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Project #: D-48-X10 Cost share #: D-48-351 Rev #: 2
Center # : 10/24-6-R8441-0A0 Center shr #: 10/22-1/F8441-0A0 OCA file #:
Work type : RES
Contract#: R90575 Mod #: -A Document : SUBCONT
Prime #: BCS-9025010 Contract entity: GTRC

Subprojects ? : N CFDA: NA
Main project #: PE #: NA

Project unit: DEAN ARCH Unit code: 02.010.170
Project director(s):
FRENCH S P DEAN ARCH (404)894-2350

Sponsor/division names: STATE UNIV OF NEW YORK / BUFFALO, NY
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Title: ESTIMATING SOCIAL & ECONOMIC IMPACTS OF INFRASTRUCTURE DAMAGE THROUGH GIS

PROJECT ADMINISTRATION DATA

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NA supplemental sheet

Administrative comments -
AMENDMENT -A AUTHORIZES A 6-MOS NO-COST EXTENSION, AS REQUESTED.

4

2-SR313

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 11/05/96

Project No. D-48-X11

Center No. 10/24-6-R8469-0A0

Project Director CIRCEO L JR

School/Lab DEAN ARCH

Sponsor ARMY/FT GILLEM, GA

Contract/Grant No. DACA88-94-D-0025-1E04

Contract Entity GTRC

Prime Contract No.

Title TECHNOLOGIES FOR RESTORATION OF SITES CONTAMINATED WITH HAZARDOUS WASTES

Effective Completion Date 960314 (Performance) 960314 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	Y	
Government Property Inventory & Related Certificate	Y	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

NOTE: Final Patent Questionnaire sent to PDPI.

D - 48 - X10
#1
(New)

Year 9
Interim Report

Estimating Social and Economic Impacts of Infrastructure Damage with GIS

NCEER 94-6301

Principal Investigator
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The GIS-based societal impact model developed in NCEER Year 8 has been extended to include economic as well as demographic impacts of infrastructure damage to the water distribution network in Memphis/Shelby County, Tennessee. This extension has been accomplished by incorporating small area data on the number of employees within each of fourteen economic sectors into the model. This detailed employment data, derived from the Census Transportation Planning Package, was available for 650 the traffic analysis zone (TAZ) in Shelby County. This small area data was linked to the water distribution network using techniques similar to those used to link the block level population data in Year 8.

The basic model was further extended by incorporating into the model a richer set of demographic data available from the Census Bureau at the Block Group level. A new criteria editor that allows the user to construct indices of social and economic impact was added to the model. These extensions of the model required a complete rewrite of the user interface for the system. The system is described in a manuscript that has been submitted to the ASCE *Journal of Infrastructure Systems* for review. A copy of that manuscript is attached. The model has also been described for potential users in presentations at the annual conferences of the Urban and Regional Systems Association (July) and the Association of Collegiate Schools of Planning (October).

The research team has been engaged with other NCEER researchers in several capacities. First, we have aggregated the small area employment data to the electric power service areas to support the economic modeling effort headed by Dr. Adam Rose. We have assisted Dr. Stephanie Chang and Mr. Ron Eguchi of EQE International with similar data aggregation requests. Second, Dr. French is participating in the Loss Assessment For Memphis Buildings (LAMB) project. In that effort he is attempting to link the population and employment data developed in Years 8 and 9 to the building stock information developed by Dr. Barclay Jones and Dr. Howard Hwang. This linkage allows us to understand the inhabitants and functions of the damaged buildings. This is critical to translating physical damage to the building stock into social and economic impacts.

In addition to the LAMB project the primary focus for the remainder of Year 9 will be sensitivity testing the model to determine how the different levels of aggregation in the input data and the selection of social impact variables affect the repair strategy. This sensitivity analysis will be combined with an expanded description of the model in the Year 9 final report.

ESTIMATING SOCIETAL IMPACTS OF INFRASTRUCTURE DAMAGE WITH GIS

By Steven P. French[1] and Xudong Jia[2]

ABSTRACT

This paper describes a GIS model designed to estimate the societal impacts of infrastructure damage from earthquakes. The model links physical components of a water delivery system to population and economic data from the U.S. Census. A prototype model has been developed and implemented for the water distribution system of Memphis/Shelby County, Tennessee. There are three components of the model: the simulation module, the assessment module and the repair module. In the simulation module, damage to the system is specified in one of two ways. Either the user indicates the damaged links interactively or the output of a separate damage model is downloaded into the module. Once the simulation module is run, the assessment module presents the impacts of the damage in terms of specified demographic variables. The repair module generates a priority list of water lines to be repaired to maximize service to user selected population. This paper combines contemporary understanding of societal impacts of disaster, research into the behavior of lifeline systems in earthquakes, and state-of-the-art GIS technology.

INTRODUCTION

Current earthquake infrastructure damage models typically produce damage estimates that are expressed in terms of physical damage. For example, in the water distribution area the ATC-13

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methodology produces estimates of the number of breaks per kilometer (Applied Technology Council 1986). While this information is useful, it does not fully meet the needs of emergency preparedness and hazard mitigation planners. What is needed is a way to translate this physical damage into its resultant impacts on society. The purpose of this research is to develop techniques for estimating the size and characteristics of population impacted by earthquake damage to urban infrastructure systems. Such social impact information can be used to allocate emergency response resources in the most effective manner and to set priorities for hazard mitigation efforts.

Current state-of-the-art infrastructure damage models use geographic information systems (GIS) to estimate earthquake damage. (For an excellent review of damage modeling techniques, see Risk Management Software and California Universities for Research in Earthquake Engineering 1994.) The GIS provides important advantages because it can handle large amounts of spatially distributed information and improve modeling by combining geotechnical information with system characteristics based on location. Typically, this type of modeling produces an estimate of the number of physical breaks in the system or an estimate of direct economic damage.

This social impact model links components of the physical system (e.g. individual water lines or pump stations) to small area population data. The GIS is used to associate block level demographic information from the 1990 Census of Population and Housing with nodes on the water distribution network. The GIS can then estimate the number and characteristics of people impacted by infrastructure damage at various locations based on the topological relationships of the distribution network. This makes it possible to characterize the societal impacts of infrastructure damage more precisely in terms of the affected populations.

This model provides the user with two alternative ways to specify the damaged condition of the water system network. The user may indicate the links that have actually been damaged in a real-time application. The system can accept a damage scenario generated by a separate water system damage data model. At this time we have developed software links to LIFELINE-W(I), the model developed by Shinozuka and Hwang for the Memphis metropolitan area (Shinozuka, Hwang, and Murata, 1992; Tanaka et al, 1993).

The assessment module translates this physical damage to the water system into the number of people and housing units affected by the damage. The model uses block level demographic information from the 1990 Census of Population and Housing that is linked to the water network. As a result each link in the water distribution network is characterized by its service population in various categories.

To support real-time system repair or to prioritize earthquake mitigation expenditures, the societal impact model includes a routine that ranks the pipe segments to be repaired based on the population served by each segment. This allows an emergency manager or hazard mitigation planner to identify the damaged pipe segments that service the most population. These software tools were developed using the ARC/INFO geographic information system. The model also allows the user to focus on selected population characteristics as well as size. For example, the model can identify those segments that serve the most elderly population. The model is also useful for estimating the number and type of users subject to service interruption.

Before discussing the model itself, a brief review of current research on societal impacts of disaster, physical damage to infrastructure and repair processes will be useful. This work presents the foundations of this research from a variety of disciplines and highlights the importance of understanding the social as well as physical impacts of the earthquake hazard.

LITERATURE REVIEW

Disaster planning, including earthquake mitigation and recovery, has long been considered a technical pursuit; building better buildings and stronger infrastructure has been the primary response to this hazard. However, the field is expanding beyond physical elements to include the social and economic impacts of disasters, as well as the process of recovery from them. In 1982, the Earthquake Engineering Institute recommended "analyses of social costs and benefits involved in mitigating and responding to earthquake disasters" (Committee on Earthquake Engineering Research, 1982). The problem is that sociological and technical research efforts have remained separate (Tubbesing 1992). As our understanding of disasters' societal impacts increases, it is important to link engineering and social science research to provide the greatest possible benefits. , the Earthquake Engineering Institute recommends social and policy scientists work more closely with the engineering community in order to develop appropriate repair and retrofit standards (Tubbesing 1992). This research project attempts to move in this direction by combining state-of-the-art GIS modeling technology with the most current views of the societal impacts of disasters.

Physical Damage

In any meaningful analysis, all of the pertinent information about societal and psychological impacts must begin with understanding of the physical damage earthquakes cause to infrastructure systems. Damage to lifelines should be thought of in terms of service outage, not in terms of damage to specific physical structures (Panel on Earthquake Loss Estimation 1989). This can be complex since lifeline systems generally cover a large area, and they are subject to a wide variety of seismic forces within the same system (Shah and Benjamin 1977). As is true for the social structures of communities, studies of actual physical damage experiences indicate that disasters tend to exacerbate existing infrastructure problems (United Nations Center for Regional Development 1990). This parallel underscores the value of proactive disaster planning and mitigation. To do this, it is essential to accurately predict the effects of earthquakes or other disasters on existing systems.

Honegger (1991) establishes the connection between Peak Ground Acceleration (PGA), soil types and earthquake damage. A process developed by Perkins (1992) for estimating housing damage uses this knowledge to prepare census tract level estimates of demand for emergency shelters. The results of the Perkins model were compared to the actual damage experienced in the Loma Prieta earthquake and were found to be reasonably accurate although more damage occurred on poor soils than would have been predicted. Earlier efforts to prioritize bridge retrofitting in Memphis and Shelby County, Tennessee combine the information on seismicity and site characteristics with knowledge of the structural characteristics of the bridges and their importance to the transportation in the region (Pereshk 1993).

GIS based models have been developed to estimate damage to buildings (Emmi & Horton 1993; French & Isaacson 1984; Patel 1991; Scawthorn, 1986; National Institute of Building Sciences, 1994) and damages to water delivery systems (Sato & Shinozuka 1991). These models effectively integrate information about the separate causes of physical damage. In order to create a system which may be used to recommend repair or retrofitting strategies, estimated damage is only one pertinent factor. As seen in the modeling of bridge damage, knowledge of the systems functioning is also crucial.

Social Impacts

In his seminal work, Eugene Haas studied communities before and after disasters to identify the factors that affected physical, housing, employment and family recovery. He developed a model that divided recovery into four phases: emergency response, restoration, replacement/reconstruction, and commemorative/betterment. Further, he identified pre-disaster community values, power structure and social structure as important determinants of the speed and shape of recovery (Haas et. al. 1977). Critiques of Haas' four phases have arisen. These criticisms were summarized by Bolin (1993), "recovery is best seen as a complex social process dependent both on material conditions rendered by the disaster and the complex array of political, economic and social forces existing before and after the disaster."

Bolin's study of household recovery from the Whittier Narrows earthquake indicates that recovery can be understood by the analysis of discrete components of a society, a household or a personality (Bolin 1993). His earlier work indicated that the psychological impact of disaster was dependent on factors such as suddenness of impact, scope of impact, length of warning, threat of recurrence, and exposure to death (Bolin 1988).

For this research project, the above studies establish a framework for considering societal impacts as a function of discrete elements that can be isolated and understood. Any of these elements which can be linked to demographic characteristics can be incorporated into our model.

There are clear indications that different groups within a society respond differently to disaster. In Bolin's Whittier Narrows study, he found that Hispanic victims were less likely to leave the area, even if their homes were heavily damaged. Most of the minority victims were poor, and there was a shortage of substitute housing which they could afford (Bolin 1993). If poor victims are unlikely to relocate, and a given disaster impacts low-income areas, this "invisible city" could be less impacted, and restoring lifeline service to the heavily damaged area may be more pressing.

Psycho-social impacts of disasters on the elderly have also received considerable attention. Bolin discovered that, compared to other age groups, the elderly recover quickly from the initial emotional impact, but they often experience a substantial decline in their standard of living (Bolin 1982). Later surveys of survivors of the Trinity River Flood in Texas found that age was not a significant predictor of post-disaster stress levels or depression (Tobin 1992). Other predictors were isolated however. Tobin found that the more people who lived in a household, the higher the stress levels of individual members; and that the more experience an individual had with disaster, the more depression was experienced. Significantly, Tobin also determined that the people who experienced the most depression before a disaster were more depressed after the disaster, and that people in poor health experienced higher stress levels (Tobin 1992). Therefore, while age alone may not have indicated more severe impact of disaster, age may be the most reliable demographic data with which to predict populations in poor health or experiencing depression.

The finding that pre-disaster conditions directly predict post-disaster conditions applies to societies as well as individuals. Thriving communities recover quickly (Rebuilding After Earthquakes, 1991). In fact, the most striking need people have after a disaster is a need for normalcy (Rogers 1984) and a desire to return to the pre-disaster city (Haas et. al. 1977). This is important, since planners and others involved in directing a community's recovery should be aware that the image most people hold for recovery is a return to what was.

There is a large information gap on the specific societal or psychological impacts of loss of infrastructure and lack of service from lifelines. Some economic analysis has taken place however. For example, after the Loma Prieta earthquake, part of what enabled businesses to recover quickly was a quick restoration of service and the redundancy built into many infrastructure systems (United Nations Center for Regional Development 1990). Lifeline repair is part of the early stage of emergency response.

The literature on societal impacts clearly indicates that different groups respond differently to earthquake damage. If we are to model societal impact, we must be able to identify the demographic groups that will be subject to different levels of damage. This model fills that role in the infrastructure area.

Repair

It is important to understand the current process of infrastructure repair in order to make meaningful recommendations about repair strategies. Essential lifelines are restored quickly since this repair must occur before recovery proceeds. Repair priorities are currently set using rules of thumb and the experience of system operators. There is little opportunity for analysis of repair priorities after a damaging earthquake. Any attempts to change repair strategies must occur prior to disasters and include the cooperation of owners, operators and regulators of the systems (Panel on Earthquake Loss estimation 1989).

Currently, water system repair follows an overall pattern of the least damaged lines fixed first. Seligson calculated time to repair as a function of number of breaks per square mile. Lines with few breaks and heavy demand are repaired first, and lines with many breaks and low demand are repaired last (Seligson 1990). The Applied Technology Council (1986) publishes a time-to-restore-service matrix for a variety of lifeline components. Attempts have already been made to computerize existing repair strategies (Iwata 1988). For the purposes of this research, it is a given that lifeline repair will occur and occur quickly, but the criteria of repairing the fastest repaired lines first may not be best. Differential impacts between various sub-populations should be considered and special attention should be paid to emergency facilities (Panel on Earthquake Loss Estimation 1989).

Based on our current understanding of societal impacts, methods of modeling physical damage, and current approaches to repair, it is possible to design a GIS-based system which combines sociological and technical knowledge. The common link is the demographic characteristics of the population. We can begin to understand the societal impacts of infrastructure damage if we can model the effects on different social groups, especially low income, the elderly and minority populations.

MODELING SOCIETAL IMPACTS

The modeling approach developed in this project characterizes societal impact in demographic terms. First round societal impacts are characterized as the number and type of population affected by infrastructure damage. The modeling is done within the ARC/INFO Geographic Information System. As shown in Figure 1, the societal impact model consists of three modules: the simulation module, the assessment module and the repair module. All three modules were developed using Arc Macro Language (AML). A graphic user interface integrates the three modules and allows the system to be run by users with little or no GIS experience. The three modules are described in detail below.

Data Preparation

This GIS-based system requires digital information about the water distribution network, block-level census data, and information about earthquake intensity. In the GIS model, the water supply network consists of links and nodes. Each link represents a water pipeline that connects two adjacent nodes. Each node represents a pump station, a tank or a hydrant. For this initial implementation, we used the Memphis/Shelby County water distribution network digitized by the Earthquake Center at Memphis State University. A number of important attributes such as pipeline diameter and roughness are stored in the attribute database. Figure 2 shows the water distribution network.

The demographic information used in this analysis was drawn from the 1990 Census. It includes the population and number of housing units for each block (the smallest geographical area within the 1990 Census of Population and Housing). This information is provided on the Summary Table Format (STF-1B) CD-ROM and is stored in a series of dBASE databases from the US Census (U.S. Department of Commerce 1991). Population data were imported into an INFO database.

Spatial information for the centroid of the block was stored in a spatial point database based on the latitude and longitude coordinates, and linked to the INFO database.

The information about earthquake intensity includes Peak Ground Acceleration (PGA) that measures the estimated ground motions for all locations in Shelby County. Given the data of water-supply network and the estimated PGA values, earthquake damage to the water-supply network can be calculated by the LIFELINE-W(I) system developed by the Civil Engineering Department of Princeton University (Tanaka et. al. 1993). Our GIS-based system can use the earthquake damage estimates directly from the LIFELINE-W(I) system, and combine them with the data on block-level population and housing units by using ARC/INFO spatial analysis tools.

One of the key technical challenges of this research was to find the most suitable way to link block level demographic data to the water distribution network. The population and housing information for each block is spatially related and aggregated to the corresponding nodes in the water system using the proximity features of the GIS system. This aggregation is crucial to the assessment of societal impacts of water-system damage and development of emergency response plans. The relating and aggregating process is shown in Figure 3 and can be described as follows:

- search the closest node for each centroid of block and assign the node number to the block. Adjust the search radius to a proper number so that all the centroids have their corresponding closest nodes. This search process is based on a reasonable assumption that all the people and housing units within a block area use water that is pumped out from the node closest to the centroid.
- aggregate (or sum up) the population and housing units of blocks with same node number and assign the results to the corresponding node. The results represent the total number of people and housing units that are served by the water distribution network through the node.

Demographic data is available at both the block and the block group level. Both of these data sets have their own strengths and weaknesses. At the block level the data is available for small areas of land that can be allocated to the centroids of the land areas. Figure 3 shows this allocation as the "stars" located within each block. Using a spatial technique called a snapping, all the data at the centroids of the blocks are aggregated to the closest water network nodes (depicted by the heavy circles). Using the relatively small census blocks, nearly all of the nodes have data aggregated to them. The association of data to the majority of the nodes provides for more accurate analysis. The ratio of "nodes with data" to "total nodes" is called the snap ratio, and in our illustration it totals to 13/14.

More extensive demographic data is provided at the block group level (4-6 census blocks comprise each block group). Figure 4 shows the same area, but at the block group level. The first marked difference is that there are fewer land areas, however they are much larger in comparison to Figure 3. As in the first case, we snapped data from the centroids of the block groups to the closest nodes. It can be seen that there are fewer nodes with snapped data due to the relatively large size of the block group polygons. This causes limitations in the application of this GIS infrastructure model. The snap ratio as seen from Figure 4 is 8/14.

It is clear that the block level provides a much better spatial resolution and congruence with the water network than does the block group. The better the snap ratio, the fewer the dataless water network nodes. Water network nodes with no information can be misleading, as we would assume that they would not affect any of the population. Thus a reduction in dataless nodes allows us to conduct a more comprehensive and comprehensible analysis.

At the block level the data is limited to a small number of variables. Table 1 shows the variables available at the block level, which are basic housing and population data. From this set of variables we are able to determine the effects to the various groups (white, black, under 18, over 65, etc.) and hence determine a strategy to optimize service.

The block group level provides a more extensive set of variables. There is more information on the breakdown of ages, the houses that utilize wells, sewage disposal and categorization of industry and its associated populations. This additional set of variables affords the opportunity to analyze the consequences of infrastructure damage on different groups in more detail. Table 2 shows the variables available at the block group level.

Ideally, we would need to have data available at the block level in order to obtain a better snap ratio, and the multiplicity of variables presented at the block group level in order to obtain a broader spectrum of analysis.

Simulation Module

The system requires the user to run the simulation module first. This module generates the breaks that will be used in the later modules. It contains two methods for estimating earthquake damage to the water network. The first method requires the operator to select pipelines damaged by the earthquake. After the operator makes his or her selections, the system displays the location of the broken pipelines within the water network. This type of simulation is useful for directing emergency response. Immediately after the earthquake, the damaged pipelines can be located within the water network. Using the assessment and repair modules, the system estimates population no longer receiving water service and suggests an order of repair to restore service.

The second method directly incorporates output from a stand-alone damage model system. The LIFELINE-W(I) system estimates damage to water-supply networks under different conditions. Although this system primarily calculates the water flow under different damage conditions, it also generates pipeline damage data that can be used in our system for assessment of societal impacts, and for the generation of a repair strategy. In the LIFELINE-W(I) System, ground motions are considered the major cause of breaks in underground pipes, and are represented by two types of scenarios: uniform distributed ground motion and interpolated site-specific ground motion. The first scenario assumes the earthquake intensity is the same everywhere in the study area, and can be measured by the Modified Mercalli Intensity (MMI). The latter scenario assumes ground motion intensity varies from place to place, and it estimates the intensity at each location within the study area by spatially interpolating peak ground acceleration (PGA) from a set of sample PGA values. Using each of these two scenarios, the LIFELINE-W(I) system estimates the occurrence rates of pipeline failure and calculates water flows in terms of pressure and water head. The occurrence rates of pipeline failure are stored in an ARC/INFO database that our system can easily access.

Figure 5 is an example of a map produced by the simulation module. In this figure, the wide dotted links represent the pipelines broken by the earthquake, and the black stars represent the locations of pump stations (or tanks) within the water supply network.

Assessment Module

This module calculates the demographic impacts of the simulated breaks on the population. It uses the inputs produced by the simulation module to estimate population impacts of the damage. In effect, the broken pipelines designated in the simulation module divide the water-supply network into a number of separate subsystems. The assessment module evaluates the connectivity of these subsystems to the system as a whole. This module then estimates the societal impacts of the damage to the water-supply network in terms of population and housing units that are still served or no longer served by the water network after the earthquake. To do this, the system follows three major steps.

First it determines which pipelines within each subsystem are still connected to pump stations (or tanks) and which are no longer connected. The pipelines connected to the pump stations (or tanks) are assumed to remain in operation after the earthquake. The pipelines disconnected from the pump stations (or tanks) are considered out of service. The system then determines the size of the population and the number of housing units still served by each subsystem. It also calculates the size and number no longer served. The population and housing units that are served by pipelines still in operation are assumed to have water service. Conversely, those linked to dead pipelines are assumed to lack water service. Finally, the module summarizes, for the system as a whole, the size of the population and the number of houses that are still served by the water-supply network and the size and number no longer served.

There are two possible outputs from the assessment module. Figure 5 is an example of one type of map produced by this module. In this figure, the solid links represent the operative pipelines after the earthquake, the dotted links represent the dead (or out of service) pipelines, and the wide dotted links represent the broken pipelines. This map displays the total population and number of housing units no longer served by the system given that five pipelines -- 579, 591, 604, 610, and 812 -- are broken after an earthquake. The alternative display is much like Figure 5 except that this map shows the total population and housing units still served by the water network.

Repair Module

Developing a good emergency response plan immediately after an earthquake is a sophisticated optimization task. It usually involves a thorough understanding of characteristics of the damaged water supply network and the societal impacts of the damage. The repair module developed in this study generates a response plan based on the service population of each pipe. The information about the broken pipelines and their related population is provided by the simulation and assessment modules.

The system simulates the repair process by selecting one broken pipeline at a time, evaluating the connectivity of the water network if that pipeline is repaired, and estimating the number of people for whom service will be restored. The broken pipeline that restores service to the most people is given highest priority. The system then assumes this pipeline has been repaired, and continues the repair analysis for the remaining broken pipelines. When completed, the system displays a priority list of repair to restore service. Figure 7 shows a priority repair list for the damaged water-supply network. In this case, pipeline 591 should be repaired first, pipeline 604 second, pipeline 812 third, and so on.

CONCLUSION

The GIS-based system developed in this research utilizes a modular approach to analyze the societal impacts of earthquake damage to an urban infrastructure system, specifically a water-supply network. The interface of this system is designed so the operator does not need to have knowledge of ARC/INFO software.

To analyze the societal impacts of infrastructure damage and generate a reasonable emergency response plan, the system simulates earthquake damage to the water-supply network using two possible methods and combining the results with demographic information from the 1990 Census of Population and Housing.

In generating an emergency response plan, this system considers the characteristics of the damaged water-supply network, the societal cost of the damage, and the capacity and size of the repair team. However, it does not consider the difficulty of restoring a broken pipeline or the time required for the repair. This issue will be considered in later research. Also, the pump stations or tanks might be out of operation after an earthquake; the system should consider their societal losses in the future.

FUTURE RESEARCH

This research will build upon the earlier work to incorporate impacts on economic activities and critical facilities. To effectively estimate the economic impacts of infrastructure damage, it is first necessary to locate the various economic activities with enough precision to determine their relationship to the infrastructure network. The U.S. Census Bureau does not publish the results of its economic census for areas smaller than the place level. Therefore address matching of local records maintained for tax assessment and business licenses provides the best method of locating economic activity. Once located, economic activities can be associated with support infrastructure using the same basic techniques currently used for population. By making this link, we can identify those activities that will be without fire protection after an event. We can also identify those business and critical facilities that are likely to experience significant service interruption. This will allow interruption and input/out modeling efforts. These economic impacts can then be integrated and balanced with the social impacts currently produced by the model.

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TABLE 1. Population and Housing Variables of STF-1B

Characteristic	Information within Characteristic
Persons	Total
Race	White Black American Indian, Eskimo or Aleut Asian or Pacific Islander
Persons of Hispanic Origin	Total

Age	Under 18 years 65 years and over
Housing Units and Units in Structure	Total 1 Unit Detached or Attached 10 or more units
Mean Number of Rooms	Mean number of rooms in the Housing Units
Tenure	Owner occupied housing units Renter occupied housing units
Mean Value	Mean Value for owner occupied housing units
Mean Contract Rent	Mean Contract Rent for renter occupied housing units
Housing units with 1.01 or more persons per room	Total occupied Renter occupied
Persons in occupied housing units	Total
Housing unit occupants	One person households Family householder, no spouse present with 1 or more persons under 18 present

TABLE 2. Population and Housing Varibles of STF-3A

Characteristic	Information within Characteristic
Persons	Total
Race	White Black American Indian, Eskimo or Aleut Asian or Pacific Islander
Households	Total Families

Age	All ages Less than 10 Greater than 60
Group Quarters	Persons living in group quarters
Industry	Persons employed in various industries by SIC codes
Income	All household income Median Household Income
Water Source	Public water system Wells/other
Sewage Disposal	Public sewage disposal Septic tank or cesspool/other

D-48-X10
(Final) #2

Estimating Social and Economic Impacts of Infrastructure Damage with GIS

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Final report
NCEER Grant 94-6301

October 30, 1996

Purpose

The purpose of this project was to extend the social impact method developed in the NCEER Year 8 project to include economic impacts as well. The Tear 8 research developed a GIS-based system (PIPELINE-FIX) that links components of the infrastructure system (e.g. individual water lines and pump stations) to small area population data. (For a detailed description of this system, see French, Jia, Meyer and Grover, 1996.) This social impact methodology associates demographic information from the 1990 Census of Population and Housing with nodes on the water distribution network. It then calculates the number and characteristics of people impacted by infrastructure damage at various locations based on the topological relationships of the distribution network. The number and characteristics of the effected population allow us to quantify the societal impacts of the damage to the infrastructure system. PIPELINE-FIX then produces a repair strategy based on user-selected demographic characteristics. Thus, this system translates the physical measures of damage to societal impacts defined by the size and type of population being served. A conceptual framework for this impact system is shown in Figure 1.

Estimating Economic Impacts

An approach similar to that used to characterize social impacts was utilized for economic impacts. Economic impacts are seen as a function of the number of employees in each economic sector that experience an interruption in service due to earthquake damage to the infrastructure system. These first round employment effects can then be loaded into an input-output model to calculate indirect effects attributable to the linkages between economic sectors.

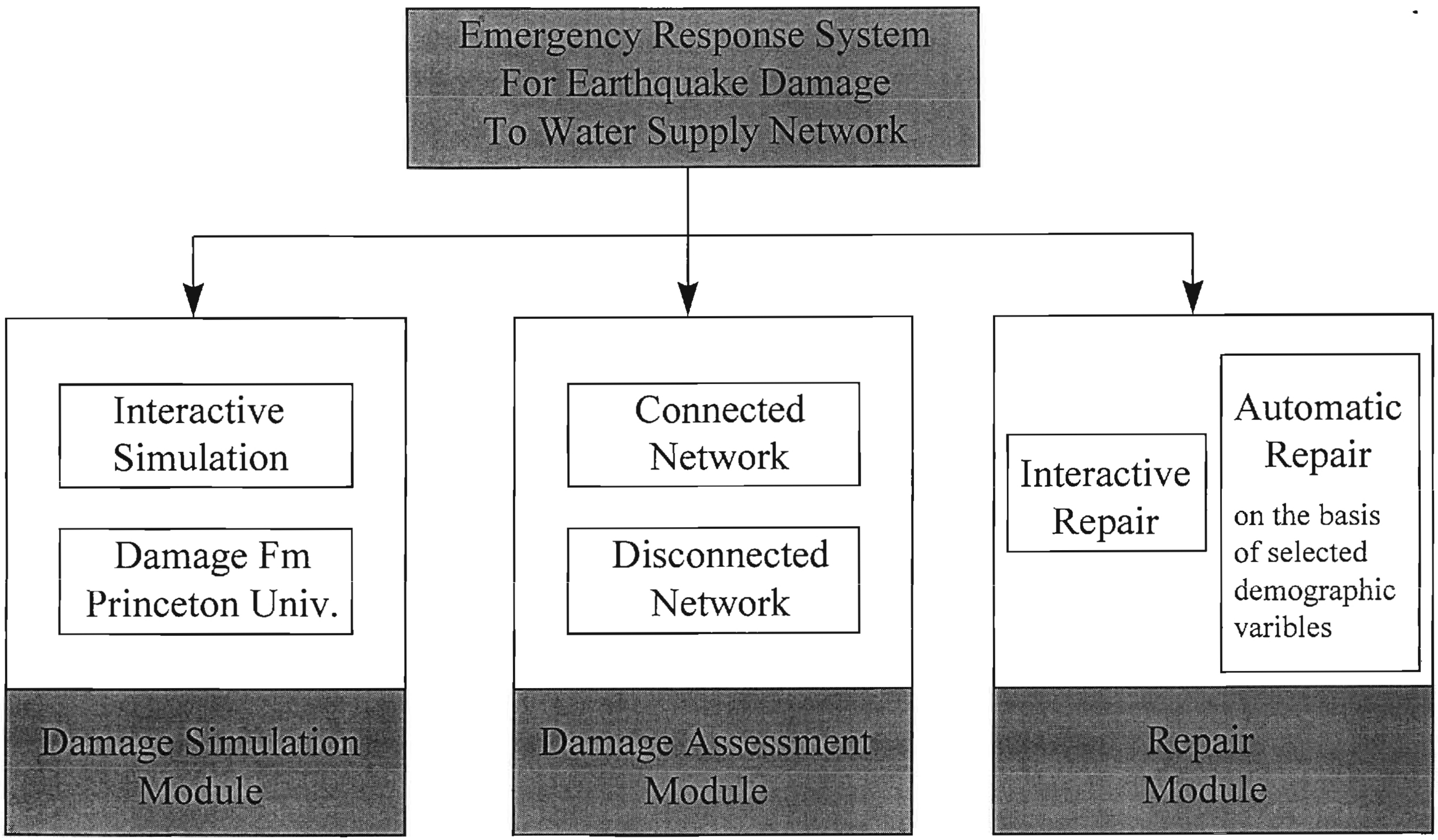

Figure 1. Conceptual Framework of the PIPELINE-FIX System

The employment information used in this project was drawn from the Census Transportation Planning Package (CTPP). This data set was developed by the Bureau of the Census and the U.S. Department of Transportation to support metropolitan transportation planning. (Bureau of the Census, 1991). This is one of the few secondary sources that provide employment data for small geographic areas. The CTPP reports employment in each economic sector as defined by its Standard Industrial Classification (SIC). For this project we grouped the employment data for Shelby County into 18 economic sectors. The economic sectors and their corresponding SIC codes are shown in Table 1.

Table 1. Economic Sectors

	Economic Sector	Two Digit SIC
1	Agriculture, Forestry, and Fishing	01,02,08,09
2	Mining	10,12-14
3	Construction	15-17
4	Manufacturing (Non durable)	20-23,26,27
5	Manufacturing (Durable)	24,25,28-39
6	Transportation	40-47
7	Communication/Utilities	48,49
8	Wholesale Trade	50,51
9	Retail Trade	52-59
10	Finance, Insurance, and Real Estate (FIRE)	60-67
11	Business and Repair Services	73,75,76
12	Personal Services	70,72
13	Entertainment Services	78,79
14	Health Services	80
15	Educational Services	82
16	Other Professional Services	81,83,84,86-88
17	Public Administration	91-97
18	Armed Forces	

The CTPP uses a number of small geographic areas called traffic analysis zones (TAZ's) to locate employment. Shelby County is divided into 618 traffic analysis zones, each slightly larger than the typical block group used in the social impact study. Figure 2 shows the Shelby County TAZ's and the total number of employees that work in each. Similar data is available for employment in each of the 18 economic sectors listed in Table 1.

A map of the Shelby County water distribution system is included as Figure 3. A key technical challenge was presented by linking the employment from the TAZ polygons to the nodes of the water distribution network. This linkage is central to the assessment of economic impacts of water system damage. To solve this problem we used a point-to-node aggregation approach similar to that used for demographic data in the earlier work. This approach aggregates the employment information to the closest nodes in the water system using the spatial technique called a snapping. The snapping processes can be described as follows:

- find the closest water system node for each TAZ centroid and assign the node number to the centroid. Adjust the search radius to a proper length so that all the centroids are associated with the closest corresponding nodes. This assignment process assumes that all the employees within a TAZ are served from the node closest to that centroid;

MEMPHIS/SHELBY COUNTY EMPLOYMENT

by Traffic Analysis Zone

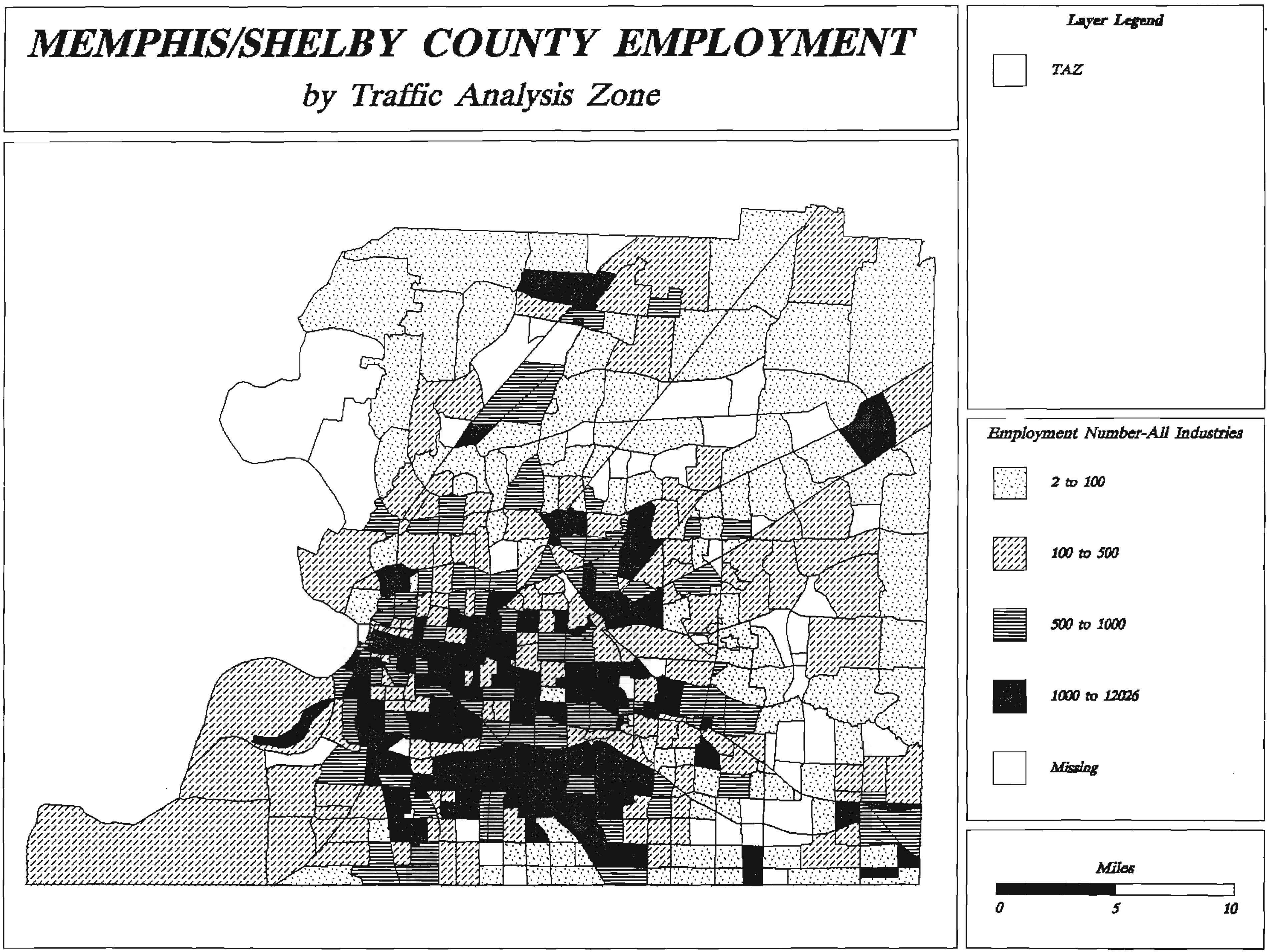

Figure 3. Memphis/Shelby County Water Distribution System

- sum up all employment with same node number and assign the results to the corresponding node. The results represent the total number for employees that are served by the water distribution network through the node.

This point-to-node snapping process is significantly affected by the number and spatial distribution of centroids. A large number of centroids (as in the case of Census blocks) provides small average distance from any centroid to its closest node. Since TAZs are relatively large compared to the size of the links in the water network, a number of nodes are left without population. This is similar to the problems encountered with Census Block Groups and discussed in the Year 8 final report..

Results

Economic impacts can be estimated using techniques similar to those developed for social impacts. The Census Transportation Planning Package is a readily available source of employment data. The PIPLINE-FIX model was modified to accept employment data from the Census Transportation Planning Package and the repair and assessment modules were modified to use this employment data.

In many cases the TAZs used to report the CTPP employment data do not provide fine enough spatial resolution to be used in conjunction with a municipal water system. Tests showed that many water system nodes were left without data due to the relatively large size covered by the TAZs.

Future Directions

Commercial and industrial building inventories provide a more precise means of locating employment than the Census Transportation Planning Package. Year 10 will modify the PIPELINE-FIX model to use employment data derived from building square footage drawn from the Shelby County Assessor's files rather than the CTPP. This will allow more precise allocation of employment to the water system node providing its service.

Related Activities

This research team was engaged with other NCEER researchers in two projects: the Loss Assessment for Memphis Buildings and the Impacts of Electricity lifeline Disruption monograph. The papers contributed to these efforts are attached.

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Engineering and Socioeconomic Analysis of a New Madrid Earthquake: Impacts of Electricity Lifeline Disruption in Memphis, Tennessee

Chapter 4
GIS Analysis of Economic Disruption

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Introduction

Until recently earthquake infrastructure damage models produced damage estimates that characterized the earthquake impact in physical terms. For examples of these types of models, see Davis et al., 1983a amd 19883b, Applied Technology Council, 1985, O'Rourke and Russell, 1991 and Sshinozuka, Hwang and Murata, 1992.[1] These models typically characterize damage in terms of breaks per kilometer or the length of time until service is likely to be restored. While this type of information was an important step forward in modeling the impact of an earthquake on infrastructure systems, it did not fully meet the needs of emergency preparedness and hazard mitigation planners. The National Research Council and others have suggested that modeling needs to go beyond physical damage to capture the social and economic impacts of earthquakes (Panel on Earthquake Loss Estimation Methodology, 1989).

As a result social scientists have been developing models that estimate the impact of an earthquake on the social and economic functions of a city or a region. (See, for example, Applied Technology Council, 1991, and Rose, Chang, Szczesniak and Lim, 1995.) These models address a wide array of impacts; here we are primarily concerned with the economic impacts of damage to infrastructure systems. Generally, loss models concerned with infrastructure damage produce estimates for two types of economic impacts - loss of productivity to business and industries that depend on these systems (direct damage). They also estimate how reduced productivity in firms impacted by service interruption may impact the productivity of their customers and suppliers (indirect damage). For both of these types of impacts the importance of firms in the regional economy is measured by the size of their employment.

This chapter describes how geographic information systems (GIS) can be used to develop links between economic sectors and one lifeline system, electric power. This type of economic modeling can help decision makers understand the full effects of an earthquake on their city or region. It can also help emergency response planners and electric utility operators allocate response resources in the most effective manner and set priorities for hazard mitigation efforts.

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[1] For an excellent review of damage modeling techniques, see Risk Management Software and California Universities for Research in Earthquake Engineering, 1994.

A geographic information systems provides a number of features that are important to the damage modeling process. Since infrastructure systems are complex networks consisting of many components with varying degrees of fragility, the geographic information system's ability to store and manipulate large amounts of information is helpful. The GIS uses a relational database to store characteristics of system components that are important in determining their response to ground shaking and other earthquake-induced effects. Unlike individual buildings, infrastructure systems are networks that are spread over wide areas that include a variety of surfical geology conditions. These differences in site conditions mean that different parts of the network are likely to experience differential ground shaking effects. It is critical to be able to associate the appropriate parts of the network with the corresponding geology and level of ground motion. The GIS provides the spatial analysis tools needed to combine site specific geotechnical information with system characteristics based on location. The GIS also provides overlay or proximity functions that make it possible to link economic activities or service populations to specific parts of the infrastructure system. (For an example of this type of analysis applied to a water system, see French, Jia, Meyer and Grover, 1996.)

In this particular research we are primarily interested in how to link firms to particular parts of the electric power distribution system. Figure 1 presents a conceptual framework that illustrates the problem. This research attempts to bridge the physical damage models and the economic loss models by linking employment with electric power service areas.

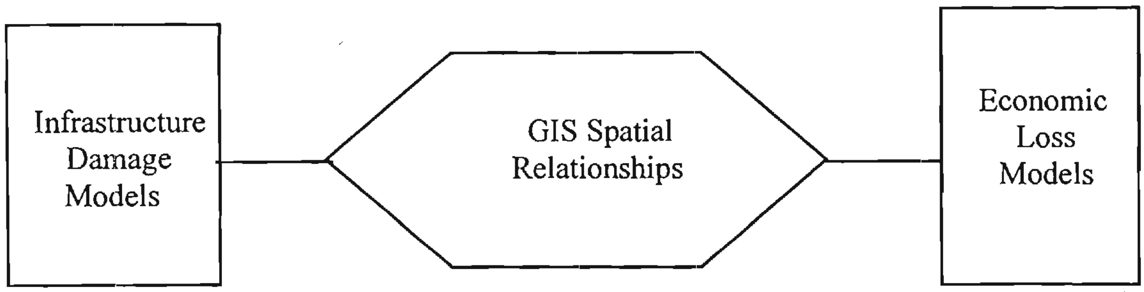


Figure 1 Conceptual Framework for Linking Lifelines and Economic Activity

Describing the Local Economy

Most economic loss models characterize the size and importance of economic sectors using employment. Employment serves as a surrogate for the firm's output or production. As part of the NCEER research program Rose and his colleagues have utilized an input-output model to estimate the inter-industry impacts of damage to the Memphis electric power system (Rose, Chang, Szczesniak and Lim, 1995). The IMPLAN input-output model used requires employment in various economic sectors to describe the inter-industry linkages in the local economy. We, therefore, needed a source of employment data by economic sector for the Memphis region. Since the electric power lifeline models produce location specific damage information, it was also desireable to find a data set that also described the location of employment in the various sectors.

The Census Transportation Planning Package (CTPP) provides the best available inventory of employees by their work location. This data set was developed by the Bureau of the Census and the U.S. Department of Transportation to support metropolitan transportation planning. (Bureau of the Census, 1991). We used the CTPP data for Shelby County to tabulate the number of employees in each of 18 economic sectors. The economic sectors and their corresponding SIC codes are shown in Table 1.

Table 1. Economic Sectors

Group #	Economic Sector	Two Digit SIC
1	Agriculture, Forestry, and Fishing	01,02,08,09
2	Mining	10,12-14
3	Construction	15-17
4	Manufacturing (Non durable)	20-23,26,27
5	Manufacturing (Durable)	24,25,28-39
6	Transportation	40-47
7	Communication/Utilities	48,49
8	Wholesale Trade	50,51
9	Retail Trade	52-59
10	Finance, Insurance, and Real Estate (FIRE)	60-67
11	Business and Repair Services	73,75,76
12	Personal Services	70,72
13	Entertainment Services	78,79
14	Health Services	80
15	Educational Services	82
16	Other Professional Services	81,83,84,86-88
17	Public Administration	91-97
18	Armed Forces	

The geographic location of individual firms is not available for privacy reasons. The location of the CTPP employment data is provided by aggregating the data to small geographic areas called traffic analysis zones (TAZ's). Shelby County is divided into 618 traffic analysis zones that cover the entire area. The number of employees for each economic sector for each zone is reported in tabular form. Figure 2 shows the Shelby County TAZ's and the total number of employees that work in each. Similar data is available for employment in each economic sector.

Spatial Analysis

To make the link between the electric power damage models and the economic models, we developed a relationship between the TAZ's and the electric power service areas based on location. To do so, required several steps: (1) we digitized the 36 electric power service areas from a map provided by Memphis Power and Light Company; (2) we performed an overlay of electric power service area boundaries on the TAZ's; and (3) we aggregated employment data from the TAZ's to the larger electric power service areas. This employment by economic sector for each electric power service area was than used to estimate the direct and indirect economic impacts of power disruption caused by an earthquake.

As can be seen in Figure 3, each electric power service area contains between 8 and 15 TAZ's. The electric power zone boundaries are not completely congruent with the underlying TAZ boundaries. For those TAZ's that are split between electric power service areas, their employment was apportioned between the two based on the area of the TAZ in each. This apportioning method assumes a uniform distribution of employment withi each TAZ. Without more detailed data on firm location, this is the best assumption that can be made an provides the best method of allocating employment to each service area. Using this method employment in 18 economic sectors was estimated for electric

Figure 2. Spatial Distribution of Total Employment in Shelby County by Traffic Analysis Zone

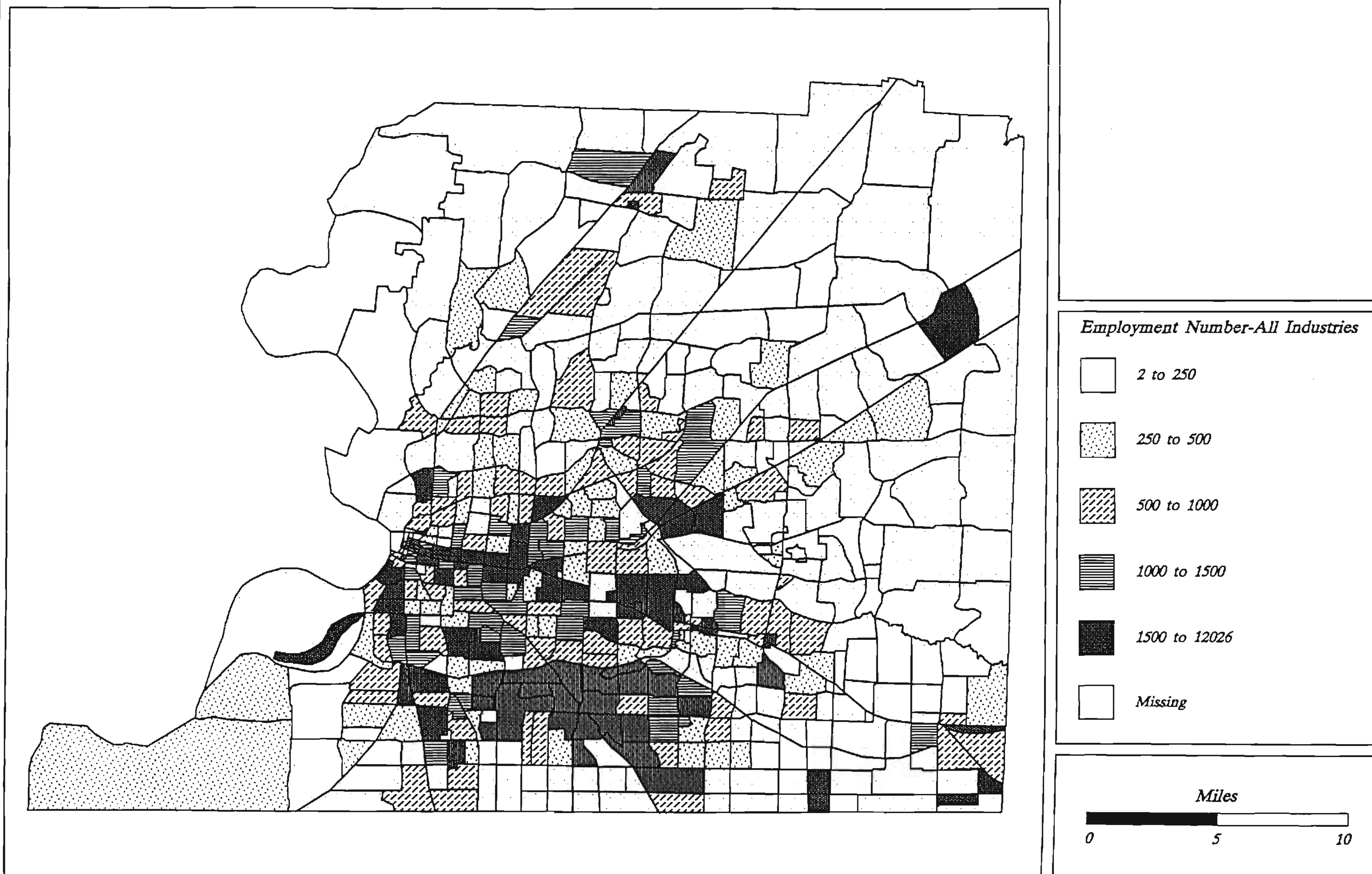
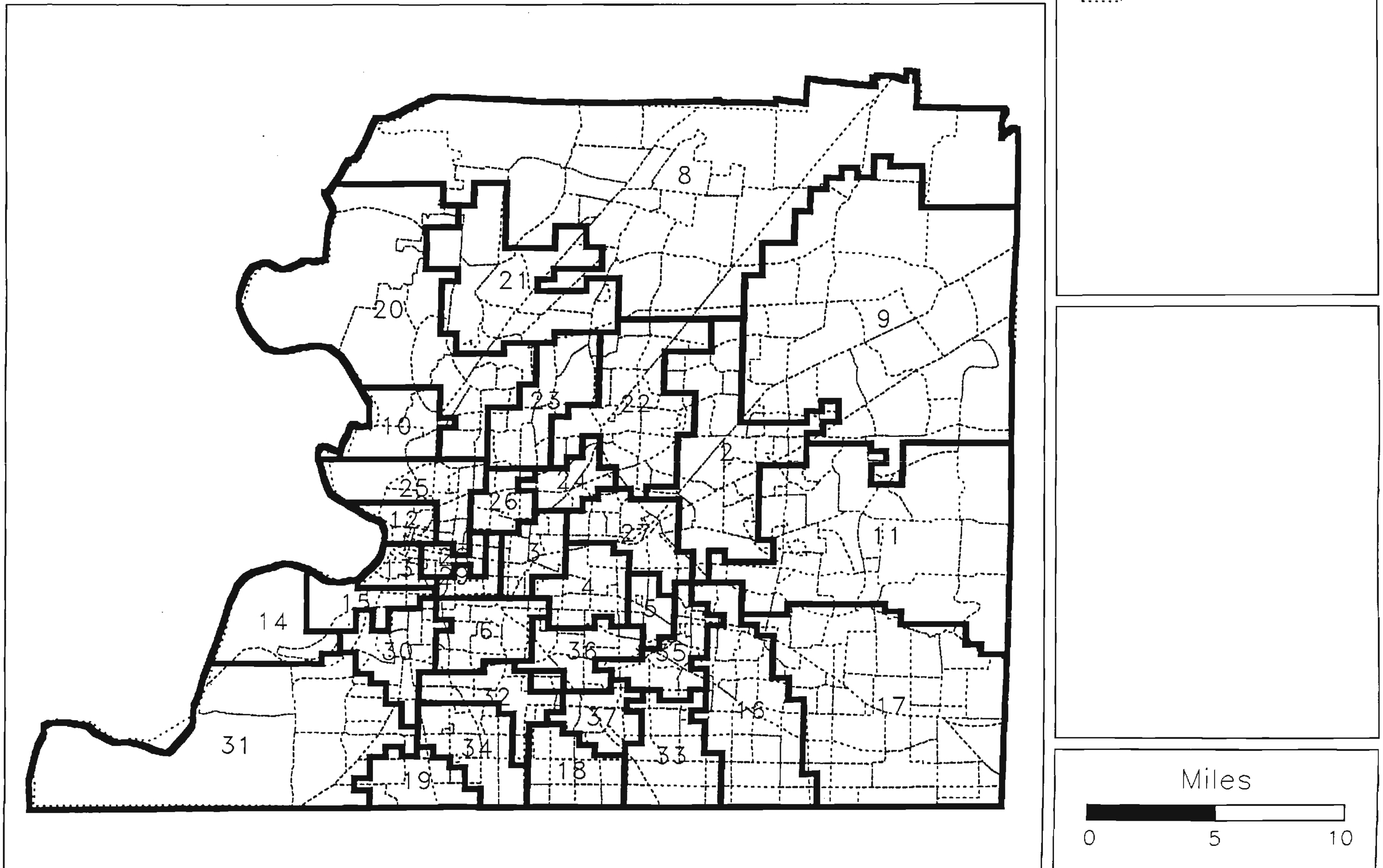


Figure 3. Electric Power Service Areas and Traffic Analysis Zones

Memphis/Shelby County, Tennessee



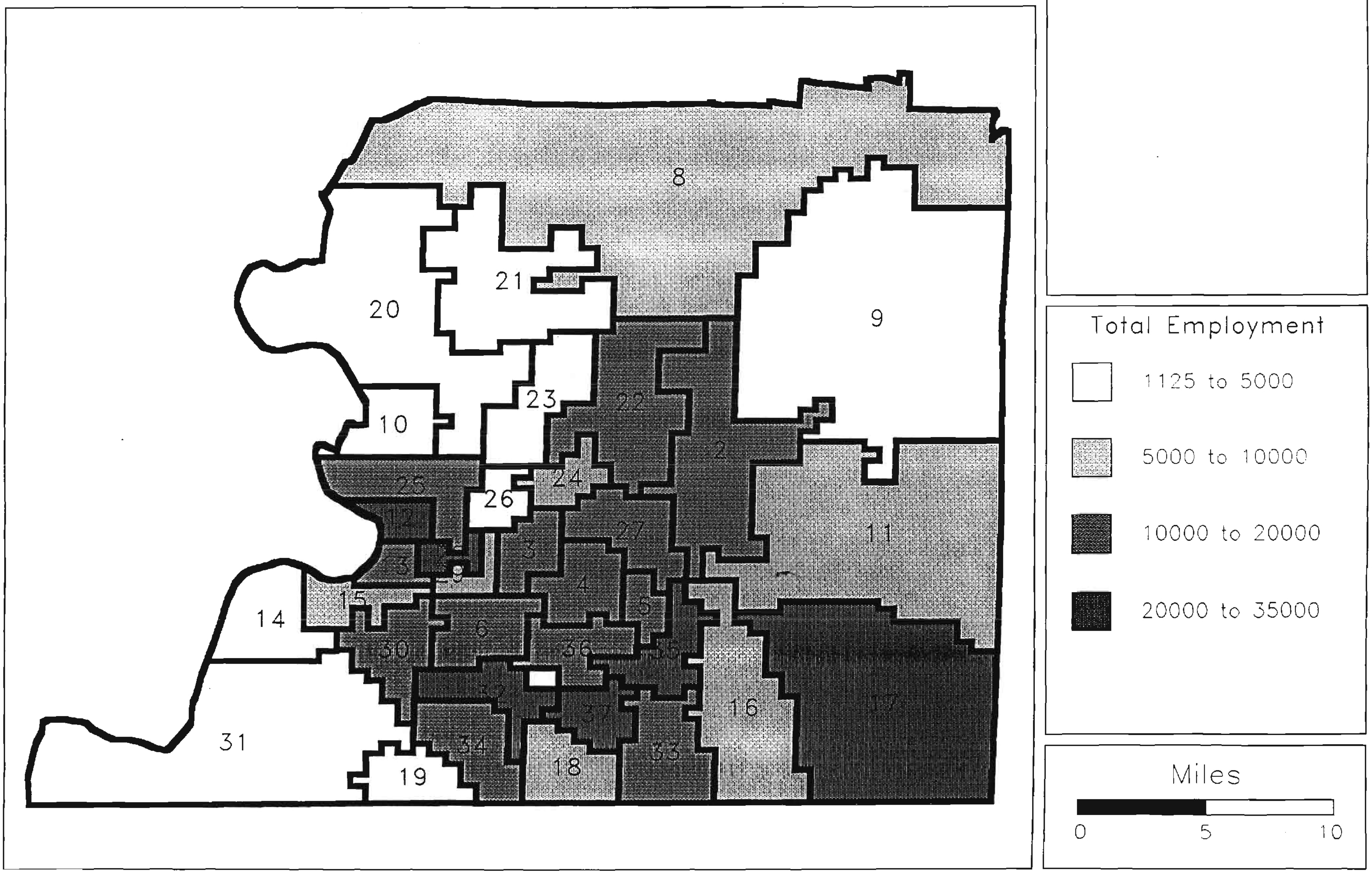
power service area. Figure 4 shows the total employment for each electric power service zone. Simliare data is avalable for each of the 18 sectors. This employment data provides the basis for estimating the economic impacts of an earthquake using the IMPLAN model

Conclusions

The GIS provides a mechanism for linking widely available employment data to the areas of interest. No employment information was formerly available for the electric power service areas, thus the economic impacts of electric power interruption could not be readily estimated. With the employment data for each electric power service area both the direct and indirect economic impacts of damage to the electric system could be estimated. This approach is widely applicable to a wide range of social and economic impact applications. While some of the employment estimates are approximations due to the incongruence of the TAZ's and the electric power service areas, the error likely to result from this problem is no greater than that caused by uncertainties thoughout the earthquake damage modeling process.

Figure 4. Total Employment by Electric Power Service Area

Memphis/Shelby County, Tennessee



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THE ECONOMIC USE OF BUILDING STRUCTURE TYPES: THE MEMPHIS CASE

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1. Introduction

In the last decade significant progress has been made in modeling the impacts of earthquakes on both physical property and on economic systems. As these loss estimation models have evolved, however, a significant gap has developed between the engineering and the social science approaches. Structural engineers have made great progress in developing models that predict the number of physical structures that are likely to be damaged by of various magnitudes. (See for example, Algermissen, 1978, Applied Technology Council, 1984; and National Institute of Building Sciences, 1994.) Typically, these models apply different fragility curves to different structural types (e.g. unreinforced masonry, steel frame, etc.) to model damage.

The National Research Council and others have suggested that modeling needs to go beyond physical damage to capture the social end economic impacts of earthquakes. As a result social scientists have been developing models that estimate the impact of an earthquake on the economic functions of a city or a region. (See for example, Rose, Chang, Szczesniak and Lim, 1995.) These models are based on the economic activities that occupy damaged structures or are economically linked to such firms. This difference in orientation produces difficulties in integrating engineering and social science loss estimation models.

With the initiation of the Loss Assessment for Memphis Buildings (LAMB) project, NCEER researchers were forced to deal with this divergence in modeling approaches, if they were to produce a comprehensive loss assessment. Figure 1 shows a conceptual framework that illustrates the problem. This paper analyzes data on the commercial and industrial building stock of Memphis, Tennessee to understand the economic and social functions of different types of structures. This research attempts to bridge the structural damage models and the economic loss models by developing a set of cross classification tables that represent the relationship between the structures and their economic use.

In order to develop the cross classification relationships, this research used a combination of statistical and geographic information system (GIS) techniques to analyze the distributions of different structure types. Matrices that depict the relations between structures and their economic use in terms of probability were produced. These matrices can be used to estimate the economic sectors that will be affected once a mix of damage structure types is estimated with a typical loss estimation model.

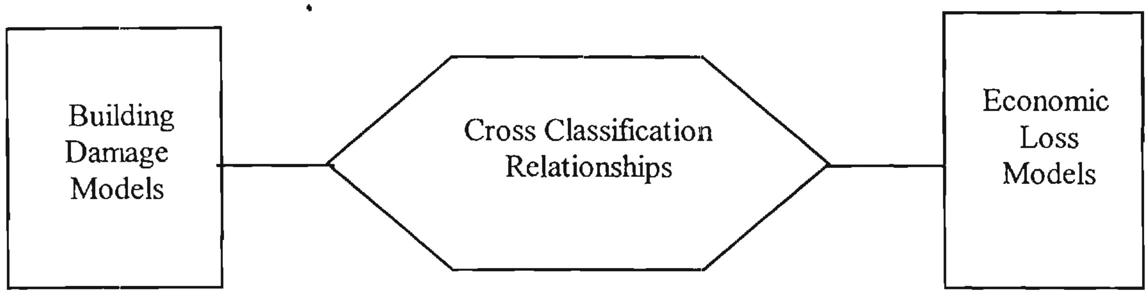

Figure 1 A Conceptual Framework for Linking Economic Use and Building Type

2. Data Sources and Data Preparation

Information about the type and economic use of buildings in the Memphis metropolitan area was originally collected by Dr. Barclay Jones (Jones and Chang, 1994). This data set was further enhanced and cleaned by Dr. Stephanie Chang of EQE International. The Memphis Tax Assessors Office provided the basic property information. This information was augmented with additional property data from the State Board of Equalization and other sources. (For a detailed explanation of the database development, see Malik, 1995) The result is a database that includes property information for more than 250,000 buildings in the Memphis metropolitan area (Shelby County, Tennessee). Since this project is concerned with the economic use of structures, we extracted just the 17,382 commercial and industrial records from the database.

The property database includes information on structure type, floor area of the building, and its use. The structure type field classifies the building into one of five general structure types: wood, unreinforced masonry (URM), reinforced concrete, metal, or steel. Floor area is measured in square feet of useable space within the structure. The assessors file also includes a field that indicates the use of each nonresidential building. The use is classified into 99 categories that meet the tax assessor's needs.

While this use field provides very important information, the assessor's classification scheme is not directly compatible with the input needs of the economic loss models developed by NCEER researchers. Using three digit SIC codes, we developed a lookup table that translates the 99 categories used by the Shelby County Tax Assessor into a set of 18 economic use groups that are based on the Standard Industrial Classification (SIC) system. Table 1 lists the eighteen economic use groups. These 18 economic use groups will be used to characterize the use of the structure throughout this research. Appendix A provides a detailed listing of the look up table used to translate assessors use codes into our economic use groups.

Table 1. Economic Use Groups

Group #	Economic Use Group	Two Digit SIC
1	Agriculture, Forestry, and Fishing	01,02,08,09
2	Mining	10,12-14
3	Construction	15-17
4	Manufacturing (Non durable)	20-23,26,27
5	Manufacturing (Durable)	24,25,28-39
6	Transportation	40-47
7	Communication/Utilities	48,49
8	Wholesale Trade	50,51
9	Retail Trade	52-59
10	Finance, Insurance, and Real Estate (FIRE)	60-67
11	Business and Repair Services	73,75,76
12	Personal Services	70,72
13	Entertainment Services	78,79
14	Health Services	80
15	Educational Services	82
16	Other Professional Services	81,83,84,86-88
17	Public Administration	91-97
18	Armed Forces	

EQE has taken the assessor's data and developed a more detailed categorization of structures to meet the needs of the LAMB project. The LAMB project has developed fragility curves for five structural types. This damage estimation approach divides the unreinforced masonry buildings into two groups based on their height. URMA includes those URM structures that are one story; URMB includes those that are two or more stories. Similarly, the LAMB classification breaks down reinforced concrete structures

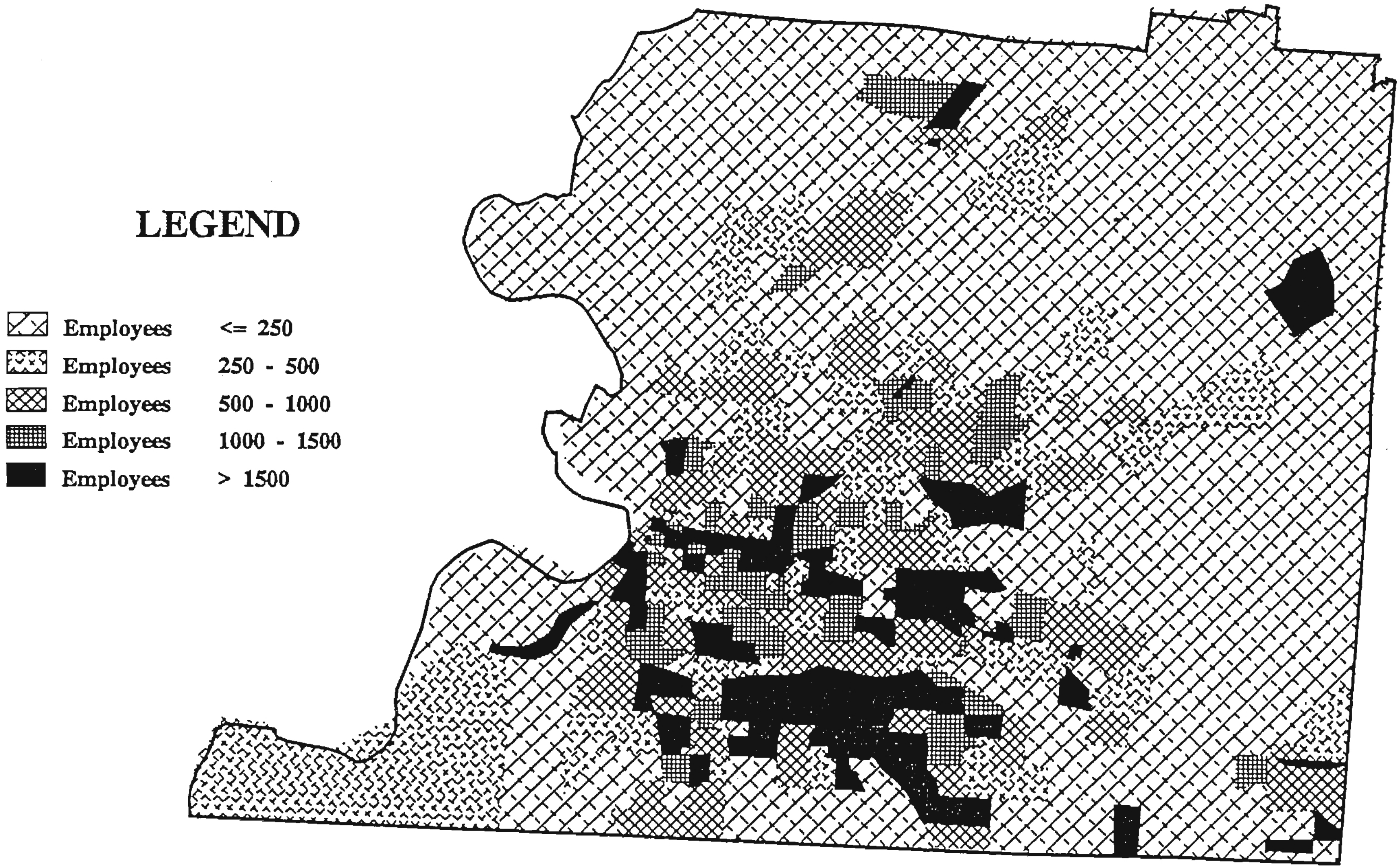

Figure 2 Spatial Distribution of Employment in Shelby County

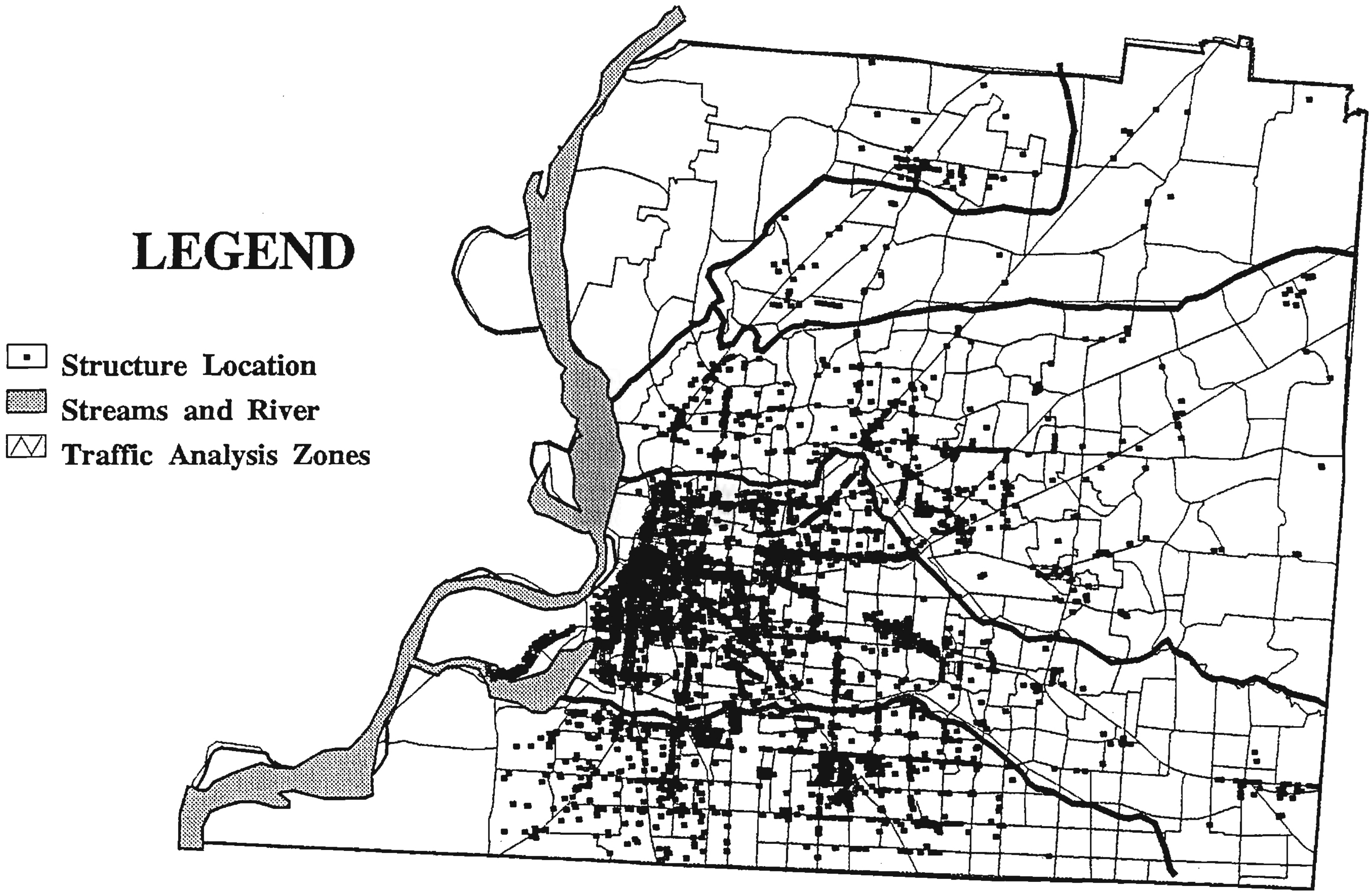

Figure 3 Locations of Building Structures in Shelby County, Tennessee

into three groups: RCA, one to three stories; RCB, four to six stories; and RCC seven or more stories. All other structures are combined together into an Other category. This research investigates both the general structural classification and the LAMB classification

Most economic loss models characterize the various sectors of the economy based on the number of employees in the sector. In earlier work we have used the Census Transportation Planning Package (CTPP) to locate employees within the Memphis metropolitan area (Bureau of the Census, 1993). The CTPP is the best available inventory of employees by their work location. The CTPP provides the number of employees in each of our 18 economic use groups within small geography areas. The geographic location is provided by dividing Shelby County into 513 traffic analysis zones (TAZ's) and reporting the number of employees for each economic sector within each zone. Figure 2 shows the Shelby County TAZ's and the total number of employees that work in each. Similar data is available for employment in each economic sector.

To make the link between the structural models and the economic models, this research must develop a relationship between the number of employees and the square footage of buildings in each economic sector. In doing so, several procedures are involved. These procedures are (1) geocoding the individual buildings, (2) performing point-in-polygon aggregation of buildings into TAZs, (3) aggregating the floor areas for each structure type for each TAZ, and (4) correlating the resulting floor areas of structure types to employment data within each TAZ.

Since the assessor's file contains x and y coordinates for each building in the Uniform Transformation Mercator (UTM) coordinate system, it is relatively straightforward to associate the buildings with their employees based on location. We generated an ARC/INFO coverage that locates each building on a map. Figure 3 represents the results of the geocoding process. In this figure, it is clear that majority of 17,382 buildings are located in or near downtown Memphis. Also, the figure indicates some TAZs do not enclose any commercial or industrial buildings.

The point-in-polygon overlay operation assigns each building to the TAZ where it is located. The floor area of individual buildings are summed for each structure type and assigned to the TAZ. Once the floor areas of structure types are created for each TAZ, they can be linked to data on the employees in various economic use groups which are available only at the TAZ level.

3. Relationship between General Structure Type and Economic Use

The first step in the analysis was to cross classify the buildings by their uses based on data included in the tax assessor's file. Table 2 shows the total floor area of each of the five general structure types within the eighteen economic use groups. Since commercial buildings can vary so widely in terms of size, we have chosen to use the square footage of structures in each category rather than the number of buildings. The table indicates that nearly half of 221 million total square feet of floor area is made up of URM structures, more than a quarter is in metal structures, and another 20 percent belong to the reinforced concrete and steel structures.

We then use the distribution of square footage within each structure type to create a probability distribution across our economic use groups. These probabilities are shown in Table 3. A graphic representation of these probability distributions is provided by the histograms shown in Figures 4 to 8. (Please refer to Table 1 for the number of each economic group.) As these figures show there is some important variation in economic use by structure type.

As can be clearly seen in Figure 8, steel buildings have the most distinctive pattern. Nearly 60 percent of these structures are used by business and repair services. Wholesale trade is the next most important use of this structure type with 12 percent of the total floor area. This is markedly different from metal buildings where more than a half of all floor area is used for wholesale trade. About 15 percent of the metal building stock is used for retail trade and another 15 percent is allocated to durable manufacturing.

Wholesale trade activities dominate both URM and reinforced concrete structure types with 36 and 44 percent of the square footage, respectively. Retail trade is also an important component of the URM building stock, comprising 32 percent. Business and repair services are more important components in the reinforced concrete stock, where they comprise 20 percent. These uses account for only about twelve percent among the URM buildings.

Wood structures account for a small proportion of the industrial and commercial building stock in the Memphis area. The uses are scattered among several economic sectors, with retail trade accounting for the largest proportion at 33 percent.

Using these probability distributions we can begin to translate physical damage information into economic impacts. A typical damage assessment model will produce an estimate of the number and square footage of buildings that are damaged within each structure type. Using the probability distributions shown in Table 3, we can assign a proportion of those buildings to each economic sector. For example, if we know that 100,000 square feet of steel buildings are expected to be damaged, we would estimate that 60,000 square feet of that amount would be in business and repair services, 12,500 square feet would be in wholesale sector and 6000 square feet would be allocated to retail trade and so forth. This technique allows us to begin to distribute physical damage to economic sectors.

This analysis clearly shows that there is some significant variation in economic use by structure type. While the correlations are not perfect, they are strong enough to allow us to estimate how damage will be distributed among different economic sectors. It is not

Table 2 General Structure Type and Economic Use

Economic Use Group (Square Feet, Million)

	Agri	Mining	Constr.	Man.(non)	Man (dur)	Trans.	Comm.	Whole	Retail	FIRE	Business	Personal	Entertain	Health	Educat.	Others	Adm.	Forces	Total
WOOD	0.000	0.000	0.000	0.006	0.284	0.092	0.000	1.535	3.056	0.043	2.445	0.932	0.080	0.562	0.004	0.223	0.000	0.000	9.263
URM	0.000	0.000	0.000	2.559	7.171	0.393	0.000	36.875	33.057	0.754	12.651	4.807	0.329	1.981	0.304	0.673	0.005	0.000	101.560
RC	0.000	0.000	0.000	0.216	3.540	0.048	0.000	11.659	3.725	0.265	5.379	0.863	0.000	0.754	0.007	0.004	0.000	0.000	26.461
METAL	0.000	0.000	0.000	2.689	9.719	0.868	0.000	36.402	9.559	0.078	3.555	0.640	0.261	0.192	0.053	0.235	0.000	0.000	64.252
STEEL	0.000	0.000	0.000	0.558	0.676	0.000	0.000	2.378	1.130	0.805	10.976	1.161	0.019	0.782	0.000	0.000	0.000	0.000	18.486

Table 3 Probabilities of General Structure Type and Economic Use

Probability of Economic Use

	Agri	Mining	Constr.	Man.(non)	Man (dur)	Trans.	Comm.	Whole	Retail	FIRE	Business	Personal	Entertain	Health	Educat.	Others	Adm.	Forces	Total
WOOD	0.000	0.000	0.000	0.001	0.031	0.010	0.000	0.165	0.330	0.004	0.264	0.101	0.009	0.061	0.000	0.024	0.000	0.000	1.000
URM	0.000	0.000	0.000	0.025	0.071	0.004	0.000	0.363	0.325	0.007	0.125	0.047	0.003	0.020	0.003	0.007	0.000	0.000	1.000
RC	0.000	0.000	0.000	0.008	0.134	0.002	0.000	0.441	0.141	0.010	0.203	0.033	0.000	0.028	0.000	0.000	0.000	0.000	1.000
METAL	0.000	0.000	0.000	0.042	0.151	0.013	0.000	0.567	0.149	0.001	0.055	0.010	0.004	0.003	0.001	0.004	0.000	0.000	1.000
STEEL	0.000	0.000	0.000	0.030	0.037	0.000	0.000	0.129	0.061	0.043	0.594	0.063	0.001	0.042	0.000	0.000	0.000	0.000	1.000

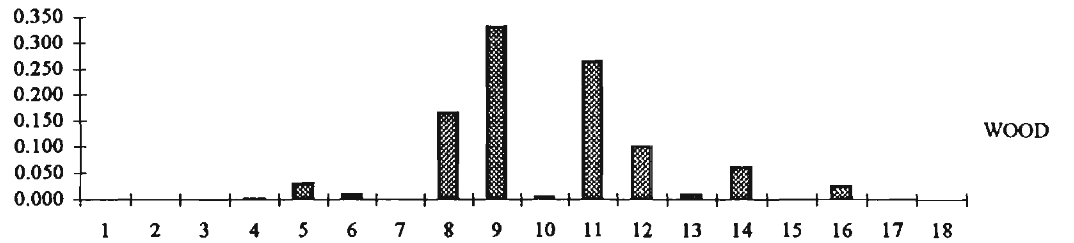

Figure 4 Probability of Economic Use of Wood Structures

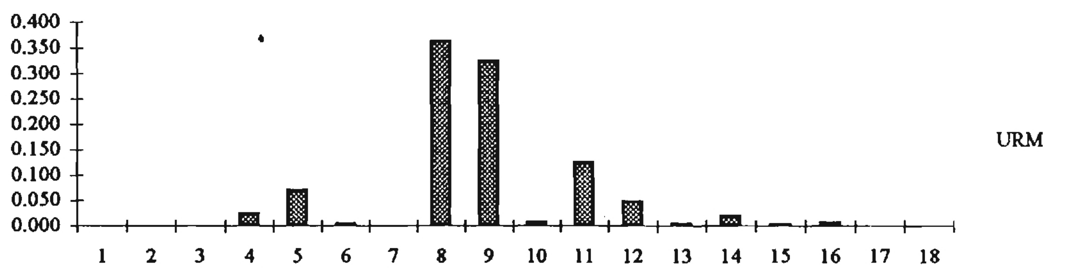

Figure 5 Probability of Economic Use of URM Structures

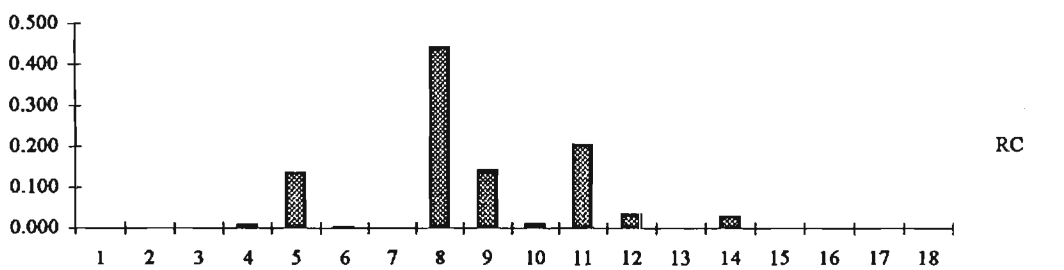

Figure 6 Probability of Economic Use of RC Structures

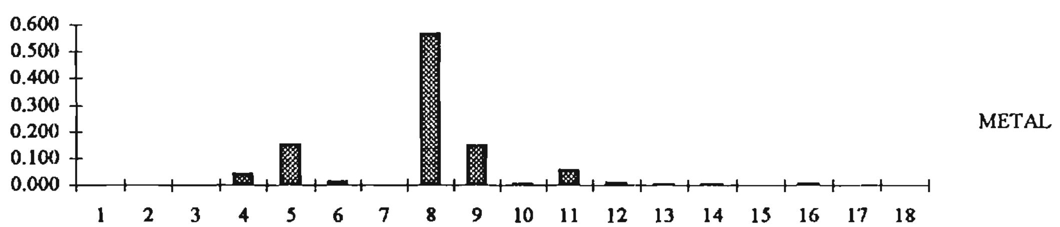

Figure 7 Probability of Economic Use of METAL Structures

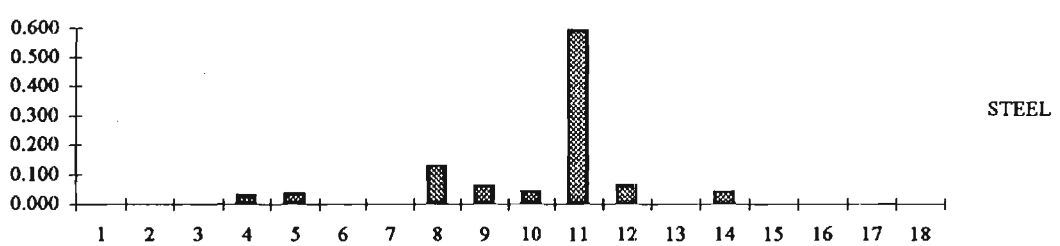

Figure 8 Probability of Economic Use of STEEL Structures

clear that these relationships can be generalized to other metropolitan areas, where the characteristics of the building stock may be quite different. These relationships should, however, be quite good for the Memphis area, since they have been developed on the most complete enumeration of buildings available.

4. Relationship between LAMB Structure Type and Economic Use

We now repeat this analysis using the more detailed LAMB building classification system. We use the same eighteen economic classes as in the preceding analysis. The cross classification of floor area by the eighteen economic use groups and the LAMB structure types is shown in Table 4. Most importantly the table shows that the LAMB structure types capture nearly 60 percent of the commercial and industrial building floor area in the Memphis/Shelby County area. Within the five structure types explicitly modeled in the LAMB effort, single story unreinforced masonry (URMA) structures are the most important, accounting for over one third of the total building stock in the study area. Roughly 10 percent of the total is comprised of multistory unreinforced masonry (URMB) structures, and another 10 percent is in the low-rise reinforced concrete (RCA) structures. RCB and RCB, the reinforced concrete structures greater than three stories, account for a very small component of the building inventory.

The probabilities of each economic use for each structure type are shown in Table 5. The histograms that graphically depict these distributions are presented in Figures 9 through 14. The economic use of the URMA buildings is dominated by wholesale (41 percent) and retail trade (35 percent). Business services and durable manufacturing each account for less than 10 percent of the URMA total. Wholesale (21 percent) and retail trade (23 percent) are again important in the URMB buildings, however, business and personal services become more important for this building type. Together, these four economic groups account for 86 percent of the URMB building area.

The reinforced concrete buildings show a very different pattern of use than do the unreinforced masonry buildings. The use of RCA buildings (one to three stories) are unique among the building types in being closely associated with a single economic sector. More than a half of RCA buildings are used for wholesale trade purposes. Durable manufacturing is the only other major use of this building type, accounting for 17 percent of the square footage. In the RCB buildings more than 80 percent of total square feet are used for business services. The RCC buildings are largely allocated to business and personal services. However, health services are also important in this building type, accounting for 15 percent of the total. This fact may be useful in identifying and modeling damage to critical facilities, often an important component of a risk analysis.

This analysis shows that the LAMB building classification system provides relatively good discrimination among economic sectors. Two of the building types, URMA and

Table 4 LAMB Structure Type and Economic Use

Economic Use Group (Square Feet, Million)

	Agri	Mining	Constr.	Man.(non)	Man (dur)	Trans.	Comm.	Whole	Retail	FIRE	Business	Personal	Entertain	Health	Educat.	Others	Adm.	Forces	Total
URMA	0.000	0.000	0.000	2.549	5.754	0.328	0.000	31.831	27.529	0.507	6.518	1.012	0.285	1.084	0.113	0.434	0.005	0.000	77.949
URMB	0.000	0.000	0.000	0.010	1.417	0.066	0.000	5.044	5.528	0.247	6.133	3.795	0.044	0.897	0.192	0.238	0.000	0.000	23.611
RCA	0.000	0.000	0.000	0.216	3.540	0.048	0.000	11.381	3.725	0.152	1.767	0.319	0.000	0.010	0.007	0.004	0.000	0.000	21.169
RCB	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.126	0.000	0.113	2.890	0.051	0.000	0.395	0.000	0.000	0.000	0.000	3.575
RCC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.152	0.000	0.000	0.723	0.494	0.000	0.350	0.000	0.000	0.000	0.000	1.719
NA	0.000	0.000	0.000	3.253	10.679	0.961	0.000	40.315	13.746	0.927	16.976	2.733	0.360	1.535	0.057	0.458	0.000	0.000	92.000

Table 5 Probabilities of LAMB Structure Type and Economic Use

Probability of Economic Use

	Agri	Mining	Constr.	Man.(non)	Man (dur)	Trans.	Comm.	Whole	Retail	FIRE	Business	Personal	Entertain	Health	Educat.	Others	Adm.	Forces	Total
URMA	0.000	0.000	0.000	0.033	0.074	0.004	0.000	0.408	0.353	0.006	0.084	0.013	0.004	0.014	0.001	0.006	0.000	0.000	1.000
URMB	0.000	0.000	0.000	0.000	0.060	0.003	0.000	0.214	0.234	0.010	0.260	0.161	0.002	0.038	0.008	0.010	0.000	0.000	1.000
RCA	0.000	0.000	0.000	0.010	0.167	0.002	0.000	0.538	0.176	0.007	0.084	0.015	0.000	0.001	0.000	0.000	0.000	0.000	1.000
RCB	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.035	0.000	0.032	0.808	0.014	0.000	0.111	0.000	0.000	0.000	0.000	1.000
RCC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.088	0.000	0.000	0.421	0.287	0.000	0.204	0.000	0.000	0.000	0.000	1.000
NA	0.000	0.000	0.000	0.035	0.116	0.010	0.000	0.438	0.149	0.010	0.185	0.030	0.004	0.017	0.001	0.005	0.000	0.000	1.000

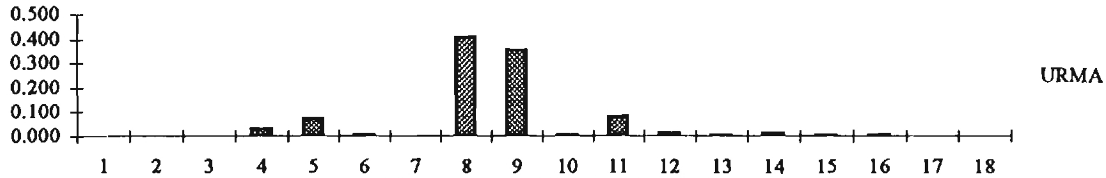

Figure 9 Probability of Economic Use of URMA Structures

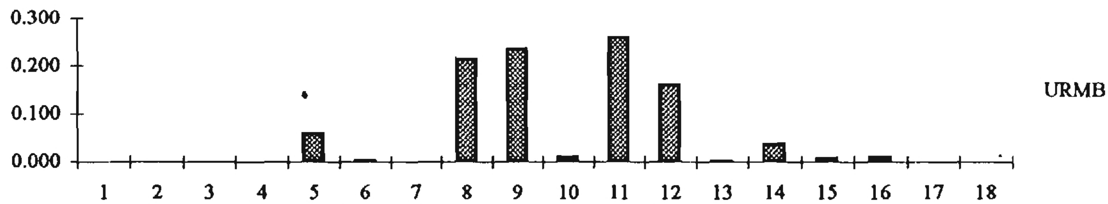

Figure 10 Probability of Economic Use of URMB Structures

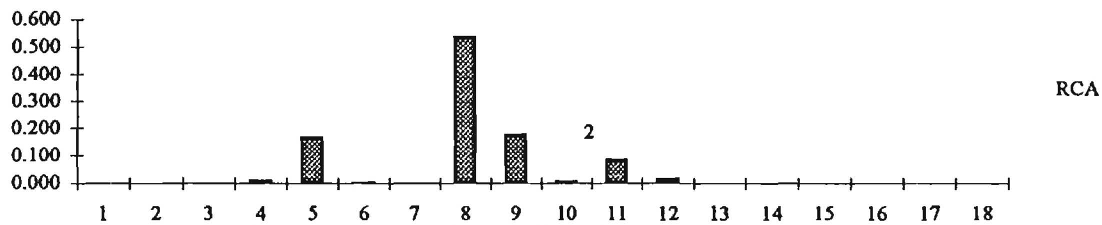

Figure11 Probability of Economic Use of RCA Structures

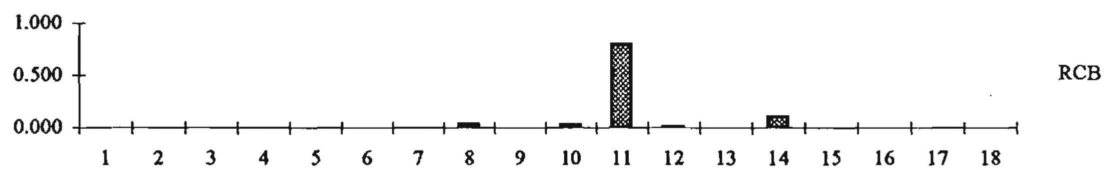

Figure 12 Probability of Economic Use of RCB Structures

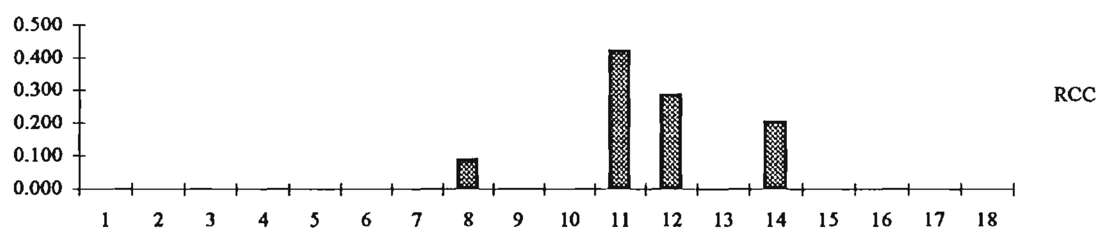

Figure 13 Probability of Economic Use of RCC Structures

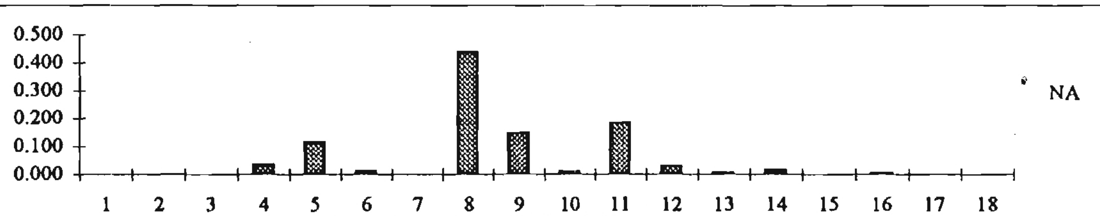

Figure 14 Probability of Economic Use of Other Structures

RCA have a large proportion of their square footage in a single sector. URMB is more evenly divided among four sectors. These patterns suggest it should be possible to produce first order estimates of the economic impacts as a part of the LAMB methodology.

5. Linking Square Footage and Employment

Most economic loss models characterize the size and importance of economic sectors using employment. As part of the NCEER research program Adam Rose and his colleagues have utilized an input-output model to estimate the inter-industry impacts of damage to the Memphis electric power system. Their model uses a set of SIC-based economic sectors that is similar to those used in the preceding analyses. To be able to model economic impacts it is, therefore, necessary to convert our estimates of damaged square footage by economic sector into employment.

The Census Transportation Planning Package (CTPP) provides the best available small area employment counts for the Memphis area. This data set developed by the Bureau of the Census to support metropolitan transportation planning provides employment data that are aggregated to relatively small geographic areas known as traffic analysis zones. Given the purpose for which it was developed this employment data does not include the structure type. We have attempted to link employees to their structures based on location. To do this we geocoded the buildings in the assessors database.

After geocoding the building locations we aggregated their square footage to the TAZ in which they are located. We then estimated the number of square feet per employee for the five most important economic sectors using a linear regression approach. The 513 TAZs served as the units of analysis. The model took the following form:

$$EMP_j = a + bSF_j$$

Where
EMP_j = the employment in economic sector j
SF_j = the square footage of buildings in economic sector j.

The results of this regression analysis are presented in Table 6. The F-statistics for three of the overall models were significant at the .05 level, however the R^2 were much lower than expected due to significant unexplained variation at the TAZ level. As can be seen in the maps of Appendix B, there were many TAZ's that have a significant mismatch between employees and building area. This suggests that one of the two data sets contains significant errors. Additional investigation is required, but our initial hypothesis is that the locational component of the CTPP data is the major problem.

Table 6. Regression Analysis of Floor Area and Employment

Economic Group	**b**	**Overall F**	**F Significance**	R^2
Durable Manufacturing	56.2	49.62	.0000*	.08
Wholesale Trade	126.0	23.70	.0000*	.04
Retail Trade	7.9	1.42	.2335	.002
Business Services	26.9	4.59	.0326*	.009
FIRE	32.7	1.14	.2856	.002

A better means for linking employees to square footage is provided by Table 7. The average number of square feet per employee is calculated using regional totals for each sector rather than the TAZ level data. While this approach loses some of the information available at the more detailed level, it is superior given the poor results from the regression approach.

The average amount of square footage per worker allows us to make a first order approximation of the employees in each sector that will be affected by any particular pattern of building damage. These employment impacts can then be used in an input-output model to estimate the effects on related industries.

6. Conclusions

This research develops a general method to link physical damage to economic impacts. The average amount of space per employee in each economic sector provides the basic link between the two formerly separate models. The results of the regression approach were not satisfactory. Further investigation of the two data sets is warranted to fully understand the mismatches that occur at the small area data. The spatial accuracy of the CTPP employment data bears particular scrutiny.

We were particularly fortunate to have detailed data on the structure type and the economic use of each structure. In areas where this is not available, developing the linkage between physical damage and economic impacts will be more difficult to develop. Future research is needed see if the structure type-use patterns developed here can by generalized at least to other cities within the same region.

For the LAMB project this methodology provides the ability to integrate economic and physical damage models. We can now apply techniques already developed by NCEER researchers to estimate inter-industry impacts of earthquake damage.

Table 7 Ratio of Square Feet for Economic Use Groups

Economic Use Group

	Agri	Mining	Constr.	Man.(non)	Man (dur)	Trans.	Comm.	Whole	Retail	FIRE	Business	Personal	Entertain	Health	Educat.	Others	Adm.	Forces
Area (Mi	0	0	0	6	21	1	0	89	51	2	35	8	1	4	0	1	0	0
Employe	4537	264	23834	29240	24615	42502	10072	26944	69485	26216	21569	16190	4586	41463	29373	22074	21818	10375
SF/Empl	0	0	0	206	869	33	0	3298	727	74	1623	519	150	103	13	51	0	0

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Appendix A

Matching Assessors Use Code to Economic Use Groups

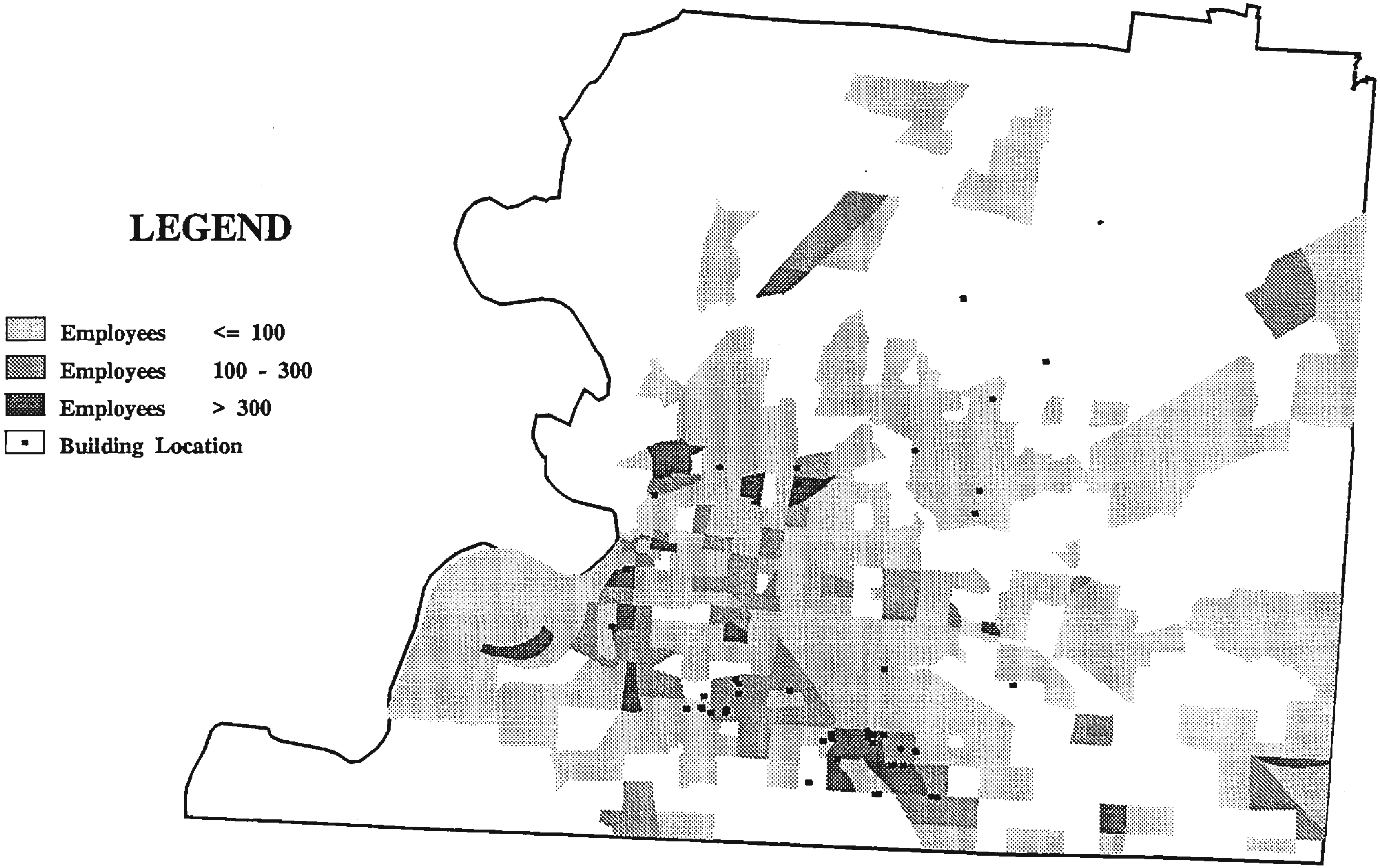
Assessors Use Code	Building Use	Group Number	Economic Use Group
04	Auto Dealer	9	Retail
05	Bank/Saving	10	FIRE
06	Bowling Ally	13	Entertainment
07	Car Wash	11	Business and Repair
08	Religious	16	Other Professionals
09	Community Center	16	Other Professionals
10	Convent	16	Other Professionals
11	Country Club	16	Other Professionals
12	Store Department	9	Retail
13	Store Disc	9	Retail
15	Drive-In-Theater	13	Entertainment
16	Fire Station	17	Public Admin.
18	Funeral Home	12	Personal Services
19	Hanger	6	Transportation
20	Hotel	12	Personal Services
21	Motel	12	Personal Services
23	Hospital	14	Health Services
24	Office Medical	14	Health Services
25	Mobile Home Pk	11	Business and Repair
26	Nursing Home	14	Health Services
27	Office	11	Business and Repair
28	Parking Garage	11	Business and Repair
29	Restaurant	9	Retail
30	Fast Food	9	Retail
32	Service Garage	9	Retail
33	Full Service Station	9	Retail
34	Store Retail	9	Retail
35	Store/Apartment	9	Retail
36	Store/Office	9	Retail
37	Supermarket	9	Retail
38	School	15	Education Services
39	Shopping Ctr Nbhd	9	Retail
40	Shopping Ctr-Strip	9	Retail

Matching Assessors Use Code to Economic Use Groups (Cont'd)

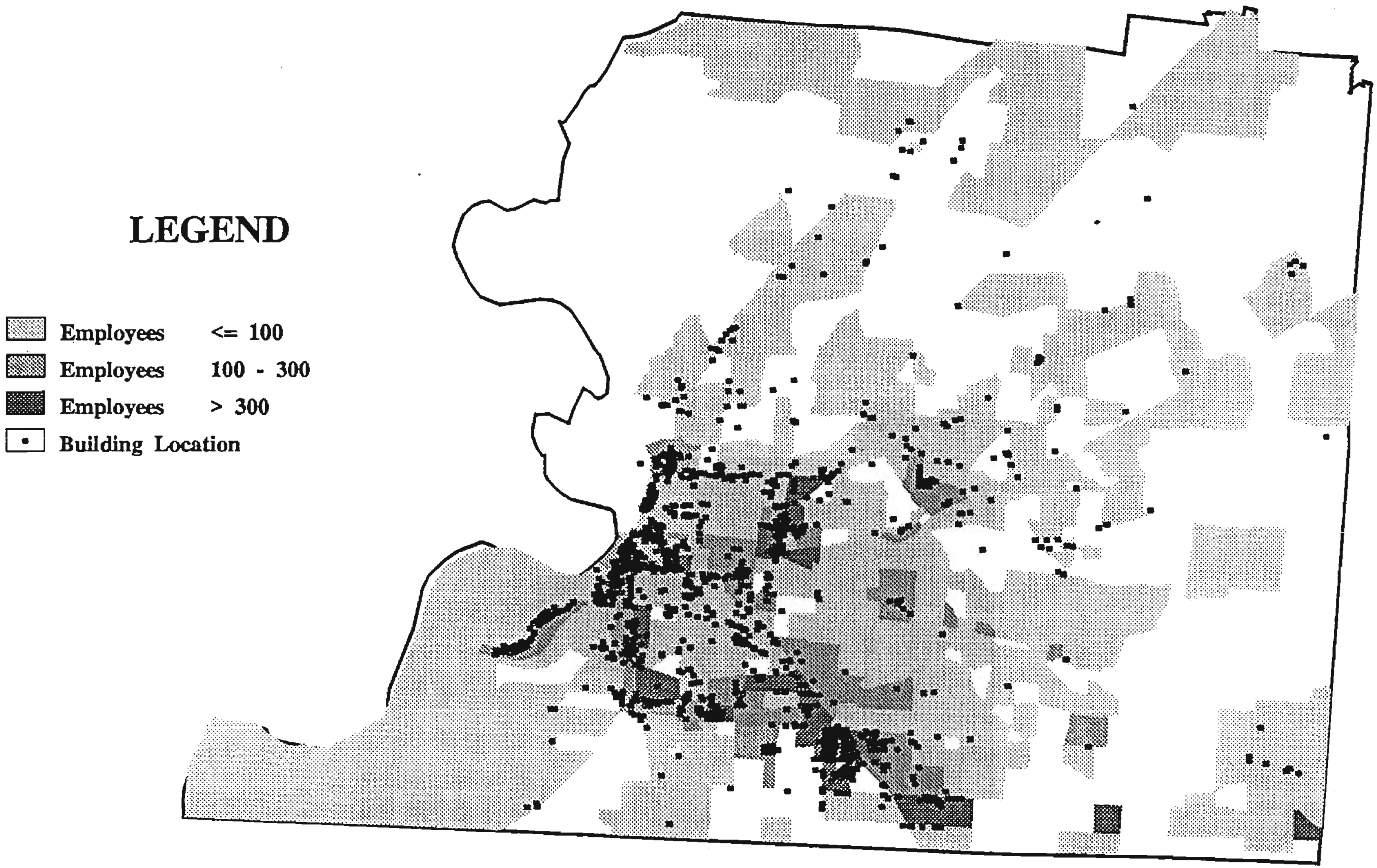
Assessors Use Code	Building Use	Group Number	Economic Use Group
41	Library	15	Educational Services
42	Laundromat	12	Personal Services
43	Picture Theater	13	Educational Services
44	Chemical Plant	5	Manufacturing (Durable)
45	Machine Shop	5	Manufacturing (Durable)
46	Manufacturing Fac.	5	Manufacturing (Durable)
47	Truck Terminal	6	Transportation
48	Warehs Distributor	8	Wholesale
49	Grain Elevator	8	Wholesale
50	Packing Plant	4	Manufacturing (Non Dur.)
53	Auditorium	15	Educational Services
54	Gymnasium	13	Entertainment
56	Indoor Recreational	13	Entertainment
65	Shopping Ctr Mall	9	Retail
68	Office Low	11	Business and Repair
69	Office High	11	Business and Repair
70	Railroad Station	6	Transportation
71	Trucking Complex	6	Transportation
72	Terminal Bus/Air	6	Transportation
73	Utility/Railraod	6	Transportation
77	Car Wash Drv	11	Business and Repair
78	Bar/Lounge	9	Retail
79	Car Wash Auto	11	Business and Repair
80	Cold Storage	8	Wholesale
81	Convenience Store	9	Retail
82	Day Care Center	16	Other Professionals
83	Health Club	14	Health Services
85	Cinema Multple	13	Entertainment
86	Night Club	13	Entertainment
87	Office Condo	11	Business and Repair
88	Self Service Station	9	Retail
89	Skating Rink	13	Entertainment
90	Vetnry Clinic	12	Personal Services
91	WRHS mini	8	Wholesale
92	WRHS Storage	8	Wholesale
94	Mini Lube	11	Business and Repair
95	Manufacturing Mill	5	Manufacturing (Durable)
96	Engineering Office	11	Business and Repair
97	Loft Manufacturing	4	Manufacturing (Non Dur.)
98	Lumber Shed	5	Manufacturing (Durable)

Appendix B

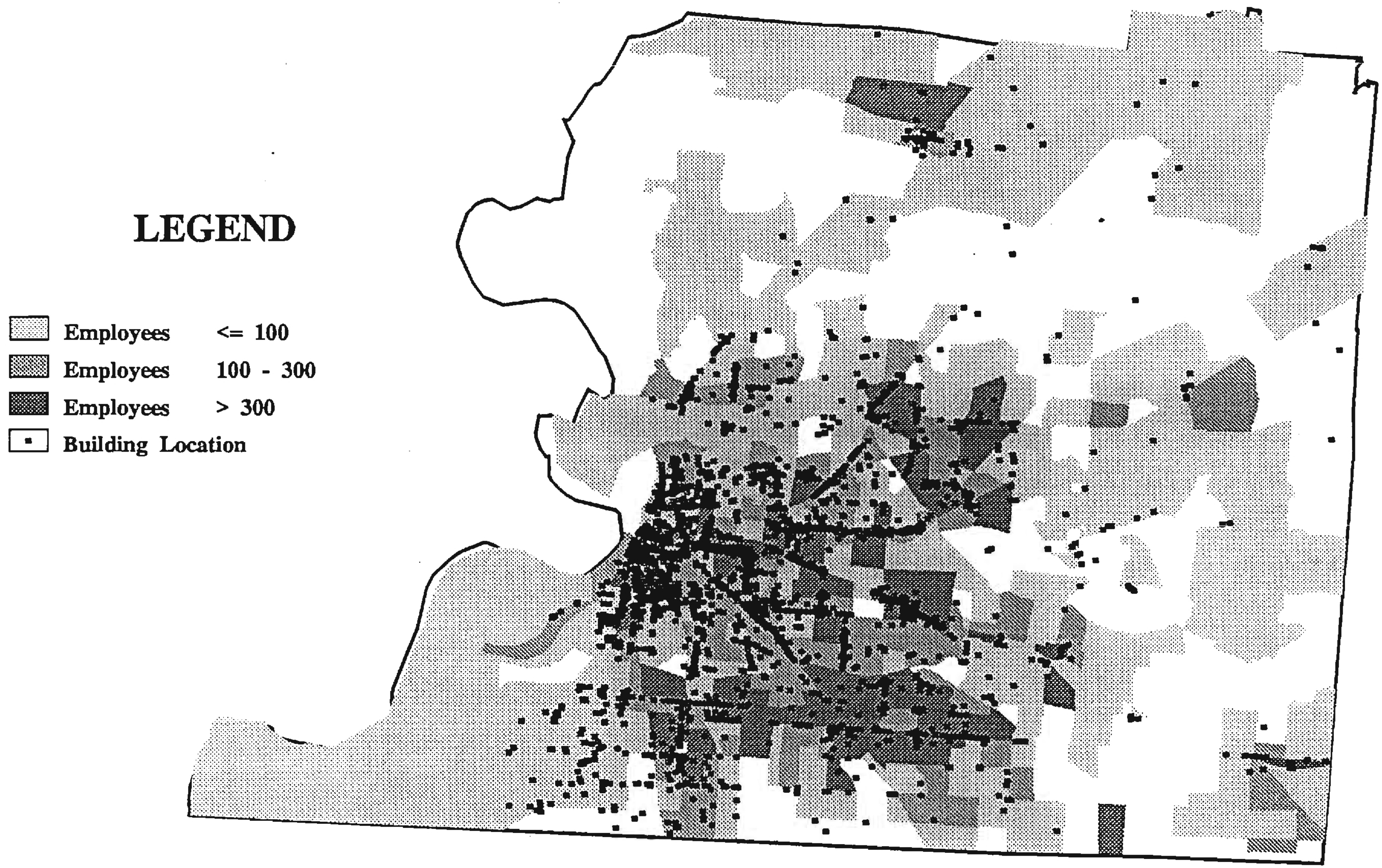
Location of Buildings and Employment within Major Economic Use Groups



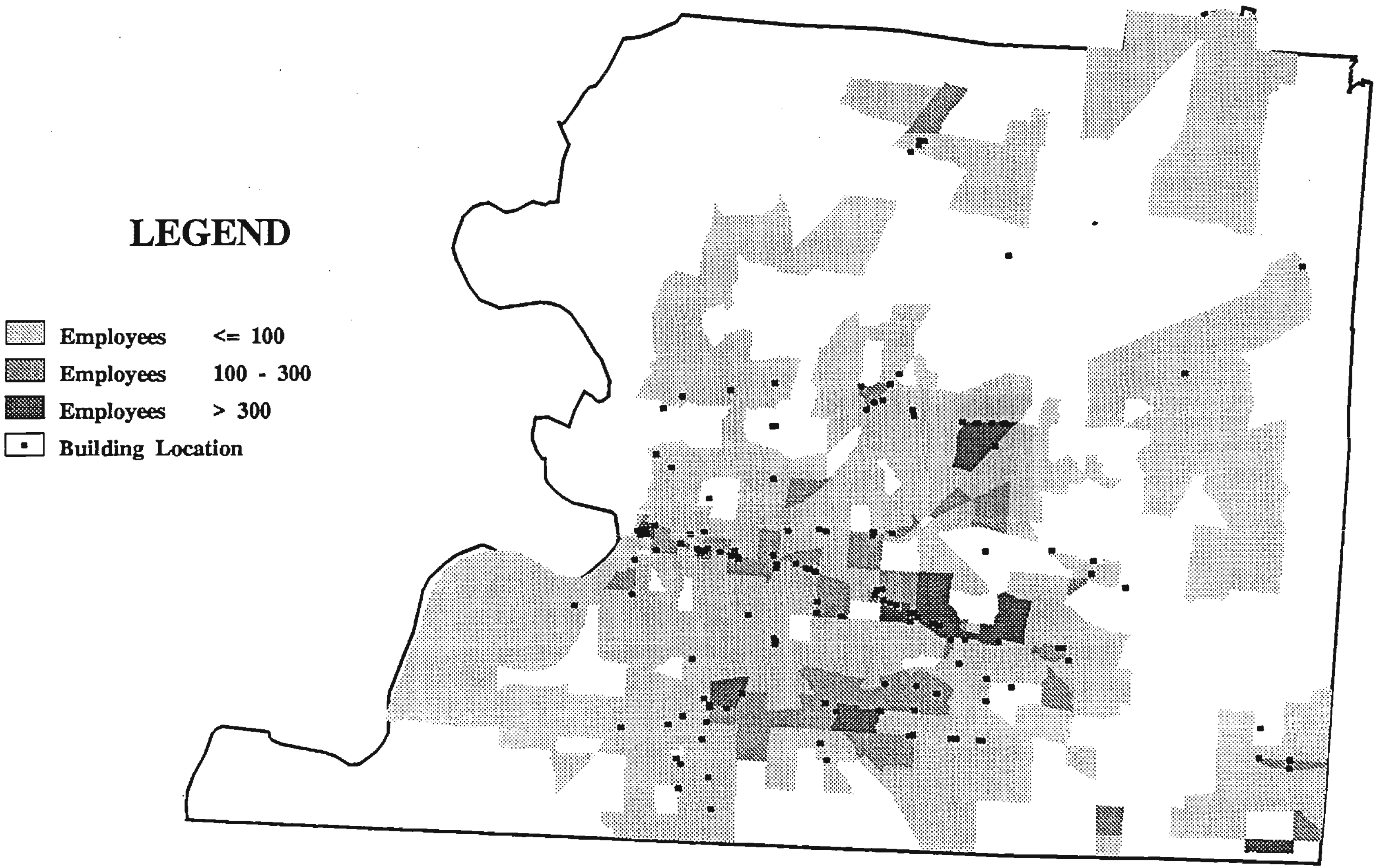
Spatial Distribution of Nondurable Manufacturing in Shelby County



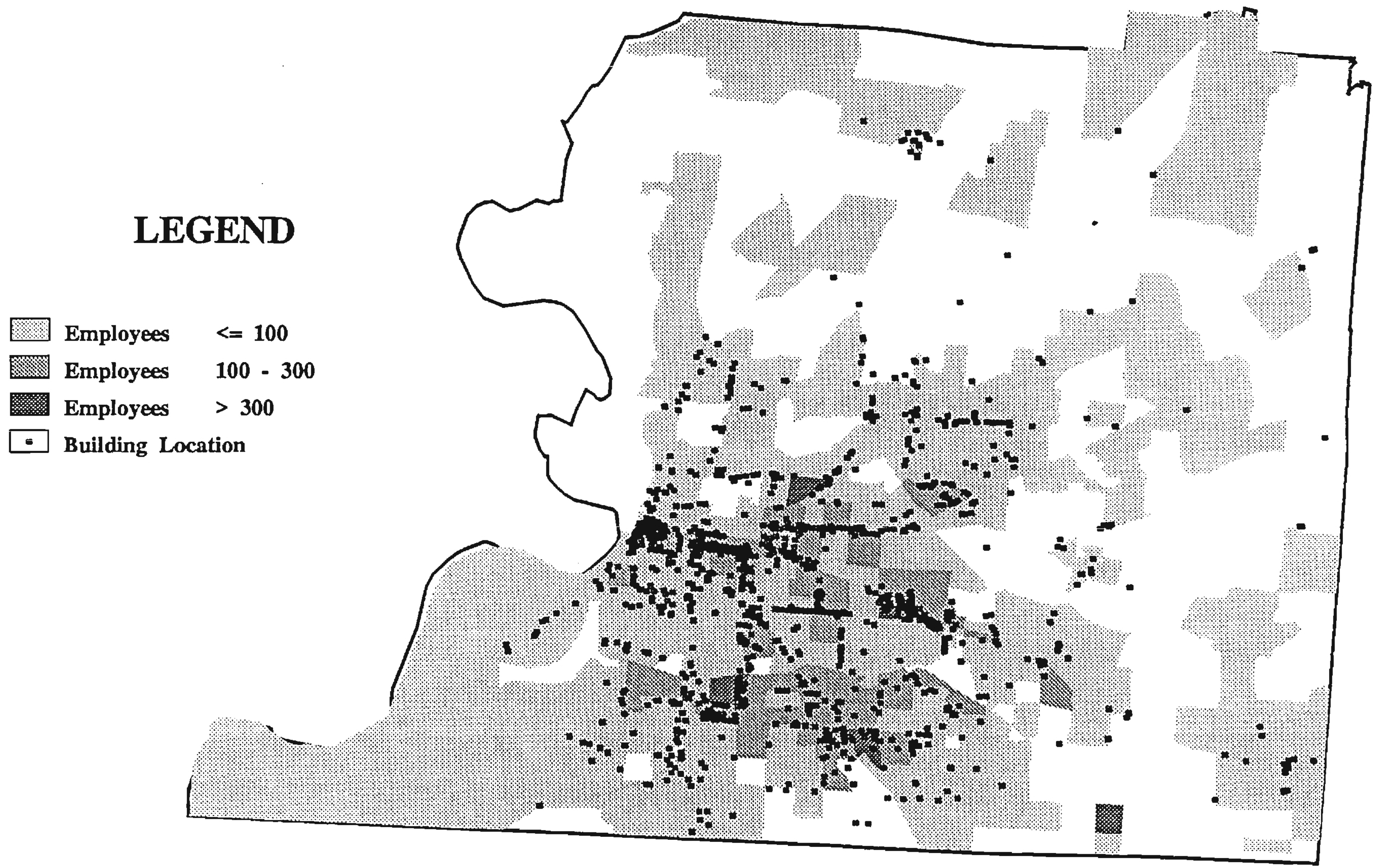
Spatial Distribution of Wholesale Trade in Shelby County



Spatial Distribution of Retail Trade in Shelby County



Spatial Distribution of FIRE Services in Shelby County



Spatial Distribution of Business Services in Shelby County