruption of natural gas service

In addition, as mentioned in the introduction to this paper, the results from the DRC business survey will be incorporated to the fullest extent possible The results of this survey should identify the lengths of time over which little or no impact on business operations should be observed To incorporate this survey data, businesses will be classified into commercial and industrial categories Timelines that indicate when essential lifeline services are needed will be plotted against an assessment of likely outage periods based on the NMSZ scenario When these outage periods extend beyond non-critical outage periods, indirect losses will be computed

The methodology that has been described in this paper has focused on the performance of natural gas systems While these systems are critical for the long-term welfare of a city, they may not be critical for immediate post-earthquake life safety reasons Therefore, application of this methodology may need to be modified in the investigation of other lifeline services As part of the Urban Seismic Risk project, the current project team is planning to apply this methodology to water and finally electric power systems It is anticipated that the economic losses associated with the disruption of these two systems will far exceed those computed for natural gas Nevertherless, it is anticipated that few changes would be made to the general methodology; the majority of the effort for these other two systems will be in the construction of the usage and economic models

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helping to reconstruct a more meaningful methodology for examining the indirect effects causes by lifeline disruption

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