

APPLICATION OF GIS FOR REGIONAL EARTHQUAKE LOSS ESTIMATION

Regional earthquake loss studies are being performed for several years to assist local and state governments, and emergency response planners in preparing for and mitigating damage from future seismic events. Earthquake loss studies often include estimates of repair costs, deaths and casualties, functional loss to lifeline systems and emergency response facilities, and regional economic impacts on a short-term and long-term basis. A major limitation of many past regional loss studies is that they are stagnant in the sense that the inventory and geologic data collected, analysis done and the reports produced cannot be updated to reflect changes in the inventory, demographics or economy of the region. One possible reason for this is since the inventory data can not be realistically included in the final reports, updating existing studies without undertaking a major data collection effort is virtually impossible. In addition, the effectiveness of the loss estimation results was limited in the sense that the analysis results have typically been summarized in a report or tabular format, making it cumbersome to quickly identify those geographic areas most likely to experience significant damage.

With the development and maturity of GIS technology, many of these limitations have been overcome and dynamic loss studies that present results in a more usable format can now be performed. A recent project, sponsored by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS) and awarded to RMS, has resulted in a powerful GIS-based software package for performing regional earthquake loss estimates. The implementation of integrated GIS technology provides an approach which permits rapid evaluation of complex inventory databases under a variety of earthquake scenarios and allows the user to interactively view results almost immediately. The results can be summarized in tables of loss values as well as maps of damage estimates that can be overlaid to easily view which areas are likely to be most severely affected.

The power of GIS technology makes creating and modifying maps a very simple task. For application in regional loss estimation, there are a variety of very useful options that are available :

- First, inventory collected and input into databases can be quickly and easily displayed on a map of the region. Using colors and symbols, many different attributes can be highlighted. For example, the number and location of seismically vulnerable structures in your region can easily be presented.
 - Second, existing maps, such as liquefaction potential maps available from the US Geological Survey, can be digitized and displayed on a map of the region. These can then be overlaid with maps of ground shaking and lifeline systems to qualitatively assess the most vulnerable lifeline components.
 - Third, using thematic maps of loss estimates, localities with high levels of damage can be quickly identified.
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- Fourth, the functionality of regional lifeline systems such as water delivery systems can be graphically displayed by mapping the system and using colors to identify those parts of the system most likely to be nonfunctional.

GIS technology provides emergency response planners and government officials with a very powerful tool to visualize and understand the impacts of an earthquake on a region. In this paper, a conceptual discussion will be presented on the benefits and application of GIS technology for regional loss estimation. In addition, examples will be used to demonstrate the effectiveness of presenting information through thematic mapping techniques.

Geographic Information System (GIS) – A General Description

A modern Geographical Information System is a computer system designed to store, analyze, and display geographic information. The geographic information may be any of an infinite variety of data sets each associated with a spatial coordinate system. The spatial referencing of the information permits the data sets to be linked. This linkage provides a powerful tool for analysis and integration of data sets from many different sources using the same GIS software. An example of various types of geographically linked data sets useful for seismic zonation is shown in Figure 1.

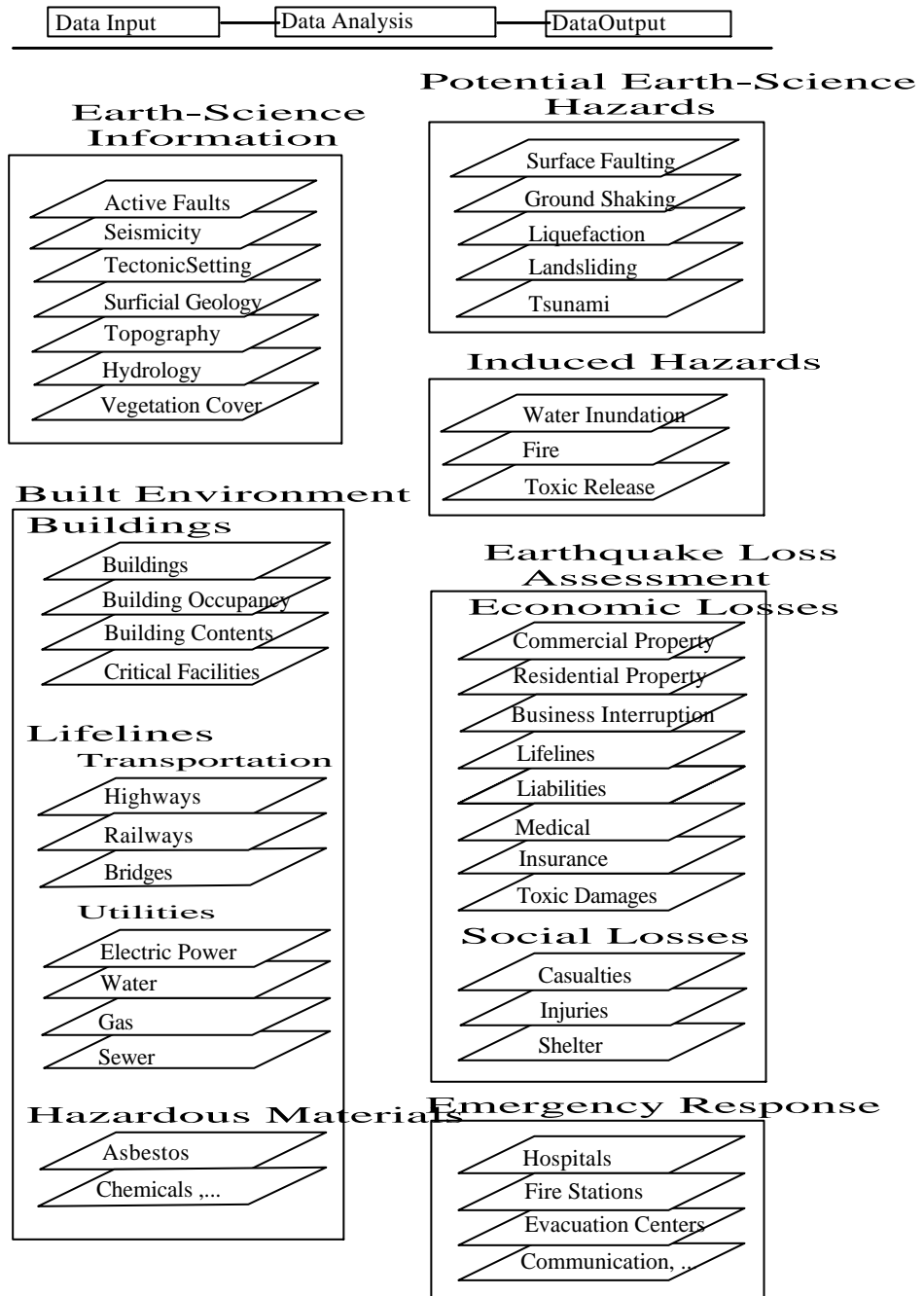


Figure 1.

In general, each GIS is comprised of basic components that permit the input, manipulation, analyses, archival, and output of spatially referenced data. Following is a brief summary of technical aspects of these components and associated analyses functions.

Formally defined a GIS is a computer-based system that provides for 1) input, 2) management (data storage and retrieval), 3) manipulation and analysis, and 4) output of georeferenced data. These basic components of a GIS are illustrated in Figure 2.

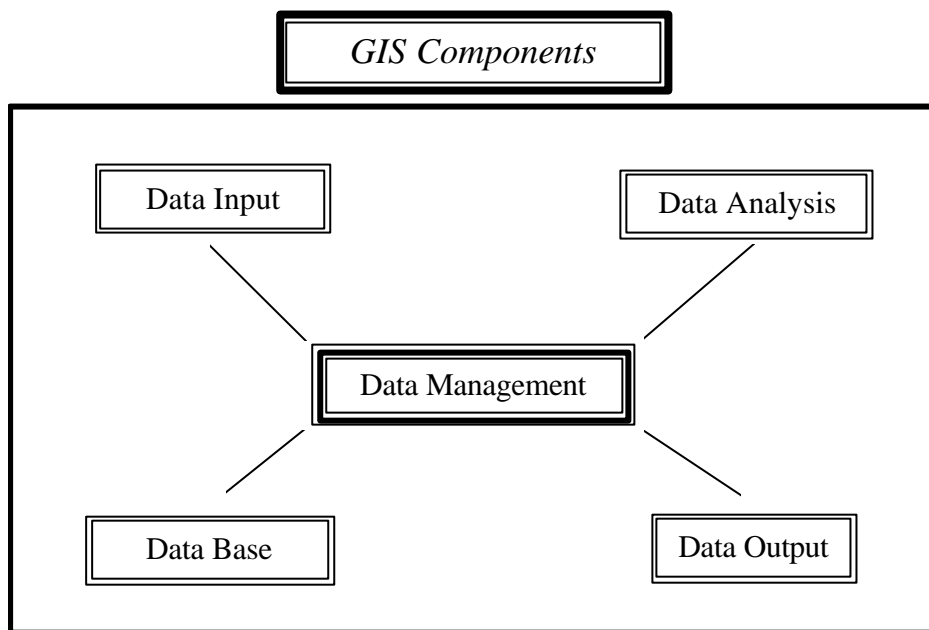


Figure 2 Components of a Geographic Information System (GIS).

Data Input

The data input component represents the resources required to convert data from existing formats to the format required for storage and analysis by the computer software and hardware. Original data sources may range from paper maps to tables to digital files, each of which may have its own format. Conversion of these data to the required digital format can be simple and relatively automatic if the original data require only conversion from one digital format to another. In other cases digitalization of maps and assignment of appropriate attributes can require major efforts. Data input is often the most costly and time consuming component of a GIS project and may represent a cost several times that of the hardware and software. However, with the rapid expansion in uses and users, digital GIS data bases are rapidly growing and many of these can be used for a variety of GIS projects. Further with the advent of scanners to create digital images of paper maps the time and cost factors have come down.

Data Management

The data stored in a GIS is comprised of two sets of information or files. One is a graphic file which specifies the location of points, lines, and polygons and a second file which specifies the characteristics or attributes of the graphic entities. The two files can serve to link and integrate a

variety of different types of information to a specific location. When data is input into a GIS it must be ascribed locations via point, line, and area definitions and attributed characteristics via the attribute file. The user can operate on these files independently to retrieve, analyze, and integrate the input data sets.

Two types of data structures are in primary use, one is termed raster and the other vector. The raster format consists of a regular grid of square or rectangular cells or pixels defined by row and column locations to which has been ascribed some value of the desired attribute. The vector format specifies the location or position of points, lines, and polygons for the data set of interest with an associated set of attributes for each. With the specification of definitions for arcs, nodes and polygons and topological relations, the vector format provides a powerful tool for rapid manipulation and processing of large data bases but it is complex. The simpler raster format is especially well suited for depicting rapidly varying geographic information and enhancement of digital images used for example in remote sensing and satellite imagery. Most modern GISs use both data structures and include software to convert certain types of data sets from one format to the other.

Data Manipulation and Analysis

Modern relational data base technology is used to store, retrieve and manipulate the graphic and attribute files of modern GISs. Analysis functions permit the integration and derivation of geographically linked data sets. They allow the overlay, query, and development of new data layers. They permit the use of external function libraries and user specified or programmed function software. Rapid advances in relational data base technology, computational speed and storage capacities of computer hardware, and GIS analysis software have led to dramatic improvements in the capabilities of GISs.

Data Output

The output or display of derived GIS products may occur in a variety of formats, including paper maps, tabular files, CRT screen display, and/or digital computer files. The particular output format specified by the user determines the necessary software functions and hardware needed for each application. Convenient display of products at various stages of development often leads to new spatial insights and improved results. Rapid advances in computer networking and the storage capacity of removable disks have greatly improved capabilities to exchange and integrate GIS data sets from various users.

Two most popular GIS systems are Mapinfo and ArcView.

Application of GIS to Seismic Risk Assessment

Earthquakes can cause significant damage to both the man made and the natural environments. The impact of these types of events can destroy entire ways of life. In addition to structural damage, seismic events can undermine the infrastructure that is vital to the function and well being of the community, can cause significant monetary losses, casualties and disease and can inflict long-term economic hardship on the local or regional economy. When we talk about the risk of a region to a seismic event, we are talking about the vulnerability of the region to damage, losses and casualties.

The magnitude of the damage and losses depend not only on the seismic hazard, but also to a great extent upon the density of the population, the location and type of building exposure, the

socio-economic makeup of the region and their spatial relationship to the hazard. If an earthquake occurs in an sparsely populated region, there will be little to no effect on regional infrastructure and little likelihood of loss of life. However, if the same earthquake were to occur near a large city, a situation could result in very high losses. Economically challenged regions with inexpensive non-engineered construction are more vulnerable and can expect heavier damage, for example Latur Earthquake in India, than regions that have large numbers of new buildings that are designed and constructed to modern codes. Local economies that are highly dependent on one or two types of businesses or industries that are destroyed by the event, unemployment can be almost complete and recovery very slow.

Seismic risk assessment can be defined as a procedure to estimate the damage and losses to a seismic event by combining seismic hazards with the inventories of the built environment. The assessment procedure can be broken down into three simple steps

- **Quantify the seismic hazards for a given event.**
As discussed in this paper, seismic hazards can consist of ground shaking demands, spectral response demands, and ground failure from liquefaction, landsliding and surface fault ruptures.
- **Quantify the built environment inventory of the affected region.**
Once the seismic hazard has been quantified, the next step is to create a spatial representation of the region's structural, demographic, and economic inventory. Inventories are the most expensive and time consuming part of a seismic risk assessment with the final damage/loss estimates highly dependent on the quality of the inventory data. GIS-based inventory collection systems have the flexibility to permit different levels of detail in inventory collection as dictated by levels of funding. Data can be collected and stored as either site-specific information or can be aggregated on a regional basis and stored with the associated geographical unit.
- **Combine inventory data with seismic hazards to assess the impacts.**
The final step involves combining seismic hazard information with spatially distributed inventory data and then applying motion damage relationships to determine damage estimates. This procedure works for regional inventory aggregation models to a comprehensive site-specific analysis of every structure in the region. In addition to building damage, loss of function, casualties, monetary losses, shelter requirements and utility service outages are examples of impacts that can be evaluated using the same process.

A GIS-based software system creates the ideal framework to integrate the various components of seismic risk assessment. GIS technology provides a powerful tool for displaying outputs and permits users to "see" the geographical distribution of impacts from different earthquake scenarios and assumptions. The interactive features of a GIS platform can provide an user-oriented environment for entering and accessing data, and allows the user to overlay input and output data on thematically shaded maps of the region. The use of different display colors permits rapid visual identification of areas with the potential for high damage and loss (i.e., areas that have both significant ground shaking and a large number of vulnerable buildings).

While GIS technology is optimal for spatial reasoning (interpretation of data in a spatial context), and for providing an intuitive graphical input/output mechanism to the user, it is a cumbersome

environment for the execution of complex numerical algorithms. Alternatively, programming languages, such as C++, can be applied to encode otherwise complex algorithmic and rule-based relationships.

Rather than accept the constraints associated with the different software environments, the current trend in software development is to create a system which integrates each of the software strategies. To the user, the resulting system can have the look and feel of a GIS-based program. However, embedded within the GIS are the RDBMS technologies, C++ support libraries necessary to support the database management and computational requirements of a regional risk assessment. Such a system is often referred to as integrated geographical information system (IGIS).

The major problems with the non GIS based frameworks are :

- The inability of a single study to meet the very different needs of users at different levels of government
- The costs of collecting inventory and performing the studies
- The stagnant nature of the results when they are in a report form, and the technical nature in which results have been presented.
- The final reports rarely contain any documentation of the inventory used, and the output often provided in a tabular format that provided little insight about the geographical distribution of the damage and losses.

The use of a GIS-based risk assessment model will overcome many of the problems identified above. Based on the resources and level of funding models can be developed which perform simplified estimates of damage and loss using limited inventory collected on a modest budget. The models can be easily modified to allow for more precise estimates with are based on extensive inventory collected at a large cost to the community

The GIS environment also accommodates the needs of a wide spectrum of potential users. The modular framework inherent to a GIS allows the user to activate or deactivate models on command. The framing of risk assessment methodology as a collection of models also permits the addition of new available state-of-the-art models (or modify models for local or regional needs) without reworking the entire methodology. This approach permits a logical evolution of the methodology as research progresses and the state-of-the-art advances. It will also facilitate rapid transfer of information between the academic/ research community and the practitioner.

Results from the GIS-based analyses are not stagnant and can to be updated as the inventory is improved, the building stock or the demographics of a region change, models change or if revised seismic hazards are quantified. Once the inventory data is input in the GIS program, information can be readily updated and any number of hazard scenarios can quickly be evaluated. An advantage of the GIS technology is that once the inventory database is built, it can be used for other purposes such as city planning, public works or emergency preparedness for other types of natural disasters.

Current Application of GIS to Seismic Risk Analysis

The National Institute of Building Science (NIBS), under a cooperative agreement with FEMA, and in collaboration with RMS has developed a nationally applicable standardized methodology for assessment of potential losses from natural hazards. The first phase of this project was to develop guidelines and procedures for making earthquake loss estimates at the regional or local scale. These loss estimates can be used by local, state and regional officials to plan and stimulate efforts to reduce risks from earthquakes and to prepare for emergency response and recovery. A secondary purpose of this project is to provide FEMA with a basis for assessing nationwide risk of earthquake losses. The methodology was recently completed and is now undergoing testing through two pilot studies

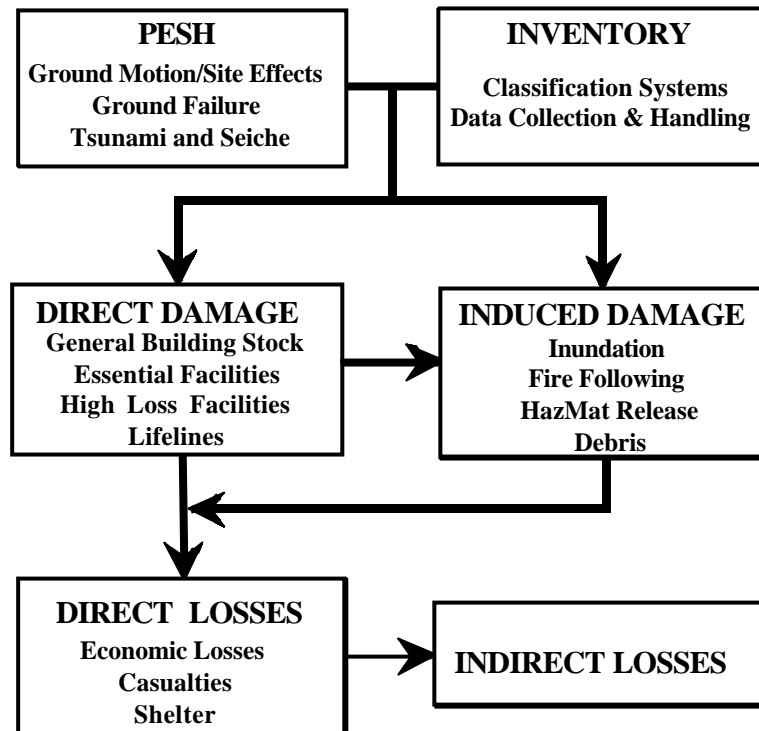
Standardized earthquake loss estimation methodology:

The earthquake loss estimation methodology will provide local, state and regional officials with the tools necessary to plan and stimulate efforts to reduce risk from earthquakes and to prepare for emergency response and recovery from an earthquake. The methodology will also provide the basis for assessment of nationwide risks of earthquake loss.

The methodology can be used by a variety of users with needs ranging from crude estimates that require minimal input to refined calculations of earthquake loss. The methodology may be implemented using either integrated geographical information system (GIS) technology provided in a software package or by application of the theory documented in a Technical Manual. Implementation of the methodology by either technical or non-technical users will be guided by an easily understood Applications Manual.

The vision of earthquake loss estimation requires a methodology that is both flexible, accommodating the needs of a variety of different users and applications, and able to provide the uniformity of a standardized approach. The framework of the methodology includes each of the components shown in Figure 2-1: Potential Earth Science Hazard (PESH), Inventory, Direct Physical Damage, Induced Physical Damage, Direct Economic/Social Loss and Indirect Economic Loss. As indicated by arrows in the figure, modules are interdependent with output of some modules acting as input to others. In general, each of the components will be required for loss estimation. However, the degree of sophistication and associated cost will vary greatly by user and application. It is therefore necessary and appropriate that components have multiple levels (multiple modules) of detail or precision when such is required to accommodate user needs.

Framing the earthquake loss estimation methodology as a collection of modules permits adding new modules (or improving models/data of existing modules) without reworking the entire methodology. Improvements may be made to adapt modules to local or regional needs or to incorporate new models and data. The modular nature of the methodology permits a logical evolution of the methodology as research progresses and the state of the art advances.



Methodology Framework

The framework of the methodology embodies each of the components shown in above Figure : Potential Earth Science Hazards (PESH), Inventory, Direct Physical Damage, Induced Physical Damage, Direct Economic/Social Loss and Indirect Economic Loss. As indicated by the arrows in the figure, the components are interdependent with the output of one module acting as input to another. In general, each of these components will be required for loss estimation. However, the degree of sophistication (and associated cost) will vary greatly by user and application. It is therefore necessary and appropriate that components have multiple levels of detail or precision. One major aspect of a loss estimation study that is not depicted in above Figure is the collection of inventory. This is probably the most time consuming and costly aspect of the study, as inventory and other relevant data must be collected and organized for each of the modules shown. Examples of the type of information that the user will need to collect include an inventory of buildings in the region, population census data, soil and geologic conditions and economic data.

In order to evaluate losses, the user must develop a description of the earthquake and its associated ground motion. In many cases this will take the form of a scenario event of specified size and location. Depending on the size of the event and the local geology, a map of ground motions (in terms of spectral acceleration) will be generated. In addition to ground motion, losses can be a function of ground failure such as landslides, liquefaction and surface fault rupture. Thus the PESH module generates estimates of the potential for ground failure in addition to estimates of ground motion. Other earth science hazards include tsunami and seiche which can result in significant losses.

Once ground motions and ground failures have been identified, damage to the built environment can be estimated. In this methodology, damage is estimated for four distinct groups: (1) general building stock, (2) essential and high potential loss facilities, (3) transportation systems, and (4) utility systems. The groups are defined to address distinct inventory and modeling characteristics. General building stock includes residential, commercial, industrial, agricultural, religious, government and educational buildings. Essential facilities include hospitals, police stations, fire stations, emergency operation centers and in some cases, schools. High potential loss facilities are likely to cause heavy earthquake losses if damaged. Examples are nuclear power plants, dams and military installations. While general building stock and essential facilities are both groups of buildings, it is likely that the user will want and will have more detailed information about essential facilities. That is, for general building stock, the inventory is not collected on a building by building basis but instead is based upon estimates of building types by census tract, city, or some other designated area. On the other hand, the user will be able to identify the locations of all hospitals, fire stations etc., and may be able to provide details of these facilities such as their heights and structural types. A similar situation occurs with high potential loss facilities. Estimates of damage will take the form of probabilities of being in a specific damage state (none, slight, moderate, extensive and complete) given a specified level of ground motion. A probabilistic damage estimate is used to reflect the many uncertainties involved.

Lifelines are distinct from buildings in that they usually consist of a network of interdependent components. Due to redundancies, damage to a component may or may not affect the operation of the system. A damaged system may still be capable of operating at below capacity. A key concern in evaluating lifelines is how long it will take to restore the system to full functionality. Thus damage estimates include restoration times.

Once estimates of direct physical damage are available, losses and induced physical damage can be determined. Induced physical damage can be defined as consequences of the earthquake, other than damage due to shaking, that lead to losses. For this methodology induced damage includes inundation, fire following earthquake, hazardous materials release, and debris generation. All of these can lead to monetary and social losses. Inundation can result from tsunamis, seiches, dam failure or levee failure. Fire ignitions may occur due to pipe breakage, electrical shorts, chemical spills or a number of other causes. The extent of the resulting fire depends on the availability of water and fire fighting equipment and personnel. The extent of consequences of a hazardous material release (e.g. casualties, building damage, pollution) depends on the type and quantity of released material. The quantity of debris that is generated depends on the type of structures that are damaged and the extent to which they are damaged. The cost of removing debris can be significant.

Social losses take the form of casualties, short term shelter needs, and long term housing needs. Casualties resulting from damage to buildings and lifelines put a demand on health care facilities and personnel. The ability to respond to the casualties depends on the functionality of hospitals and other health care facilities. The loss of function of buildings either due to damage or due to non-functional utilities results in displaced households. These households will need alternative short-term shelter provided by friends relatives or agencies such as the Red Cross. For units that take a long time to repair, long-term alternative housing must be located. This can be accommodated by using vacant units, importing mobile homes, moving to non-impacted areas or eventually repairing or reconstructing housing.

A final step in estimating earthquake losses is converting damage into monetary losses. Two types of economic loss are addressed by this methodology. Direct economic loss refers to the cost of repair and replacement of structures and systems that are damaged as a consequence of the earthquake. Both structural and non-structural damage and losses to business inventory are included. In addition, dollar losses that are the direct consequence of building or lifeline loss-of-function are included as direct economic losses. These include costs of relocation, income losses and rental losses. The broad and long term implications of these losses are considered as indirect economic losses. Examples of indirect economic impacts are changes in tax revenue, employment and consumption.

Conclusion

GIS is the solution for making the Region Earthquake Loss Estimation a cheap and dynamic proposition, making the estimates easily understandable, helping in quick decision making. The FEMA project shows that combining the following; a very powerful Region Earthquake Loss Estimation System can be developed :

- Power of computation speed and GIS
- Ability to perform multiple scenarios without new inventory collection
- GIS bridge gap between needs of regional emergency planners response people and costs, and accuracy
- Develop technology that will allow wider group of individuals to have access to results and to participate in loss estimates to Assess seismic risks in particular region.
- Augment inventory

References

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