**The Use of GIS in Loss Estimation and Risk Assessment**

by

Gil Jamieson* and Jeff Milheizler*

ABSTRACT

Recent developments in the technology of Geographic Information Systems (GIS) have facilitated data analysis and display. The power of today's computer systems, in conjunction with state-of-the-art software, gives users the ability to analyze large quantities of data in a relatively short period of time. The Federal Emergency Management Agency (FEMA) is taking advantage of these developments. FEMA has developed a nationally applicable state-of-the-art earthquake loss estimation methodology called HAZUS. This program looks at an earthquake hazard and compares it to the built environment that is affected by the hazard. In addition to providing estimates on the amount of building damage and the cost of replacing and/or repairing these buildings, HAZUS also looks at secondary effects of the quake such as fires that may result due to the event and how many people may require shelter. These results provide emergency managers with a better understanding of potential earthquake losses. Although HAZUS includes a large amount of default data, it is important to understand that improving this information will improve the loss estimate. Loss estimation provides an excellent opportunity for international collaboration and partnership. As HAZUS expands into the multi-hazard realm, these opportunities will increase. Likewise, the benefits of GIS will be more fully realized and HAZUS will become a "multi-hazard loss estimation methodology."

KEYWORDS: earthquake modeling; geographic information systems; HAZUS; loss estimation; mitigation

## 1. INTRODUCTION

Until fairly recently, it has been difficult to analyze a region's susceptibility to damage from natural hazards. Data on hazards, as well as the built environment and population exposed to these hazards, has only been available in the form of paper maps or tables. Only recently has this information been digitized to the extent that it is valuable in computer modeling. This digital information, when used in conjunction with a geographic information system (GIS), opens up new analysis capabilities.

GIS provides us with the power to get a more explicit view of the risks associated with a community. As technology advances and computers become more powerful, the ability to process data is growing exponentially. Due in large part to this technological advancement, the use of GIS has enjoyed a considerable growth in recent years. The ability of GIS to represent digital data graphically makes it invaluable to a wide range of individuals, ranging from the government planner to the small business owner. Knowing the geographic location of different societal components allows governments to decide where to focus their energy, and small business owners to locate the optimal business site. The use of GIS is expanding and deserves to be recognized for its applicability in the area of risk assessment. The Federal Emergency Management Agency (FEMA) uses GIS technology in a number of programs. One of these programs, "HAZUS," deserves more detailed discussion.

The HAZUS program has been developed under the leadership of the National Institute of

*Hazard Identification and Risk Assessment Division, Mitigation Directorate, Federal Emergency Management Agency, Washington, DC, USA, 20472

Building Sciences and has been overseen by two committees. The first is an eight-member project work group, consisting of earthquake experts, and chaired by Robert Whitman, a professor of Civil Engineering at the Massachusetts Institute of Technology. The second is an eighteen-member project oversight committee, chaired by Henry Lagorio, a professor of architecture at the University of California at Berkeley, that provided input from the viewpoint of potential users. By incorporating recommendations from each of these groups, HAZUS is a loss estimation methodology that is technically sound and user-friendly.

## 2. A STRATEGY FOR DISASTER LOSS REDUCTION

In 1995, FEMA published the National Mitigation Strategy which establishes goals to substantially increase public awareness of natural hazard risk and to significantly reduce the loss of life, injuries, economic costs, and disruption of families and communities caused by natural hazards. FEMA recognized that to support this goal we needed a consistent means of characterizing risk from the various natural hazards and of estimating the losses that could result. Such a standardized loss estimation / risk assessment tool will allow emergency managers and mitigators to identify opportunities and underscore the need for mitigation measures that reduce those losses.

Results obtained through the HAZUS analysis are not limited to direct physical damage to buildings. Estimates are also made concerning casualties and shelter requirements, the functionality of lifeline systems and essential facilities, direct and indirect losses, and an assessment of the induced hazards of flood, fire, and hazardous material releases. A mitigation module is under development that will also allow HAZUS to be used to calculate how the general building stock will be affected with and without mitigation, thereby further demonstrating the economic benefits of specific mitigation actions.

## 3. BACKGROUND OF THE HAZUS EARTHQUAKE LOSS ESTIMATION METHODOLOGY

The HAZUS Earthquake Loss Estimation Methodology is a standardized, nationally applicable, PC-based, loss estimation methodology. The methodology overlays earthquake hazards with building inventory, lifeline information, and other data in order to forecast the level of losses occurring during a pre-defined event.

HAZUS runs on an integrated GIS platform. The methodology takes the ease-of-use and functionality that GIS has to offer and adds some features of its own. In addition to the normal GIS functions available, HAZUS has added functions specific to the loss estimation field. These additional capabilities range from defining the hazard, to changing analysis parameters, to viewing the results in a pre-designed report.

HAZUS makes the risk assessment more valuable by providing the results as both a mappable table and as a summary report. Mapping the results provides a powerful visualization of the effect the event has on the community. By seeing where the most damage is predicted to occur, mitigation efforts can be concentrated in these areas. The summary reports that HAZUS produces provide the results in a format that can be easily imbedded in reports and provided to a variety of potential users. It is important not only to perform the risk assessment, but also to present the results in a form that produces action.

HAZUS was designed as a series of "modules," rather than as one continuous program. This modular approach provides flexibility for the addition of future loss estimation models as new models can be directly linked to the already developed product. By designing future models in this same modular format, these models will easily mesh with the program and be able to share modules with similar functions.

HAZUS is designed to allow loss estimates to be performed at different levels of accuracy. The data required for a low-level (Level I) analysis is included with the HAZUS software, and, as a result, this estimate requires minimal effort. At the opposite extreme, the high-level (Level III) analysis is the most precise, and, consequently, requires the most effort. A Level III estimate requires detailed data to be collected and input into the software. From this information, a detailed analysis is conducted that provides a better estimate of the potential damage for a given event. The Level II analysis resides between these two extremes. This analysis uses a combination of detailed data and assumptions. The same basic structure as a Level I analysis is employed, except that certain characteristics have detailed data. For instance, detailed soil mapping may be available for input into the software or the user may have a better hospital database. The HAZUS program can use this improved information while still using the default data in the other modules. This three-level structure provides the user with flexibility depending on the amount of detail required and the amount of data available. Through the use of modules, the program can proceed through its analysis without being dependent on data input.

## 4. THE IMPORTANCE OF INVENTORY

The development of a sound inventory base is an essential first step in the HAZUS risk assessment / loss estimation process. In a GIS environment, the detail and accuracy of the data impacts the credibility and accuracy of the loss estimates obtained from the analysis. The results produced by any risk assessment performed under GIS are only going to be as valuable as the data that is used in the analysis. As more and more data is included in the estimate, the results will improve. Figure 1 outlines the risk assessment process and the paramount role that inventory plays in the process.

Three data components are necessary in order to perform a loss estimate. These are: the location of ground motion, the different degrees of motion within this location, and the inventory of susceptible items along with their reaction to various strengths and types of ground shaking. Different structures and lifelines react differently. It is important to understand this designation and analyze each type of element separately. Knowing that seismic waves of a certain magnitude cause approximately 25% damage to a steel frame building allows an estimate of seismic damage to be computed. Having a grasp of the inventory, understanding the size and strength of the event, and knowing the various damage states associated with each structure are combined to arrive at the final estimate. GIS makes this analysis possible with a minimum of effort.

HAZUS contains a considerable amount of default inventory for residential, commercial, and industrial buildings, as well as data for lifeline systems and demographics. Additional data, however, as well as more detailed data, can make significant improvements in the results obtained from the analysis.

This issue, the sensitivity of results to high-resolution inventory data in comparison to default information, was examined during the development of HAZUS. While it was found that a more credible forecast can be made with the high-resolution data, a characterization of risk using the default data was a good first step toward reducing a community's vulnerability and risk to the hazard. In fact, pilot tests have shown that while detailed data does provide a better loss estimate, estimates performed using default values were still credible.

FEMA has developed a "Building Inventory Tool" as a component of HAZUS so that users can improve the loss estimates they construct through a HAZUS analysis by incorporating their own building inventory data. This tool maps the building inventory data according to a consistent building classification and occupancy scheme for analysis purposes. Local hazard maps and geotechnical maps depicting soil information can also be imported into HAZUS.

By making data importation simple, we hope that communities will be more willing to gather improved data.

## 5. RUNNING A HAZUS LOSS ESTIMATE

The first step in running the loss estimation methodology is to select an area for study and provide information about the size and location of the earthquake to be modeled. Also, before the analysis is run, the user should input any improved data that may have been collected. From here, the HAZUS methodology begins to work. Based on the specified size and location of the event, the HAZUS algorithms determine the ground motion associated with the event by looking at local geology and other factors that impact the spread of seismic waves. In addition, HAZUS determines where ground failure may result. The results of these two Potential Earth Science Hazards (PESH) analyses are then carried down through the other modules in order to determine how the event impacts the study region. Figure 2 provides a flowchart of the loss estimation methodology.

The results obtained from the ground shaking and ground failure analyses are compared against the building inventory. Structures in the study region have been classified into 36 different building types (i.e. steel-frames, unreinforced masonry, etc.) and 28 occupancy classes (i.e. residential, commercial, etc.). For each of the 36 model building types, "fragility curves" have been established. These describe how the building will respond to varying levels of ground motion. Structural and non-structural damages are estimated from these curves. Damages are calculated by examining those building components that are sensitive to acceleration and those that are sensitive to inter-story drift.

While essential and high potential loss facilities, and lifelines, are handled on a site-specific basis, the general building stock is handled differently. Analysis is performed on a census tract basis. Buildings for each census tract are aggregated to the centroid of that tract. In the United States, approximately 2500 to 8000 people, on average, reside in each census tract. The census tract level analysis for the general building stock provides a good estimate as to the potential damage in the area of study. An immense amount of time and resources would be required in order to do a site-specific analysis on every building in the study region. Through aggregation to the census tract level, this time commitment is reduced, and the estimate is still found to be credible.

In addition to the data described, the methodology also includes data for high potential loss facilities (e.g. dams, fixed nuclear facilities). While specific estimates are not made on these facilities, GIS allows the user to overlay these structures on a ground motion map or other base layer and see how they are affected (i.e. how much ground motion they experienced).

Similarly, lifelines are examined. Lifelines comprise transportation and utility systems. The transportation systems include roads, bridges, railways, light rail, bus stations, ports, ferries, and airports. The utility systems consist of potable water, wastewater, oil, natural gas, electric power, and communication systems. Each of these is examined in terms of its probability of functionality and the time required for the damaged system to be restored. The functionality is dependent on the damage sustained by the major components of the lifeline system (e.g. electric power switching station). Additionally, HAZUS, through its GIS platform, provides the ability to display these systems on top of a ground motion map. By looking at lifelines in this way, HAZUS produces an estimate as to where damage is likely to occur, the probability that this damage will occur, and how long it will take to repair this damage.

Once the direct physical damage has been determined, induced physical damage is calculated. The induced physical damage module includes inundation, fire following earthquake, hazardous materials, and debris.

Losses associated with this module do not result directly from ground shaking.

The inundation module is capable of examining losses resulting from dam failure, tsunami, seiche, or another source of inundation. In order for these calculations to occur, however, inundation maps must be provided. From these, HAZUS looks at the inventory affected by this inundation and reports back a value that describes the associated losses.

The fire-following earthquake module looks at where fires may occur as a result of the earthquake. HAZUS examines several factors that may affect this. Some of these are the location of fire stations, the number of engines employed by each station, how quickly these engines can respond, and the speed and direction of the wind.

Analysis of hazardous materials releases is not currently available. However, a database of hazardous materials locations is provided in HAZUS. From this, through the GIS interface, the user can look to see which hazardous materials sites may be affected by the earthquake event and the types of chemicals stored at these sites.

The debris component of HAZUS calculates the amount of debris that is generated from the building damage projection. It further divides this into two categories – debris that can be removed using "normal" clean-up machinery and that which requires special equipment. These components affect the speed of emergency response and recovery time.

Social losses are another component of the study region that is examined. Social losses include the number of casualties caused by the earthquake and the number of people that will require temporary housing. HAZUS calculates casualties on four levels. These range from injuries requiring basic medical attention to those that result in death. Each of these is determined based on the level of damage sustained by the structural inventory and the time of day that the event occurred. For instance, if the event occurs at 2:00 am, the majority of the population will be at home. Therefore, the number of casualties will be largely driven by the damage to residential structures.

The temporary housing component is dependent on a couple of factors. First, the methodology looks at the number of households that are displaced due to structural damage or loss of utilities. From this estimate, HAZUS examines the population demographics in order to estimate which of these displaced households are likely to require shelter. Not every displaced household will require shelter. Some of these will opt to stay with relatives or friends. HAZUS takes this fact into consideration and arrives at an estimated shelter demand.

HAZUS also estimates direct and indirect economic losses. These are the dollar losses experienced by the region. The direct economic losses include such things as building loss, building contents loss, relocation cost, wage loss, rental income loss, and the cost of repairing damaged lifelines. The indirect losses are those losses that are felt long after the event. These include such things as the employment rate at different time periods after the event, and how long it will take the region to rebuild. All of these are ramifications that result from the earthquake, and should be included in any loss estimate.

## 6. CONCLUSIONS

The advent and recent improvements in Geographic Information System (GIS) technology have facilitated the production, grouping, and analysis of various hazard data sets. Information, previously available in a stand alone paper format, can now be compiled and used to convey graphically a better understanding to the public of their exposure and vulnerability to natural hazards.

The HAZUS Loss Estimation Methodology described here uses the technology to conduct an analysis and produce losses associated with the Earthquake Hazard. It is our belief, that if elected officials and emergency managers develop a better understanding of the potential for losses from future earthquakes, they will be more inclined to take the necessary steps to mitigate and reduce these losses. HAZUS is currently being expanded to demonstrate how specific actions to rehabilitate buildings can reduce loss. Results can be calculated on the mitigated building performance and compared with the results for the existing condition. Similarly the introduction of improved building codes can be modeled to show disaster loss reduction opportunities.

We have emphasized the importance in this article of the need for good building inventory. Good building inventory in this context means an accurate assessment of the building's location in relation to maps depicting high resolution soils data and a good understanding of the age, height, and engineering design that was used in the construction of the building. We believe that equipped with this type of data it is possible to move into the "all hazard" loss estimation / risk assessment field. The GIS technology will permit layering this high resolution building data over various hazard themes. These might include areas of potential flooding, areas subject to high winds, and/or areas subject to tsunami. The new challenge for the engineering profession is to develop building and lifeline "fragility curves" for these new perils consistent with what they have accomplished for earthquake. The United States has formed a team of experts to begin to study and evaluate these possibilities.

The science of loss estimation represents a wide-open opportunity for international collaboration and partnership. Clearly one potential project is to evaluate the applicability and use of HAZUS in studying the potential earthquake hazard in Japan. Opportunities and questions abound over understanding the differences in how the built environment in our two countries will respond to strong ground motion as well as assessing the similarities. We should look for opportunities to further calibrate HAZUS using international earthquake events. Similarly, together we should study how HAZUS might be used as an "international measure" to assess worldwide progress in reducing the earthquake risk.

These questions and many others remain for us to answer. The challenge is significant, but the opportunity afforded us through technology to meet these challenges is more promising than ever before.

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# FEMA RISK ASSESSMENT SYSTEM

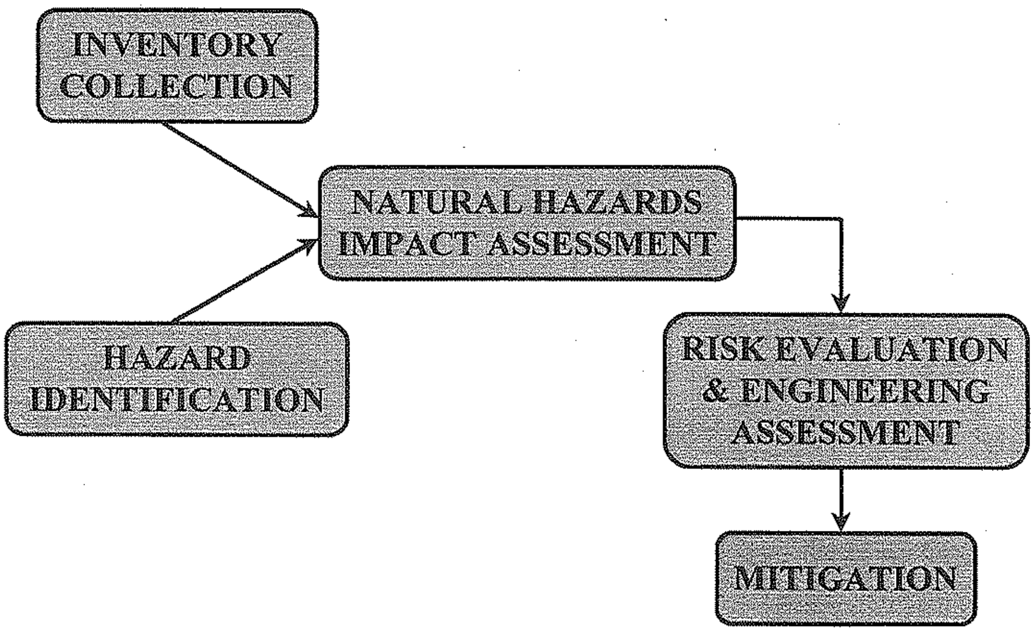


**Figure 1: FEMA Risk Assessment System**

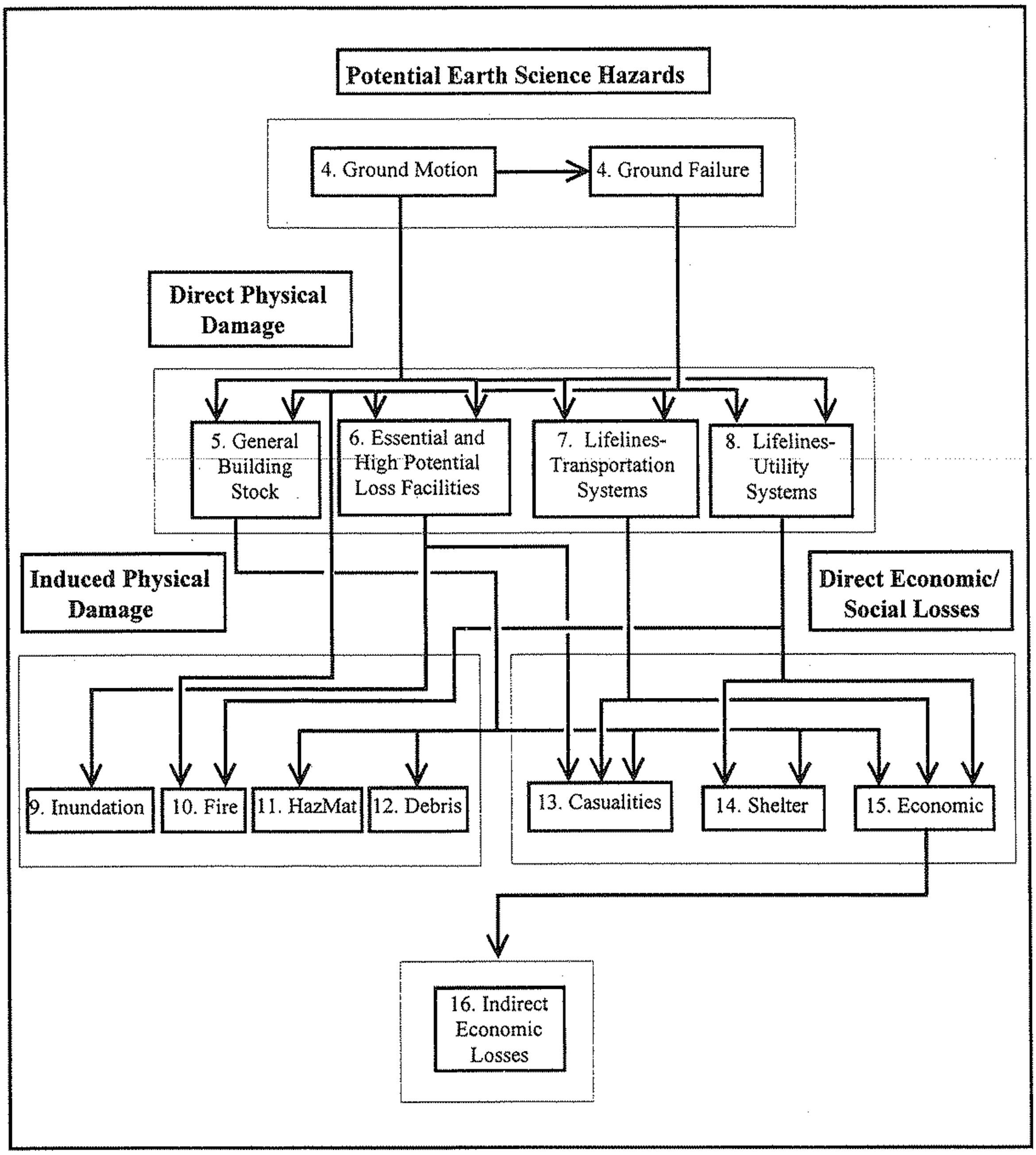


**Figure 2: Flowchart of the Earthquake Loss Estimation Methodology**