

Development of a Decision Support System for Hurricane Evacuation Management

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ABSTRACT

This article describes a project that is developing an Evacuation Management Decision Support System (EMDSS) to assist public officials in monitoring a hurricane's onset and determining when and where to initiate evacuations. Surveys will be conducted to collect currently unavailable data on warning/preparation times, compliance/spontaneous evacuation rates, evacuation route utilization, and evacuation costs for both risk area residents and transients (especially business and tourist travelers). Other surveys will collect data from businesses in evacuation areas regarding the economic impacts of the evacuations on them. The data from all of these surveys will fill significant voids in the research literature. In addition, these data will be stored in a database that will be linked to the EMDSS. This software system will provide support to public officials facing situations that require them to balance the threat to public safety against evacuation costs under time constraints and uncertainty. The project will perform a major interdisciplinary function by integrating theories from social psychology with those from transportation planning to develop an improved evacuation time estimation model, and with those from household and business economics to develop an evacuation cost model. These perspectives will be integrated with concepts from decision analysis and decision support systems to produce the EMDSS.

KEYWORDS: hurricanes, evacuation management, decision support systems

1.0 INTRODUCTION

Since the Galveston hurricane of 1900, improved systems for detection, warning, and evacuation have decreased the loss of life from hurricanes in the United States. However, population growth in coastal areas is likely to reverse this trend unless prompt and effective measures are taken. A low loss of life could be maintained if hazard-resistant land use and building construction practices were adopted rapidly enough to offset increases in population growth, but economic and political barriers to adoption make it difficult for this to occur. Consequently, improvements in the ability to evacuate threatened populations will be needed as well.

Research conducted over the past 50 years has shown that evacuation is an effective protective response to a variety of environmental hazards (Tierney, Lindell & Perry, 2001). In some cases, such as localized flooding, an evacuation decision is relatively simple because the scope of impact is so small that few people are affected and the speed of impact is so slow that even risk area residents can monitor the hazard onset and determine for themselves when to evacuate. For example, Perry, Lindell and Greene (1981) reported that residents of a flooded area near Sumner, Washington detected the hazard and implemented an evacuation with no official intervention whatsoever. In other cases, such as hurricanes, the scope of impact is large and has a rapid onset, but it is possible to detect the hazard onset and estimate physical characteristics such as its location, magnitude, and timing of impact. These data can be used to estimate social and economic impacts on a community to determine if the projected impact location is inhabited, if the impact magnitude will exceed the strength of local structures, and if the impact will occur before people can be evacuated.

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Ideally, the decision to implement an evacuation is based upon both scientific facts and community values. The scientific facts include the physical characteristics (location, magnitude, and timing of impact), but these are blurred by uncertainty because only probabilistic statements can be made in advance of hurricane landfall about the physical characteristics of the hazard that will occur at the time of landfall. Indeed, a hurricane's track, intensity, and time of landfall can change substantially if 72 hours elapse between a forecast and the time of impact.

There also is uncertainty about outcomes such as cost and time requirements of an evacuation, the number of deaths expected if a hurricane strikes when there has been no evacuation, and officials' loss of credibility if an evacuation takes place and the hurricane strikes elsewhere. Community values must be considered in establishing the tradeoffs between benefits (lives saved) and costs (expenses incurred), especially in the presence of uncertainty about the benefits and costs and also about constraints such as the time required to implement an evacuation.

The complexity of the evacuation decision is compounded by the fact that the assessment of hazard impact characteristics is made by one group of individuals—technical analysts—and the resolution of community values is properly made only by another group—politically elected officials. In many situations, it is easy for the line between scientific facts and community values to blur and for technical analysts to overstep their roles. This problem is especially likely to arise in major environmental emergencies because such events are rare for any given community. Consequently, the political officials who should make evacuation decisions tend to have little experience with such problems and are likely to defer to the technical analysts (Miller, 2001).

The complexity of the evacuation decision can be significantly reduced, although not entirely overcome, by using an *evacuation management decision support system* (EMDSS) that has been designed to support political officials when they must make evacuation decisions. The EMDSS should be designed to acquire dynamic (i.e., real-time) data about environmental extremes such as hurricanes. It also should be able to retrieve static data about the size and location of the vulnerable population, evacuation time estimates (ETEs), and estimates of evacuation costs. Finally, an EMDSS should be designed to display decision-relevant information in a manner that assists public officials in making timely and effective evacuation decisions under uncertainty. If an EMDSS can be developed successfully for hurricanes, it is likely that it could be adapted successfully to other hazard agents such as landslides, volcanic eruptions, and wildfires.

1.1 HURRICANE DECISION SUPPORT SYSTEMS (DSSs)

There currently are three hurricane DSSs that allow decision makers to input data about a hurricane and use this information to monitor its progress toward the coast. HURREVAC (Federal Emergency Management Agency, 2000) is a computer program that allows the user to track a storm's progress by downloading or manually inputting data from National Hurricane Center (NHC) Forecast/Advisories. Analysts can use storm track information to forecast the storm's future location and determine when its expected time of landfall is approaching the evacuation time estimate (ETE) for a local official's jurisdiction. They also can display the projected wind swath to identify areas at risk from high winds. HURRTRAK (PC Weather Products, 2001) is a similar product distributed by a commercial vendor.

ESTED (Texas Department of Public Safety Division of Emergency Management, 1999) also uses data from NHC Forecast/Advisories but processes it in a somewhat different manner and produces different output. Like HURREVAC, ESTED uses NHC data to determine when the storm's expected time of landfall is approaching the ETE for a threatened location. In addition, however, ESTED also provides an estimate of the arrival of the storm surge. An important feature of ESTED is its reliance on the "principle of least regret" (the minimax principle) to determine the time remaining until an evacuation decision "must" be made. This calculation is based upon the worst case assumption that local officials should initiate an evacuation if a storm could reach their jurisdiction before an evacuation could be completed if the storm proceeded directly toward their jurisdiction, no matter how small is the NHC's strike probability for that jurisdiction. The guidance in the ESTED manual also advocates that the scope of an evacuation should be based on the assumption that the hurricane could increase in strength by one category before landfall.

Each of the existing hurricane DSSs provides some of the information that decision makers should consider in making evacuation decisions. In particular, they allow the decision makers to track the storm

and to determine when an evacuation should be initiated by comparing the anticipated time of landfall with ETEs for affected jurisdictions. HURREVAC and HURRTRAK display information about uncertainties in landfall location (i.e., strike probabilities), but none of the programs displays information about uncertainties in other aspects of a storm's behavior such as its category (i.e., the probability of increasing or decreasing its intensity) or its forward movement speed (i.e., the probability of significantly increasing or decreasing the time remaining until landfall). These factors would affect the scope and timing of a jurisdiction's need for an evacuation.

Similarly, none of the existing hurricane DSSs displays information about uncertainties in ETEs. This is unfortunate because there is significant uncertainty about all of the variables that affect a jurisdiction's ETE—warning/preparation times, compliance/spontaneous evacuation rates, number and type of vehicles, and evacuation route utilization all can be expected to vary from one evacuation to another. Presenting ETEs as point estimates is likely to cause public officials to have overconfidence in the accuracy of these estimates and could cause them to delay—perhaps dangerously—the initiation of an evacuation.

Finally, none of the existing hurricane DSSs allows the analyst to assess the tradeoff between these storm characteristics and the cost of an evacuation. This tradeoff obviously is important because evacuations are very costly; Alexander (1993) reported that Dade County, Florida spends \$2 million to mobilize once it receives a hurricane warning. Other costs of an unnecessary evacuation include substantially lost revenues to local businesses and out-of-pocket expenses incurred by evacuees. The problem for the decision maker is that the economic costs definitely must be incurred (although most decision makers probably cannot estimate these costs accurately) but the benefit (reduction in lives lost) is uncertain. This latter point raises an issue that is a great concern to local officials—the loss of credibility in future warnings if they initiate an evacuation that subsequently turns out to be unnecessary because the storm strikes elsewhere.

1.2 DECISION ANALYSIS

The most appropriate technology for coping with uncertainty is decision analysis (Raiffa, 1968), and the decision to initiate a hurricane evacuation can be represented pictorially by means of a decision tree (e.g., Clemen, 1996, p. 58). Figure 1 shows that the choice of whether or not to recommend an evacuation is indicated by the square on the left of the tree and the two alternative courses of action branch toward the right. Each of the branches from the decision intersects a circle that represents an uncontrollable event—whether or not a hurricane strikes the public official's jurisdiction. Because the hurricane either will or will not strike, there are two branches that emanate from each of the circles. Each of the four branches on the right-hand side of the diagram represents one of the four outcomes that can occur when there are two decision alternatives and the uncontrollable environmental event can have two states. Each of the four outcomes can be evaluated in terms of the number of lives lost, the credibility lost, and the economic costs incurred. Note that in making an evacuation decision, the only cost to consider is the cost of the evacuation itself, not the cost of a hurricane impact (should it occur). This is because the cost of the evacuation is the only economic cost that can be avoided by withholding an evacuation recommendation.

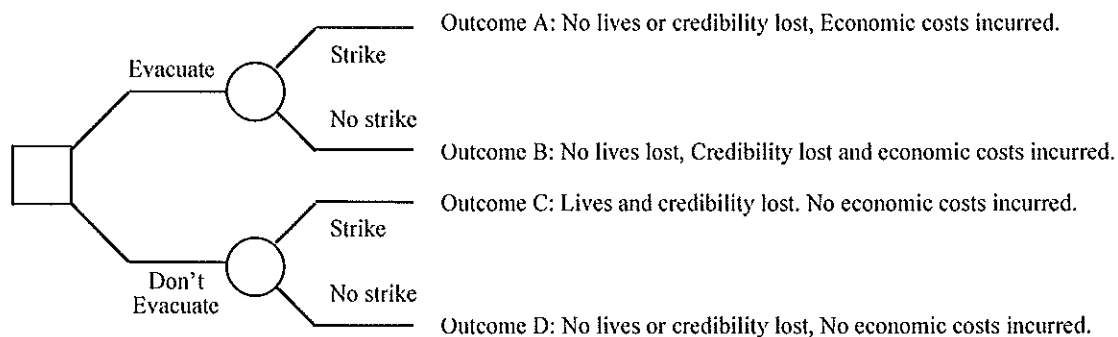


Figure 1: Evacuation decision tree

Outcome A is a correct decision because the evacuation saved lives and maintained credibility that would have been lost if the storm had not struck. Nonetheless, evacuation costs are incurred. Outcome D also is a correct decision, but this is because no lives turn out to have been at risk, no credibility is lost, and no evacuation costs are incurred. By contrast, Outcome B is a decision error (a “false positive”) because

evacuation costs are incurred even though no lives are lost. Outcome B reduces credibility and decreases future warning compliance. Outcome C also is a decision error (a “false negative”), but for the opposite reason. No evacuation costs are incurred, but lives are lost because of the failure to recommend an evacuation and lost credibility is likely to increase spontaneous evacuation in future hurricanes.

The difficulty in making an evacuation decision can be seen in the fact that the National Hurricane center’s *maximum* strike probabilities are 18% at 48 hours, 25% at 36 hours, and 50% at 24 hours. However, ETEs exceed 30 hours for major urban areas along the Gulf and Atlantic coasts, so local officials in these jurisdictions must decide whether to implement an evacuation when there is only about a one-in-three chance that they will be struck by the hurricane. If a decision maker’s jurisdiction is directly on the hurricane track, this uncertainty will not cause problems because most decision makers would opt to evacuate. Conversely, if the strike probability is less than 1%, most decision makers would choose not to evacuate. However, there is a range of probabilities between these two extremes at which a decision whether or not to evacuate will be extremely difficult to make, but existing hurricane DSSs provide no guidance on how to address this uncertainty. Moreover, as noted above, existing DSSs are limited to treating the time at which the decision must be made as a deterministic value. That is, the ETE for a given jurisdiction is provided as a point estimate (e.g., “27 hours”) even though the data upon which the ETEs are based should be characterized by distributions of values (e.g., 10% certain to be less than 22 hours; 50% certain to be less than 27 hours; and 90% certain to be less than 33 hours”). Finally, existing hurricane DSSs ignore evacuation costs altogether. Methods of addressing ETEs and evacuation cost estimates are addressed in the next two sections.

1.3 EVACUATION TIME MODELLING

ETEs are determined by the capacity of an evacuation route system to handle the demand that is placed upon it. Basic traffic engineering principles for analyzing daily traffic demands (e.g., Homberger, Hall, Loutzenheiser & Reilly, 1996; Transportation Research Board, 1998) are relevant to ETEs, but must be adapted to the special conditions that exist in evacuations (Urbanik, 1994, 2000). In particular, demand is determined by warning and preparation times, not by normal diurnal rhythms of travel to work or shopping and return to home. Moreover, demand is almost exclusively unidirectional (i.e., inland) and the rarity of evacuations precludes effective learning from experience. This is because daily commuting provides drivers with hundreds of opportunities per year to learn which route is optimal for them, but hurricane evacuations are so rare (most coastal residents have never experienced one) that it is impossible for drivers to learn which route will minimize their evacuation time. In turn, this means that it is not possible for an equilibrium to emerge that will distribute the demand evenly across all evacuation routes.

In small coastal communities with low inland population densities, ETEs are determined by warning and preparation times because demand never reaches capacity. As the population of these coastal communities increases, simple manual methods such as dividing capacity (in vehicles per hour) into demand (total number of evacuating vehicles) will provide reasonable approximations as long as the warning elicits 100% compliance in the areas at risk and no spontaneous evacuation in areas not considered to be at risk. When these conditions are not met, and especially when the evacuation route system is a complex network, computer-based methods must be used. Many previously proposed methods for computing ETEs are problematic because the analysts have made incorrect assumptions about evacuee behavior. Specifically, they assumed that all of those who are warned (and only those who are warned) will leave and that all registered vehicles would be taken. They also used postulated rather than empirical trip generation time distributions and assumed that evacuees would distribute themselves evenly over the available evacuation routes (Abkowitz & Meyer, 1996; Barrett, Ran & Pillai, 2000; Hobeika & Kim, 1998; Safwat & Youssef, 1997; Tweedie, Rowland, Walsh, Rhoten & Hagle, 1986).

Lindell and his colleagues (Lindell & Perry, 1992; Lindell, Prater, Perry & Wu, 2002; Lindell, Prater & Wu, 2002) have concluded that such assumptions are inadequate for hurricane evacuations and can systematically underestimate ETEs. Their conclusion was based upon a considerable amount of research addressing evacuation warning response (Mileti & Peek, 2000; Sorensen, 2000; Tierney, Lindell & Perry, 2001) and hurricane evacuation behavior in particular (Baker, 1979, 1991). Research on warning response has been valuable in identifying the factors that are associated with warning compliance, which is important because warned populations’ level of compliance has been found to vary substantially from one hurricane to another. For example, Dow and Cutter (2002) reported an evacuation rate of 65% during Hurricane Floyd in South Carolina but Riad, Norris, and Ruback (1999) found only a 42% rate of

compliance with evacuation warnings in their samples of victims from Hurricanes Hugo and Andrew. Similarly, Prater, Wenger and Grady's (2000) data showed that only 34% of their respondents evacuated from the Texas counties most severely threatened by Hurricane Bret.

A major limitation of the warning response research conducted to date is that little of it has examined the *timeliness* of evacuation. For example, Urbanik, Desrosiers, Lindell and Schuller (1980) proposed that the evacuation process consists of four time components. These are: a) the time required by authorities to make an evacuation decision, b) the time required for a household to receive a warning, c) the time that a household devotes to preparation for evacuation, and d) the response time required to travel to safety. Lindell and his colleagues (Lindell, Bolton, Perry, Stoetzel, Martin & Flynn, 1985; Lindell & Perry, 1987, 1992) reported warning and preparation times from four floods and the eruption of Mt. St. Helens, Sorensen and Rogers (1989) reported warning and response time data from two hazardous materials spills and Sorensen (1991) analyzed factors that accounted for household differences in warning and preparation times. However, no evacuation time data have been reported for hurricane evacuations. To overcome the lack of data from actual hurricane evacuations, Lindell, Prater, Sanderson, Lee, Zhang, Mohite and Hwang (2001) collected data on Texas coastal residents' *expectations* about the time it would take them to perform six activities in preparing to evacuate after they received a warning. The authors of this report acknowledged that the interpretation of these data are somewhat problematic because coastal residents' pre-impact expectations might not be accurate estimates of the time that they would take during an actual hurricane emergency. Nonetheless, distributions of preparation times generated from *coastal residents'* beliefs about their behavior probably are more accurate than *analysts'* beliefs about that behavior, especially if the analysts have no empirical data on which to base their beliefs. Nonetheless, coastal residents' expectations about their preparation times need to be validated by conducting surveys of evacuees following actual hurricanes.

The evacuation of tourists and other transients is a problem that has been neglected until very recently (Drabek, 1996) and even that study did not address warning and preparation times for this population segment. Lindell, Prater and Wu (2001) contended that it is likely that tourists will be warned more rapidly than local residents and will prepare to evacuate much more rapidly. However, this hypothesis also needs to be validated in surveys of evacuees following actual hurricanes.

Spontaneous evacuation is another problem that has received increasing attention since Zeigler, Brunn and Johnson (1981) called attention to this phenomenon following the nuclear power plant accident at Three Mile Island. Later studies provided explanations for this phenomenon (Houts, Lindell, Hu, Cleary, Tokuhata & Flynn, 1984) and recent studies have confirmed its occurrence in hurricanes (Gladwin & Peacock, 1997). The level of spontaneous evacuation is partially determined by a *perceived risk gradient* (Lindell & Earle, 1983) that, in the case of hurricanes, is likely to be a function of individuals' perceptions of their distance from the coast, elevation above mean sea level, and the structural integrity and number of stories of their homes. Spontaneous evacuation also is likely to be affected by coastal residents' perceptions of the expertise and trustworthiness of environmental hazard management institutions such as local, state, and federal emergency management agencies.

In the absence of studies reporting spontaneous evacuation rates as a function of physical parameters such as topographical elevation and distance from the coast, Lindell et al. (2001) collected data on Texas coastal residents' expectations about whether they would evacuate in each of the five hurricane categories and cross-tabulated these responses by the *risk area* in which the respondents live. The state of Texas defines hurricane risk areas in terms of the hurricane category at which a given location would be affected by wind and surge, so Risk Area 1 is the portion of a coastal jurisdiction that is expected to be affected by the surge inundation or damaging winds of a Category One hurricane. Lindell et al. (2001) found that rates of expected spontaneous evacuation decayed exponentially as a function of risk area (topographical elevation and distance from the coast) and also that expectations of spontaneous evacuation had a significant inverse relation to confidence in the accuracy of evacuation warnings. As is the case with the preparation time data, these evacuation expectations data are of uncertain predictive validity so they need to be confirmed by additional data from actual evacuations.

A fourth issue of major significance in modelling hurricane evacuations concerns coastal residents' choice of evacuation routes and destinations. Data from recent hurricane evacuations (Dow & Cutter, 2002; Prater, et al., 2000) show that the majority of evacuees do not distribute themselves evenly over the available evacuation routes. Instead, they take the most familiar routes inland (especially interstate

highways), thus overloading those evacuation routes and creating traffic jams that take many hours to clear. The data from actual evacuations are replicated in evacuation expectations data (Lindell, et al., 2001), which suggests that the problem of imbalanced evacuation route loading arises from beliefs that coastal residents have formed long before a hurricane threatens. These results suggest that local emergency managers could balance evacuation route loading by providing information about alternate routes, traffic management support along those routes, and cell phone access along those routes. However, further research is needed to test these hypotheses.

Finally, a major unrecognized problem in ETEs is uncertainty about the estimates, which is illustrated by the fact that traffic volume is determined by (among other variables) the number of vehicles per household. Unfortunately, this quantity has been shown to vary widely, with Post, Buckley, Shuh and Jernigan (1999) reporting a range of 1.21 to 1.54 evacuating vehicles per household in the different counties that evacuated from Hurricane Georges. Uncertainty about the number of evacuating vehicles per household that should be expected for other hurricanes should be incorporated into ETE procedures because it is the number of evacuating vehicles, not the total number of registered vehicles or the total number of persons, that determines the load on the evacuation route system. The uncertainty that is evident in the estimated number of evacuating vehicles per household should raise significant concerns in evacuation planners and emergency managers because this indicates that one also should expect to find significant variation in warning and preparation time distributions, compliance and spontaneous evacuation rates, and choice of evacuation routes. Consequently, deterministic ETEs can be criticized as conveying a misleading sense of certainty to decision makers.

1.4 ECONOMIC COST MODELLING

Recent reviews of disaster impact assessment (Committee on Assessing the Costs of Natural Disasters, 1999; United Nations Commission for Latin American and the Caribbean, 1999) have ignored the topic of evacuation cost assessment completely, which suggests that no research has been done on this topic. The economic cost of an evacuation to a community can be estimated by considering the different sectors that are affected. Government agencies incur mobilization costs when they activate personnel to provide warnings (especially door-to-door warnings), transportation support (e.g., buses for transit-dependent residents), traffic management (e.g., highway department personnel at critical intersections), and security (e.g., police patrols) in the area to be evacuated. There also are out-of-pocket costs incurred by local residents (mileage expenses for the distance travelled and per diem expenses for lodging and food) and lost revenues to local businesses (e.g., due to tourists and business visitors who leave earlier than otherwise or who cancel their reservations).

Two important questions that need to be addressed are the magnitude of the expenditures in evacuations and whether these expenditures are, in fact, lost to the community. Government mobilization costs can be considered to be economic losses, but local residents' evacuation expenses would not necessarily represent a loss of revenue to community businesses if they were deducted from household budget categories that would have been spent outside the community anyway. For example, if a household considered an evacuation to be an earlier-than-scheduled visit to family in another community that substituted for a visit already planned (and budgeted) for a later time, then these expenses should be counted as deferred, rather than foregone, expenditures within their home community. This scenario is likely to be quite prevalent because most evacuees stay with friends and relatives (Drabek, 1986; Mileti, Sorensen & O'Brien, 1992). Similarly, tourists or other transients who postpone scheduled visits to an evacuated community might cause a cash flow problem for local businesses, but this would not represent an economic loss unless the trips were made instead to other communities (e.g., alternate vacation destinations). If there is an inelastic demand for visits to the evacuated community (e.g., an outside company's sole supplier is there), visits cancelled because of an evacuation are likely to be rescheduled for a later date. In summary, the assessment of evacuation costs raises many important questions that have not been addressed in previous evacuation studies and further research is needed to answer them.

2.0 RESEARCH PLAN

This project has two principal objectives, the first of which is to address serious gaps in the scientific research on hurricane evacuations. In particular, the design of previous research has been limited significantly by lack of variation in the types of social units studied and a lack of comparison sites. The proposed research design will remedy these defects by studying three types of social units (resident

households, tourists, and businesses) and the studies will be conducted in three locations—all three of which will be communities experiencing hurricane evacuations (but not necessarily hurricane strikes). The project will address some questions not previously addressed in hurricane surveys (warning and preparation times, spontaneous evacuation, reasons for spontaneous evacuation, evacuation route choice, evacuation costs) as well as collect further data on some questions that have been addressed previously (e.g., warning compliance, reasons for compliance, number and type of vehicles taken).

The second objective is to develop an EMDSS that will provide local officials with better data on uncertainties in the scientific data on storm behavior and community response and better methods for making appropriate evacuation decisions in the presence of uncertainty. The project will consist of four major tasks: a) a household survey to collect evacuation time and expenditure data, b) a tourist survey that will collect similar data, c) a business survey to collect evacuation loss data, and d) EMDSS development. Each of these tasks is described below.

2.1 HOUSEHOLD SURVEYS

The household questionnaire development task has been initiated first so data can be collected promptly if a suitable hurricane strikes during the remainder of the 2002 season and the questionnaires can be sent out within three months of the evacuation. In any event, household data collection will take place in the 2003 and 2004 hurricane seasons. The questions will assess warning and preparation time distributions for residents and tourists, the number of evacuating vehicles per household for residents and tourists, the rate of compliant evacuation in warned areas, the rate of spontaneous evacuation in unwarned areas, the distribution of evacuees over available evacuation routes and destinations, and perceived barriers to the use of alternate routes.

Data on each of the three hurricane evacuations will be collected from a stratified sample of 525 households, with 75 respondents sampled at each of seven different levels of threat. Risk Areas 1-5 will correspond to the geographical areas that are vulnerable to the corresponding hurricane categories. Risk Area 6 will be any area of a coastal county that is inland from Risk Area 5 and Risk Area 7 will be any area of a "second tier" county that is located immediately inland from a coastal county. This procedure for geographic stratification is very similar to the one used by Prater, et al. (2000) and Lindell, et al. (2001). The major difference from these previous studies is that they were conducted in Texas, where risk areas have been defined officially by considering the joint effects of wind and surge (e.g., Ruch & Schumann, 1997, 1998). Surge penetration analyses are very time consuming and expensive because they require data from the NHC's SLOSH model, but inland wind penetration can be estimated quickly and easily using Kaplan and De Maria's (1995) inland wind decay model (IWDM). Consequently, the IWDM will be used to define the risk areas for any hurricane study sites that are not already categorized in terms of risk areas.

Data will be collected by mail questionnaires sent to each of the sampled households following Dillman's (1978) procedures, as previously implemented by Lindell and Prater (2000, in press). Sample members will be sent an initial questionnaire and those who do not respond within 10 days will receive a reminder postcard, followed by two more questionnaires at 10-day intervals if they continue not to respond. The analyses to be conducted on the household data will identify variables (especially geographic and demographic characteristics) that are predictive of these evacuation time components. Simple descriptive analyses also will be used for data on compliance and spontaneous evacuation rates and the choice of evacuation routes. Multivariate analyses also will be used to predict these variables from respondents' geographic and demographic characteristics. The results of these analyses will allow emergency planners to predict the likely levels of the dependent variables from geographic and demographic characteristics of the residents in their jurisdictions. In turn, these data can be used to provide more accurate ETes.

2.2 TOURIST SURVEY

The design of the tourist questionnaire is being conducted concurrently with the development of the household questionnaire. The tourist questionnaire will also obtain data on warning and preparation time distributions, the number of evacuating vehicles per household, the rate of compliant evacuation in warned areas, the rate of spontaneous evacuation in unwarned areas, the distribution of evacuees over available evacuation routes and destinations, and perceived barriers to the use of alternate routes. The major difference between the household and tourist questionnaires is that the latter will be designed to be administered over the telephone and, consequently, will be shorter. The tourist survey will be conducted

at only one hurricane evacuation site, which might be different from any of the household survey sites if none of the latter has an adequate mix of recreational and business visitors.

2.3 BUSINESS SURVEYS

The business questionnaire will be designed after the completion of the household and tourist questionnaires. The business questionnaire will obtain data on the number of days each business was closed by the evacuation and the associated loss of revenues minus any decrease in variable costs such as labor. The questionnaire also will attempt to determine if there was any “rebound” in revenue experienced after the evacuees’ return that offset revenues lost during the evacuation.

Business surveys will be conducted in two communities and the sampling procedure will stratify commercial and industrial businesses in terms of the categories used by Dalhamer and D’Sousa (1997) and Tierney (1997). However, the study also will include local government agencies as an additional stratum in the business sample. Experience indicates that the response rate for a mail survey of businesses could be low (e.g., Lindell & Perry, 1998), so the business questionnaire will be limited to 15 minutes in duration and will be administered by telephone. Data on the economic impacts of the evacuation will be broken down by business category and examined for statistically significant differences.

3.0 ANALYSIS OF HISTORICAL STORM STABILITY DATA

As noted earlier, local officials cannot make fully informed evacuation decisions because they need information about likely storm behavior that is not currently available. They are given information about strike probability for their jurisdictions, but they also need information about the conditional probability of a hurricane changing from one category to another, especially the probability of intensifying by one or more categories. They also need information about the probability that a hurricane will significantly increase its forward movement speed. Historical storm data will be analyzed to compute tables of these conditional probabilities.

4.0 EMDSS DEVELOPMENT

The development of the EMDSS is based upon the premise that hurricane evacuation decisions are unstructured decisions that arise from emergent situations raising novel issues, requiring knowledge that is difficult to obtain, and needing creative strategies for solution (Holsapple & Whinston, 1996). The EMDSS will focus on two decision phases that are central to decision support systems: *design* (formulating alternative courses of action) and *choice* (selecting the alternative that is the most appropriate solution to the decision maker’s objectives). In addressing these phases, the EMDSS will be guided by the principles of decision analysis (Clemen, 1996; Raiffa, 1968) and will have five major features. Specifically, it will:

- Acquire and display dynamic situational data about hurricane behavior from other hurricane programs (e.g., hurricane name, hurricane category, hurricane location, forward movement speed, estimated time of landfall, strike probability, and projected impact area from HURREVAC or HURRTRAK);
- Link to and display static background social and geographical data relevant to evacuation decision making (e.g., population data and coastal jurisdiction maps from a GIS such as ArcView);
- Store and display storm stability data (e.g., category transition probability, forward movement speed transition probability);
- Store and display evacuation data (e.g., evacuation time estimates and evacuation costs for each storm category); and
- Support the decision maker in making tradeoffs between evacuation benefits and costs under conditions of uncertainty.

In addition, the EMDSS will address a third phase, *implementation monitoring* (providing a checklist of actions that need to be performed to ensure that the evacuation is completed in a timely and effective manner). This implementation monitoring checklist will be adopted from the three appendixes to Lindell and Perry (1992) that address whether a recommended protective action should be implemented, whether a recommended protective action can be implemented, and whether a recommended protective action can be maintained and subsequently terminated. The implementation monitoring feature will provide tools for monitoring sequential task completion, the percentage of risk area clearance, and special facility response.

The EMDSS development process is proceeding in four stages. First, a *user needs and capability assessment* is being used to establish the EMDSS objectives and system requirements. Second, a *conceptual system design* will be developed that, in turn, will yield design specifications. Third, these design specifications will be used during the *detailed design* phase to produce an operational prototype. Fourth, a *prototype evaluation* will be conducted to guide incremental *prototype modification*.

4.1 USER NEEDS/CAPABILITY ASSESSMENT

The user needs/capability assessment is based on scientific (e.g., Baker, 1979; 1991) and practitioner (e.g., Ruch and Schumann, 1997, 1998) studies of hurricane emergency preparedness and will be supplemented by discussions with the staff of the Texas Governor's Division of Emergency Management and emergency management coordinators (EMCs) on the Texas Coastal Advisory Team. These discussions, which also will provide information about end-user capabilities, will be supplemented by data from Lindell, Sanderson, and Hwang's (2002) survey of EMCs. This study documented uneven access to computer technology and substantial variation in the use of computer applications.

4.2 CONCEPTUAL SYSTEM DESIGN

Figure 2 illustrates the EMDSS's preliminary conceptual system design, but work during the first year of the project will further define the EMDSS's functionality, coordination, and the user interface (especially training needs for unfamiliar demands on users). The conceptual design will produce specifications that include a database schema showing the categories of data to be represented and the relationships among those categories, and a logic flowchart showing the flow of information processing.

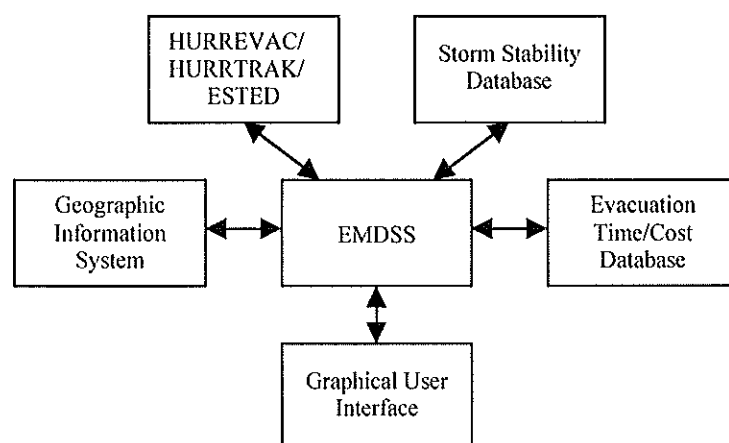


Figure 2: Conceptual system integration model

4.3 DETAILED DESIGN

System integration will be a major objective, so the EMDSS is being written in Visual Basic to facilitate export/import with HURREVAC and ArcView through the clipboard (to export from the other system and import into EMDSS). A major design objective will be to develop a "point and click" interface that maximizes user compatibility ("user friendliness"). This will be achieved by providing a human-computer interface that relies extensively on existing conventions for the Windows menu-driven interface and the office applications (word processing, spreadsheets, email, and web browsing) that Lindell, Sanderson, and Hwang (2002) have found that EMCs use most frequently.

4.4 PROTOTYPE EVALUATION AND MODIFICATION

The initial version of the EMDSS will be an evolutionary prototype that will be tested to assess its ability to meet user needs. Initial testing will be conducted using graduate students in the Environmental Hazard Management program (as surrogates for communities' EMCs) and the Bush School of Public Service (as surrogates for communities' chief administrative officers). Later testing will be conducted using the staff of state and local emergency management agencies. The initial prototype will operate on a single personal

computer, but will be designed for upgrade to a distributed multi-user EMDSS that supports individual notebooks/event logs and an asynchronous messaging system that will facilitate coordination from different physical locations. Evolution to a web-based system would be invaluable for alerting inland counties' Emergency Operations Centers about the status of evacuation decisions and evacuation implementation. In this connection, Prater, et al. (2000) found that some inland jurisdictions were unaware that Corpus Christi had begun to evacuate until traffic volumes began to rise dramatically in their downtown areas. Needless to say, such lack of notification can significantly impede effective traffic management.

5.0 REFERENCES

- Abkowitz, M. & Meyer, E. "Technological advancements in hazardous materials evacuation planning." *Transportation Research Record*, 1522 (1996) 116-121.
- Alexander, D. *Natural Disasters*. New York: Chapman & Hall (1993).
- Baker, E.J. "Predicting response to hurricane warnings: A reanalysis of data from four studies." *Mass Emergencies*, 4 (1979) 9-24.
- Baker, E.J. "Hurricane evacuation behavior." *International Journal of Mass Emergencies and Disasters*, 9 (1991) 287-310.
- Barrett, B., Ran, B. & Pillai, R. "Developing a dynamic traffic management modeling framework for hurricane evacuation." *Transportation Research Record*, 1733 (2000) 115-121.
- Clemen, R.T. *Making Hard Decisions: An Introduction to Decision Analysis*, 2nd Ed. Belmont CA: Duxbury (1996).
- Committee on Assessing the Costs of Natural Disasters. *The Impacts of Natural Disasters*. Washington DC: National Academy Press (1999).
- Dalhamer, J.M. & D'Sousa, M.J. "Determinants of business-disaster preparedness in two U.S. metropolitan areas." *International Journal of Mass Emergencies and Disasters*, 15 (1997) 265-281.
- Dillman, D.A. *Mail and Telephone Surveys: The Total Design Method*. New York: Wiley (1978).
- Dow, K. & Cutter, S.L. "Emerging hurricane evacuation issues: Hurricane Floyd and South Carolina." *Natural Hazards Review*, 3 (2002) 12-18.
- Drabek, T.E. *Disaster Evacuation Behavior: Tourists and Other Transients*, Monograph 58. Boulder CO: University of Colorado Institute of Behavioral Science Program on Environment and Behavior (1996).
- Federal Emergency Management Agency *HURREVAC and Inland Winds: Documentation and User's Manual Version 1.0*. Washington DC: Author (2000).
- Gladwin, H. & Peacock, W.G. "Warning and evacuation: A night for hard houses." Pp. 52-74 in W.G. Peacock, B.H. Morrow and H. Gladwin (eds.), *Hurricane Andrew: Gender, Ethnicity and the Sociology of Disasters*. London: Routledge (1997).
- Hobeika, A.G. & Kim, C. "Comparison of traffic assignments in evacuation modeling." *IEEE Transactions on Engineering Management*, 45 (1998) 192-198.
- Holsapple, C.W. & Whinston, A.B. *Decision Support Systems: A Knowledge-Based Approach*. Minneapolis/St. Paul: West Publishing Company (1996).
- Homberger, W.S., Hall, J.W., Loutzenheiser, R.C. & Reilly, W.R. *Fundamentals of Traffic Engineering*, 14th Ed. Berkeley CA: University of California Institute of Transportation Studies (1996).
- Houts, P.S., Lindell, M.K., Hu, T.W., Cleary, P.D., Tokuhata, G. & Flynn, C.B. "The protective action decision model applied to evacuation during the Three Mile Island crisis." *International Journal of Mass Emergencies and Disasters*, 2 (1984) 27-39.
- Kaplan, J. and De Maria, M. "A simple empirical model for predicting the decay of tropical cyclone winds after landfall." *Journal of Applied Meteorology*, 34 (1995) 2499-2512.

Lindell, M.K., Bolton, P.A., Perry, R.W., Stoetzel, G.A., Martin, J.B. & Flynn, C.B. *Planning Concepts and Decision Criteria for Sheltering and Evacuation in a Nuclear Power Plant Emergency*. Atomic Industrial Forum/National Environmental Studies Project. AIF/NESP-031(1985).

Lindell, M.K. & Earle, T.C. "How close is close enough: Public perceptions of the risks of industrial facilities." *Risk Analysis*, 3 (1983) 245-253. Reprinted in S. Gerard, R. K. Turner & I. J. Bateman (eds.) *Managing the Environment for Sustainable Development Vol. 4, Environmental Risk Planning and Management*, Northampton, MA: Elgar.

Lindell, M.K. & Perry, R.W. "Warning mechanisms in emergency response systems." *International Journal of Mass Emergencies and Disasters*, 5 (1987) 137-153.

Lindell, M.K. & Perry, R.W. *Behavioral Foundations of Community Emergency Planning*. Washington DC: Hemisphere Press 1992).

Lindell, M.K. & Perry, R.W. "Earthquake impacts and hazard adjustment by acutely hazardous materials facilities following the Northridge earthquake." *Earthquake Spectra*, 14 (1998) 285-299.

Lindell, M.K. & Prater, C.S. "Household adoption of seismic hazard adjustments: A comparison of residents in two states." *International Journal of Mass Emergencies and Disasters*, 18 (2000) 317-338.

Lindell, M.K. & Prater, C.S. "Risk area residents' perceptions and adoption of seismic hazard adjustments." *Journal of Applied Social Psychology* (in press).

Lindell, M.K., Prater, C.S., Sanderson, W.G., Jr., Lee, H.M., Zhang, Y., Mohite, A. & Hwang, S.N. *Texas Gulf Coast Residents' Expectations and Intentions Regarding Hurricane Evacuation*. College Station TX: Texas A&M University Hazard Reduction & Recovery Center (2001).

Lindell, M.K., Prater, C.W., Perry, R.W. & Wu, J.Y. "Recent developments in hurricane evacuation time estimation." *US-Taiwan Workshop on Natural Disaster Reduction* (2002) 12-1-12-8.

Lindell, M.K., Prater, C.W. & Wu, J.Y. *Hurricane Evacuation Time Estimates for the Texas Gulf Coast*. College Station TX: Texas A&M University Hazard Reduction & Recovery Center (2001).

Lindell, M.K., Sanderson, W.G. & Hwang, S.N. "Local government agencies' use of hazard analysis information." *International Journal of Mass Emergencies and Disasters*, 20 (2002) 29-39.

Mileti, D.S. & Peek, L. (2000). "The social psychology of public response to warnings of a nuclear power plant accident." *Journal of Hazardous Materials*, 75, 181-194.

Mileti, D.S., Sorensen, J.H. & O'Brien, P.W. "Toward an explanation of mass care shelter use in evacuations." *International Journal of Mass Emergencies and Disasters*, 10 (1992) 25-42.

Miller, C.D. "Long-term strategy for mitigating volcanic risk in cities." Paper presented at *Cities on Volcanoes 2*, Auckland NZ (2001).

Oak Ridge National Laboratory. *OREMS: Oak Ridge Evacuation Modeling System*, Version 2.50. Oak Ridge TN: Oak Ridge National Laboratory (no date).

PC Weather Products, Inc. *HURRTRAK-EM/PRO Professional Atlantic Hurricane Tracking and Analysis System*. Marietta GA: Author (1996).

Perry, R.W., Lindell, M.K. & Greene, M.R. *Evacuation Planning in Emergency Management*. Lexington, MA: Heath Lexington Books (1981).

Post, Buckley, Schuh & Jernigan *Hurricane Georges Assessment*: Tallahassee FL: Author (1999).

Prater, C., Wenger, D. & Grady, K. *Hurricane Bret Post Storm Assessment: A Review of the Utilization of Hurricane Evacuation Studies and Information Dissemination*. College Station TX: Texas A&M University Hazard Reduction & Recovery Center (2000).

Raiffa, H. *Decision Analysis*. Reading MA: Addison-Wesley (1968).

Riad, J.K., Norris, F.H. & Ruback, R.B. "Predicting evacuation in two major disasters: Risk perception,

- social influence, and access to resources." *Journal of Applied Social Psychology*, 29 (1999) 918-934.
- Ruch, C. & Schumann, G. *Corpus Christi Study Area Hurricane Contingency Planning Guide*. College Station TX: Texas A&M University Hazard Reduction & Recovery Center (1997).
- Ruch, C. & Schumann, G. *Houston/Galveston Study Area Hurricane Contingency Planning Guide*. College Station TX: Texas A&M University Hazard Reduction & Recovery Center (1998).
- Safwat, N. & Youssef, H. *Evacuation Time Estimates*. College Station TX: Texas A&M University Hazard Reduction & Recovery Center (1997).
- Sorensen, J.H. "Hazard warning systems: Review of 20 years of progress." *Natural Hazards Review*, 1 (2000) 119-125.
- Sorensen, J.H. "When shall we leave? Factors affecting the timing of evacuation departures." *International Journal of Mass Emergencies and Disasters*, 9 (1991) 153-165.
- Sorensen, J.H. & Rogers, G.O. "Warning and response in two hazardous materials transportation accidents in the U.S." *Journal of Hazardous Materials*, 22 (1989) 57-74.
- Stallings, R.A. "Ending evacuations." *International Journal of Mass Emergencies and Disasters*, 9 (1991) 183-200.
- Texas Department of Public Safety Division of Emergency Management. *ESTED-TX Version 99 User's Manual*. Austin TX: Author (1999).
- Tierney, K.J. "Impacts of recent disasters on business." The 1993 Midwest floods and the 1994 Northridge earthquake. Pp. 189-222 in B.G. Jones (ed.) *Economic Consequences of Earthquakes: Preparing for the Unexpected*. Berkeley, CA: National Center for Earthquake Engineering Research (1997).
- Tierney, K.J., Lindell, M.K. & Perry, R.W. *Facing the Unexpected: Disaster Preparedness and Response in the United States*. Washington DC: Joseph Henry Press (2001).
- Transportation Research Board. *Highway Capacity Manual, Special Report 209, 3rd Ed.* Washington DC: Author (1998).
- Tweedie, S.W., Rowland, J.R., Walsh, S.J., Rhoten, R.P. & Hagle, P.I. "A methodology for estimating emergency evacuation times." *The Social Science Journal*, 23 (1986) 189-204.
- United Nations Economic Commission for Latin American and the Caribbean. *Manual for Estimating the Socio-Economic Effects of Natural Disasters*. Port of Spain, Trinidad and Tobago: Author (1999).
- Urbanik, T. "Hurricane evacuation demand and capacity estimation." In E.J. Baker (Ed.) *Hurricanes and Coastal Storms: Awareness, Education and Mitigation*. Tallahassee, FL: Florida State University (1979).
- Urbanik, T. "State of the art in evacuation time estimates for nuclear power plants." *International Journal of Mass Emergencies and Disasters*, 12 (1994) 327-343.
- Urbanik, T. "Evacuation time estimates for nuclear power plants." *Journal of Hazardous Materials*, 75 (2000) 165-180.
- Urbanik, T., Desrosiers, A., Lindell, M.K. & Schuller, C.R. *An Analysis of Techniques for Estimating Evacuation Times for Emergency Planning Zones*. NUREG/CR-1745. Washington DC: US Nuclear Regulatory Commission (1981).
- Zeigler, D.J., Brunn, S.D. & Johnson, J.H. "Evacuation from a nuclear technological disaster." *Geographical Review*, 71 (1981) 1-16.