Abstract

During and immediately after disasters logistic systems and planners are severely handicapped by lack of accurate information as to the extent of the disaster in terms of people, businesses, communities, communication and transportation systems. Geographic Information Systems (GIS) are powerful tools in the decision-making processes before, during and after a disaster. Many organizations are working on the combination of GIS and Expert Systems to improve disaster alert and warning. This paper proposes that if current research on GIS and Expert Systems is combined with Neural Networks, the entire process of logistical response to flood disaster planning, mitigation and recovery can be improved significantly. The combination of these technologies would provide accurate, up to the minute flood plain impact maps that would allow the graphic overlay of existing and projected flood impact areas with transportation grids, lines of communication, population maps, business impact areas, hazardous material source points and contaminations. Existing data collection systems of precipitation gages, steam flow gages, and stream depth gages can provide data to an integrated Neural Network allowing it to “learn” about future flooding events. This would provide real-time monitoring and updating of floodplain data producing significant improvements in flood prediction accuracy and speed. An ancillary benefit would be more accurate flood plain maps for watershed land use planning, development and logistical response planning.

Introduction

Geographic Information Systems (GIS) are being widely used in a wide variety of applications worldwide. One of the more beneficial uses is in the area of disaster planning, mitigation, and recovery. GIS are designed specifically to store, manipulate, analyze, and display spatially referenced data and, therefore, can assist the work of disaster response network specialists. The GIS display systems, combined with Overlay techniques, visually portrays the existing spatial relationships of geographic features and all other natural or man-made systems and networks. In traditional overlay techniques, transparencies showing the spatial distribution and intensity of individual disasters are overlaid on GIS maps showing the total impact as illustrated in figure 1.1.
Using overlays allows the logistics specialist to evaluate real and potential impacts and/or disruptions of the logistic systems in a disaster impacted area. These systems include rail and road transportation networks, river or coastal navigation systems, communications consisting of both hardwired and radiobroadcasting systems, disaster response systems including fire, police, hazardous material, and medical response and facilities. The use of FIS technology removes the limitations of hardcopy overlays allowing any number of overlays to be digitally included in the display.

The combination of GIS and Expert Systems (ES) greatly expands the utility of GIS. This allows the user to not only have a visual mapping capability with the ability to overlay the maps with information from many databases but also enables the computer to use expert abilities to make decisions based on the GIS information.

This paper suggests that this technology be further expanded to include the use of Neural Networks to enable the computer to continuously update and improve the GIS information and will provide for more accurate and timely information to the user.

Literature

Mecklenburg County, North Carolina, developed GIS applications to use GIS data in their Storm Water Services Department and their Engineering and Building Standards Department. The primary application is comprised of a suite of four applications providing the user with quick access to flood zone proximity, storm water engineering, land development, and water quality/quantity. Overlays provide data such as streets, hydrology, floodplains, political boundaries, planometrics, and commissioner’s districts. These applications will greatly improve the efficiency of day-to-day operations for the internal staff. The flood zone proximity application has already been proven to greatly reduce staff time required to manually look up flood zone information for several thousand inquiries per year. (Tingle, 1998).

Problems with GIS

One of the major problems in flood disaster response is that floodplain data is out of date almost as soon as the surveyors have put away their transits. Watersheds and floodplains are living entities that are constantly changing. The very newest floodplain maps were developed around 1985 with some of the maps dating back to the 1950’s. Since that time, the watersheds documented the resulting floodplains have changed, sometimes drastically. Every time a new road is cut, a culvert or bridge is built, or a change in land use occurs, the flood plain is altered. This is borne out in Federal Emergency Management Agency (FEMA) statistics that show that over 30% of flood damage occurs at elevations above the 100-year floodplain. (FEMA, 1995) Clearly this makes planning for and logistical response to disasters a very difficult task.

It also complicates the problems of the logistics planner. Three times in Tremble, Ohio, floods inundated much of the town during one eighteen month period. This flooding included the only fire station. The depths of the waterlines on the firehouse wall were three feet, four and a half feet, and ten feet. The 100-year flood plain maps clearly show that the fire station is not in the flood plain. This, of course, was no help to this community during the process of planning and building the fire station or during the flooding events and subsequent recovery when they had no fire protection.

In Denver, Colorado, many of the underpasses on Interstate 25 are subject to flooding during moderate or heavy rains. This is not because of poor planning or construction. It is due to the change in land use adjacent to the Interstate right of way. During planning and construction, much of the land was either rural agricultural or natural vegetation. Since construction, this land has been converted to urban streets, parking lots and other non-absorbent soil covers resulting in much higher rates of storm water runoff.
Integration of GIS and Expert Systems

Recently, a number of researchers and disaster response and planning organizations have integrated Expert Systems (ES) and GIS technology. This provides a decision support system for disaster response teams in charge of process monitoring of rapidly increasing emergencies. Designing these systems means combining the tasks of automating data processing, providing efficient access to all relevant data, and synthesizing pertinent information. (Wybo, 1998)

The concept behind ES is the transfer of the technical expertise of a human to a computer program. This knowledge is then stored and users, not experts, can access and use the knowledge to assist in complex decisions when needed. When the expertise of hydrologists and meteorologists is available via the computer and combined with the topographic information and databases available in a GIS system, the result is a decision support system that is available immediately for both planning and response to a disaster.

On September 6, 1996, Hurricane Fran struck North Carolina. The path of destruction covered most of the state. Before the storm, GIS models were applied to calculate the size of the potential storm surge for several categories of hurricanes and storm speeds. Emergency managers used these models to make decisions about potential flooding and identified which portions of the population needed to be evacuated. The availability of this detailed data gathered before the extreme event occurred constituted a major difference between disaster information flow after Hurricane Andrew in 1992 and Hurricane Fran in 1996 (Dymon, 1999).

Cited earlier in this paper, Mecklenburg County, North Carolina, is using expert systems in conjunction with GIS to relieve the workload of county staff in determining the proximity of specific parcels of property to the 100 and 500-year flood plain. (Tingle, 1998).

DuPage County, Illinois’ Division of Stormwater Management is using two GIS application elements, steam cross-sections and flood routing elevations to delineate floodplains. This application allows the rendering of three dimensional depth/surface depictions. This system uses the topographic database of GIS to be combined with existing flood analyses elevations to delineate floodplains using ES applications. (McLaughlin, 1998)

Neural Networks

In recent years, many published papers have shown the results of research on neural networks and their applications in solving problems of control, prediction, and classification in industry, environmental sciences, and meteorology (McCann, 1992; Bonar et al. 1993; Jin et al. 1994; Aussem et al. 1995; Blankert and Aha, 1996 Eckert et al 1996; Marzban and Stumpf, 1996).

Computing methods for transportation management systems are being developed in response to mandates by the U. S. Congress. This mandate sets forth the requirements of implementing the six transportation management systems that Congress required in the 1991 ISTEA Bill. Probably all the management systems will be implemented with the help of analytical models realized in microcomputers. The techniques used in these models include optimization techniques and Markov prediction models for infrastructure management, Fuzzy Set theory, and Neural Networks in conjunction with GIS and Multimedia based Information System for asset and traffic safety management, planning, and design (Wang and Zaniewski, 1995).
In a paper published by the *Journal of Computing in Civil Engineering*, Xudong Jai presented a method for representation and reasoning of spatial knowledge. Spatial knowledge is important to decision making in many transportation applications that involve human judgment and understanding of the spatial nature of the transportation infrastructure. This case study demonstrated the use and depiction of spatial knowledge and how it provides graphical display capabilities and derives solutions from this knowledge (Jai, 2000). This application is analogous to the prediction of flooding events within a watershed and their effects on transportation and other logistic systems.

A neural network, using input from the Eta Model and upper air surroundings, has been developed for the probability of precipitation and quantitative precipitation forecast for the Dallas-Fort Worth, Texas, area. This system provided forecasts that were remarkably accurate, especially for the quantity of precipitation, which is, of course, of paramount importance in forecasting flooding events (Hall and Brooks, 1999).

**Conceptual Design**

While NN are being applied to a wide range of uses, this author was unable to identify NN applications in the direct management of floodplains, floodplain maps, or other disaster response programs. The closest application is a study done to model rainfall-runoff processes (Hsu, K., H. V. Gupta, and S. Sorooshian 1995). They developed an NN model to study the rainfall-runoff process in the Leaf River basin, Mississippi. The network was compared with conceptual rainfall-runoff models, such as Hydrologic Engineering Center (HEC)-I and the Stanford Watershed Model, and to linear time series models. The NN was found to be the best one-step ahead predictions. From the research and applications that are currently being explored, it is clear that the addition of NN learning abilities would be invaluable to disaster planners, disaster logistics, mitigation, and recovery.

All current applications, of which this author is aware, of GIS and ES rely on floodplain data that is seriously out of date. Even those few areas where new data is being researched and used still suffer from increasing obsolescence because of the dynamic characteristics of floodplains. Using a NN program, historical data and real time data collection from existing and future rain gauges, flow meters, and depth gauges, a watershed and its associated floodplains can be updated constantly. This constant updating will result in floodplain maps that are current and accurate at all times.

With this system, real time floodplains, based on current and forecast rainfall, can be produced, overlaid with transportation routes and systems, road systems, fire and emergency response routes, and evacuation routes. With real flood impact areas delineated, the ES system can access telephone numbers of residences, businesses, governmental bodies, and emergency response agencies and place automated warning and alert calls to all affected people.

With such a system, “false” warnings and alerts would be minimized, thus, reducing the “crying wolf” syndrome of emergency warning systems. This syndrome occurs often when warnings are broadcast to broad segments of the population, and only a few are actually affected. After several of these “false” warnings, the public starts to ignore all warnings—even those that could directly impact them. This would also allow for sequential warnings, if the disaster allows, so that evacuation routes would not become completely jammed and unusable.

In order to implement and test such a system, a specific watershed will have to be selected. Many watersheds in the U.S. are relatively limited in surface area and have well documented histories of rainfall and subsequent flooding ranging from minor stream bank inundation to major flooding events. Such a watershed should be selected so that historical data can be used to train the NN system and to test it. Figure 1.2 depicts the flow diagram of the development and training process of this proposed Artificial Neural Network (NN).

NNs are based on biological models of the brain and the way it recognizes patterns and learns from experience. The human brain contains millions of neurons and trillions of interconnections working
together allowing it to identify one person in a crowd or to pick up one voice at a cocktail party. The structure allows the brain to learn quickly from experience. A NN is comprised of interconnected processing units that work in parallel, much the same as the networks of the brain, and can discern patterns from input that is ill-defined, chaotic, and noisy.

Figure 1.2 (Source: Turban and Aronson [1998]).

Once the development process reaches step 9, the neural network will continue to learn from current, real-time events.
Advantages of using NNs include the following: (French et al. 1992; Raman and Sunilkumar 1995).

- A priori knowledge of the underlying process is not required.
- Existing complex relationships among the various aspects of the process under investigation need not be recognized.
- Solution conditions, such as those required by standard optimization or statistical models, are not preset.
- Constraints and a priori solution structures are neither assumed nor enforced.

The general procedure for network development is to choose a subset of the data containing the majority of the flooding events, train the network, and test the network against the remaining flooding events. In this situation, the recorded documented flooding events over the recorded history of the watershed would be divided into two sets—one large training set and a second smaller testing set. Once the NN has been trained and tested for accuracy, it then will continue to use data provided via teleconnections from rain gauges, depth gauges, flow rates meters, and depth gauges throughout the watershed to continually learn and update itself. At the same time, the NN will be able to provide accurate flooding impact maps for every precipitation event as the event is occurring. The included Expert Computer System will be able to use this data to determine affected areas and populations. The ES can, at the same time, produce maps of evacuation corridors, emergency response corridors, and transportation corridors that are unaffected and still usable during the flood event. This will speed the evacuation of areas that are in danger of flooding, allow the most rapid emergency response, and provide usable routes for transportation of emergency and recovery supplies into the disaster area.

**Conclusion**

Ongoing research clearly show the tremendous potential of neural networks to use incomplete, chaotic, and noisy data to make predictions that are as good or better than other methods. In the area of disaster planning, mitigation and recovery, timeliness, and accuracy is critical. This is especially true when disaster response teams are frantically attempting to re-establish lines of communication and transportation. Accurate maps predicting and reporting affected areas would be invaluable. By combining the abilities of Geographic Information Systems, Expert Computer Systems, and Artificial Neural Networks, communities would have access to the most complete and accurate maps. At this point in time such maps are non-existent. This paper outlines the potential use and benefit of combining existing technology in a way that has not been done before in order to create these maps.
REFERENCES:


Gleasner, Laura, 1999, “A World of Information”, Earth Data Analysis Center, University of New Mexico.


