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HOSPITAL EVACUATION: ISSUES AND COMPLEXITIES

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ABSTRACT

Hospital evacuation is a difficult process that requires a robust strategy and careful execution. In the past, threats leading to possible evacuation were primarily natural disasters. In recent years the broadened nature of threats, including hazardous material spills and terrorist incidents, has complicated this already complex problem. Its importance continues to grow, but there is still no consistent approach to tackle this problem. Plan development and evaluation are crucial to the plan's refinement which leads to successful response when an evacuation threat occurs. This research describes the issues inherent in planning and evaluation along with the complexities of constructing appropriate models for emergency preparedness and evacuation.

1 INTRODUCTION

What happens when the hospital, that is expected to provide the support for first responders in an emergency situation, also needs to be evacuated?

A vast majority of emergency response plans focus on a host hospital being able to accommodate the influx of patients resulting from the disaster. However, few formal studies have specifically addressed the issues that an actual hospital faces when their occupants must vacate. In this paper, the issues and complexities inherent not only in hospital evacuation planning but also the execution of this plan will be discussed.

A review of the existing literature reveals the following facts. In the context of emergency planning, researchers have focused on general population evacuations, typically as it pertains to the use of roadway infrastructure to move people away from the hazard (Sheffi et al. 1982, Hobeika and Jamei 1985, Pidd et al. 1996, Hobeika and Kim 1998, Wolshon 2001, Franzese and Joshi 2002, Chang 2003, Cova and Johnson 2003, Radwan et al. 2005). The Subcommittee on Emergency Evacuation (TRB-SEE 2005), sponsored by the Transportation Research Board, provides an excellent source for current research investigations. Some researchers have addressed aspects of the evacuation problem such as decision making procedures (Tufekci 1995, Iakovou and Douligeris 2001, Sorensen et al. 2004) and emergency preparedness training (Pollak et al. 2004). Others have considered risk evaluation in an emergency or disaster situation where hospitals serve as support for first responders (Frantzich 1997). However, the problem of developing robust hospital evacuation plans is still largely unresearched.

Consideration of hospital evacuation occurs when a threat to the population grows to include the hospital itself. However, the hospital under consideration is likely an integral part of a broader emergency response plan to deal with those injured or exposed to the threat, which could result in a decision to not evacuate despite the threat to the hospital. During the 20th Century these threats were primarily hurricanes and floods. In more recent years, serious consideration has also been given to hazardous material spills and terrorist incidents. Since most experience has been with hurricanes and floods, few hospitals outside areas exposed to those threats have experience with decisions or processes dealing with evacuation. Broadening the number of possible threats expands both the scope of the problem and the amount of hospitals which may be at risk.

Natural disasters and other threats can lead to a number of processes of significance to hospitals. This research addresses the evacuation strategy, more specifically the development of an evacuation plan (including the decision to evacuate) along with its evaluation for refinement and improvement. In initiating this research, we surveyed regional hospitals to determine the current state of evacuation planning in South Carolina. Due to the percent of coastline within the state, the natural focus for evacuation has centered around hurricanes. Thus, many additional insights mentioned in this paper will relate to such evacuation planning where a hospital may have at least a few days in which to make evacuation decisions.

Last year, the Department of Health and Environmental Control of the state of South Carolina issued an Emergency Order that required all health care facilities in the state to prepare and/or update their emergency evacuation plans (DHEC 2004). It is recognized that hospital evacuation plans exist, and some may even be effective and robust. Without a thorough examination of the issues and complexities of evacuation, however, we cannot properly assess the evaluation of existing plans or construction of plans where they are needed.

There are several critical issues when considering the evacuation of a hospital. First, the nature of the threat may define the threat's severity, urgency of evacuation required, and ability to function during the evacuation. The risk to staff and patients may also depend on the nature of the threat, though it is to be expected that risk will increase prior to and during the evacuation. The actual act of evacuation, specifically the destinations and means of transportation, is an important part of this process that is perhaps the best understood. Conversely, problems that are highly variable depending on the type of threat along with the aspect of evacuation underway are: the extent of need for continuing acute care, demands for supplies and demands placed on resources.

The complexities of hospital evacuation lie primarily in areas that affect the ability to model the entire event, but are also dependent in part on issues, e.g., the nature of the threat. The threat itself may be a determining factor in its probability of occurrence and timing, but these may also be extremely difficult to predict. Further, these probabilities will likely change over time, to include the response to the threat. Emergency response logistics, such as contention for resources (both to deal with the evacuation and to provide care), can also significantly add to complexity. Model complexity is frequently related to the number of terms or the number of activity stages. With hospital evacuation at the present time, both of these are growing larger. Finally, complexity is also present in the dependence on the facility itself for many of the risk probabilities and activity times, making transferability of planning success or development of generic models extremely difficult.

Classic description of models as deterministic and stochastic, or descriptive and normative, further adds to the richness of this research problem. The process of developing a robust plan, and then evaluating it, improving it, and executing it, will certainly contain some deterministic elements. However, this process is almost by its very nature stochastic and, as a result, will contain elements of risk. It is unlikely that any single modeling approach will be successful. The following sections discuss these issues and complexities in more detail. The final section will attempt to synthesize these into a few gross directions for further research.

2 ISSUES

While this section does not present an exhaustive list of issues in this area, these are certainly among the most important. It is doubtful that any planning process will truly address all issues. However, the robustness of the plan will depend on solid coverage of the most essential issues. This set also is a means of illustrating the variety of issues within this research.

2.1 Nature of Threat

One of the longest standing issues addressed by regional hospitals, and still one of the most important due to its frequency, is the threat of a natural disaster. Evacuation planning for floods and hurricanes (and to a lesser extent, wild fires) has long been of concern to hospitals, depending on their locations. While tornados, earthquakes and building fires can be highly damaging, the lack of warning makes them much more difficult to incorporate into a plan. Additionally tsunami disasters have recently received international attention due to the devastating effects arising from the Indonesian earthquake of 2004. One common factor is that all of these events include a physical threat to the hospital itself. Hurricanes and floods present threats that may allow some time for evacuation, with tsunamis allowing less time and earthquakes, tornados, and building fires almost none at all. The type of geographical area also varies widely among these examples.

As frequency of toxic material transportation over highways, railroads and rivers has increased in the past century, an awareness of the occurrence of spills has grown (MacDonald 1994). Risk of nuclear accident continues to be a part of planning in hospitals within the threat zone of a reactor. More recently, concerns over weapons of mass destruction (WMD) and bioterrorism attacks released by terrorist groups have also grown, along with the desire to be prepared for such an event (Evans 2004). While the physical character of these may be similar to hazardous materials or nuclear accidents, the threat probabilities are less well known.

2.2 Risk to Patients and Staff

The nature of risk that patients and staff would face depends highly on the nature of the threat. While the risk due to hurricanes and floods is well known, the risk due to hazardous materials varies widely depending on the material. Regardless, risk must continue to be the focus as the primary motivation for planning for evacuation.

Risk level may also vary with patient acuity, and be dealt with in different ways. For example, patients near release may be released early. At the other extreme, patients with conditions too severe for evacuation tend to be sheltered-in-place. If an evacuation is mandatory, the issues surrounding the removal of patients that are able to be moved becomes especially difficult. For the larger category of patients that can readily be transferred to other sheltering facilities, the evacuation destination may vary depending on the type of sheltering facilities available. Whereas more critical patients will likely only be eligible to move to one specific location.

A more subtle but still significant factor is that risk may involve impaired ability to function for the hospital staff. This could occur due to the threat itself, but it could also occur simply because an evacuation is in progress.

Not only is the concern properly identifying the types and natures of risk, but also it is critical to quantify the level of each risk, addressed in Section 3.2.

2.3 Evacuation Mode

Evacuation mode is the focus of some existing plans and models, and it is perhaps the issue most amenable to planning and modeling. Hospitals in hurricane threat areas, for example, may be experienced at evacuation. They may have agreements with destination facilities in place, as well as resources identified for patient transportation.

One of the more difficult problems with this issue is consideration of threats which grow to include the destinations, or a threat whose magnitude consumes the destination resources. The U.S. hurricane season of 2004, for example, severely taxed resources both by direct impact and by the extent and frequency of the storms. It was not unusual for evacuees to find themselves the target of a storm after evacuation (Hoffman 2005).

2.4 Continuing Care

This issue exists at some level in almost every example. In some cases care may be required at a limited number of levels, but in others it may span the full range of patient acuity. Regardless of the extent, the need for continuing care requires resources and further complicates the evacuation.

Depending on the nature of the threat, requirements for acute and continuing care can increase. While most acute care depends on the population size, and thus its need declines as the population itself evacuates (as a hurricane approaches, for example), a hazardous material spill or terrorist incident could add significantly to the acute care needs while also posing a threat to the hospital. As the threat to the hospital grows along with the added victims requiring treatment, the evacuation decision and process become much more complex.

2.5 Resource Demands

Evacuation requires resources of types and levels which the hospital is not likely to possess for routine operations. The threat itself may consume some of these or otherwise reduce their availability. Busses, bridges, highways and ambulances are not only needed for evacuation, but they could be unable to provide service before being used, because of this impending disaster.

Another subtlety of this problem is that medical professionals, of necessity, become involved in the logistics of evacuation. This reduces their availability for patient care while being consumed in activities for which these resources may not be well suited. Thus not only do the demands of evacuation conflict with providing care, but those providing the care are called upon to perform functions with which they are not familiar.

3 COMPLEXITIES

The complexities of planning and executing a successful evacuation arise primarily from the dimensionality and interaction of issues. The varieties of threats, variations in risk, need for resources and other factors combine and interact in ways difficult to predict and in numbers that in themselves can make planning difficult.

3.1 Threat Probabilities and Timing

The nature of the threat carries with it a magnitude of threat to the facility (along with staff and patients) and a time scale. The likelihood of the threat itself is difficult to determine. The amount of notice before evacuation is an important factor in the evacuation's success, but this depends not only on the threat but also on a number of different decision processes.

In some scenarios, the hospital administration is responsible for the evacuation decision; in others, however, it may be mandated by local or state government. This could be a significant complication, which must be addressed within a brief time frame. Other threats which do not allow a staged evacuation based on reasonably good predictions of arrival, could require imminent evacuation with much less time to prepare.

A significant complication, perhaps approaching worst case, occurs when evacuation is determined to be required but the threat makes evacuation impossible. One example would be a hurricane approaching a barrier island where a regional hospital is located. Should the storm accelerate unexpectedly, the evacuation route could become unavailable making an evacuation impossible.

3.2 Change of Risk Over Time

After identifying the types of risk individuals can face, it is worth noting that all risks do not occur at the same time or with the same level of severity. For example, some component of personal risk for both staff and patients arises from the threat, while another risk component arises from the evacuation process. As the threat approaches, the threat from the risk may also increase. (One example is the inclusion of tornados in approaching hurricanes.) A few classifications of patient risk could include further injury, worsened sickness, or even death as a result of the threat. These risk levels will change over time; it is even possible that there is a shift in the level of risk from a high risk of injury/sickness to a high risk of death.

Risk associated with the evacuation process comes from a number of sources. First, evacuation involves personnel becoming engaged in non-routine activities. Although drills and exercises can be used to reduce problems during emergencies, there should be no expectation that staff can handle evacuation activities with the skill level associated with their everyday responsibilities.

The risk associated with these non-routine, stressful activities may increase due to fatigue and dislocation. While the effects of fatigue in shift work are relatively well known, evacuation may involve double shifts (or longer) added to routine work days. Requirements to function in unfamiliar areas, whether these are different parts of the hospital or different geographic locations, further complicates this problem.

3.3 Resource Contention

Typically some of the resources required in evacuation are not on hand or in the direct control of the hospital such as transportation resources or care resources at the destination. Hospital resources are also affected by the evacuation, but in different ways.

The medical professionals have as their first priority the care of their patients. However, the personnel themselves are resources which may be diverted from their primary focus, leading to internal conflict between caregiving and evacuation preparation and execution. Conflicts within departments are also more likely to occur when evacuation processes are not sufficiently well defined. Coupling this with the fact that these professionals also have families with safety concerns, it is not clear how effectively the evacuation tasks can be completed.

One of the human tendencies that needs to be countered here is optimism. While it may be attractive to use optimistic time estimates for evacuation activities, the likelihood is that these activities will take longer than estimated unless fatigue, unfamiliarity with work areas, conflict with caregiving, and engagement in non-routine activities are taken into account.

3.4 Scale and Scope

Hospital evacuation involves a large number of activities within a large number of hospital functions. Some activities depend on the number of patients, while others do not. The number of activities, with varying levels of sequence and dependence, could be quite large.

The complexity of a model, whether descriptive or normative, tends to grow with size and variety in structure. In hospital evacuation, we have both size (in number of terms and number of stages) and variety in structure (sequence, interdependence, contention for resource).

3.5 Facility-dependent Activity Times

The complexities addressed to this point could be encountered in any strategy and plan for hospital evacuation. However, the details in how the plan is constructed and executed depend in many ways on the facility itself. This includes its geographic location, its construction, and its patient population.

Clearly the evacuation of a long term care facility will be different from the evacuation of a general purpose regional hospital. Within a single class of facilities we will also find that the patient population and its mix of patient acuities can change on a daily basis. Geographic location is also a factor; for example, mountain states will not plan for hurricanes just as coastal states will not plan for blizzards. This leads to the likelihood that not only will plan requirements vary by type and location of facility, but they will also vary over time within a facility. There may be no way to address the extent of variation by type or location.

Variation over time within a facility requires a very robust planning process. The plan needs to recognize the impact of the changing patient population as well as turnover in personnel. Having recognized the extent of this impact, it then needs to address at least the most significant activities affected by within-facility variation.

4 MODELING APPROACHES

A conventional approach to model development considers the nature of the problem or sub-problem and then attempts to match this with a model type. Some possible model types for sub-problems in hospital evacuation are project networks, mathematical programs, and simulations. The integration of interacting components of the evacuation problem will likely require the use of several approaches.

Inherent in the discussion of modeling approaches is model use. Models can be used to assist in plan development as well as in evaluation of plans or assessment of emergency exercises.

4.1 Project Models

In one sense hospital evacuation can be well described by a critical path model (CPM). The evacuation process can be thought of as a set of activities, some of which are constrained by resources, but all of which must be completed for success. Considering probabilistic completion times for the activities, an alternative modeling approach could be the Project Evaluation and Review Technique (PERT) model (Winston and Venkataramanan 2002).

From a different perspective, some of these activities may fail and require contingencies. This is more like Q-GERT (Pritsker 1979) or a network of activities with probabilistic success as well as completion time. This approach to modeling, whether deterministic or not, depends a great deal on knowledge of the activities and their interactions, and so it may be limited to certain parts of the evacuation decision and plan.

4.2 Mathematical Programming

This approach as well requires knowledge of the activities and their interactions. A mathematical program may be applicable to the transportation and scheduling components in particular (Winston and Venkataramanan 2002 and Ahuja et al. 1993). This aspect of evacuation planning has received a relatively high level of attention, and is the focus of some evacuation plans, perhaps leading to the level of knowledge that would be required in constructing a useful model. In order to have a representative model, we may require time windows within which evacuation tasks will be completed. Yet, since most of the tasks comprised in an evacuation plan are stochastic in nature, we would likely need to develop a probabilistic or stochastic model, which can quickly become extremely hard to solve efficiently.

A mathematical program of just the transportation component would still be large and complex. While this component is relatively well known, it still contains dependencies and interactions that may be complex or poorly defined. The transportation component would still need to communicate with the facility evacuation and other model components, which may lead to the development of a larger decision support system (see Section 5). Finally the ability to include overall levels of risk could be difficult.

4.3 Simulation

Given the extent of risk, interaction, and sequence-dependent success, simulation may be a good choice for sub-models or models of component processes. The conventional wisdom would be that the complexities that make mathematical or network programming difficult would make simulation a logical choice (Law and Kelton 2000, Santos and Aguirre 2004).

This conventional wisdom is probably correct with regard to development of the models. However, the same complexities of scope and scale that make mathematical programming difficult will also make analysis of simulation results difficult. The possibility is very good that, while a high fidelity model can be developed, it might be almost impossible to analyze in a meaningful way.

Thus, we would recommend a simulation model with sufficient detail to produce meaningful quantitative output on decisions and requirements during an evacuation. Often knowing when not to include additional details and tasks in a model is a combination of art and science, and this would require additional research.

Over the last decade, there has been significant progress on integrating optimization techniques with simulation (Tekin and Sabuncuoğlu 2004). Building a simulation/optimization model could allow us to measure the effectiveness of evacuation policies and find alternative evacuation strategies that meet some minimal risk and cost objectives. With recent developments in simulation optimization, not only can we represent and evaluate complex real-world systems with simulation, but we can also use advanced searching methods to identify near-optimal (or, at the very least, improved) plans and routings.

4.4 Hybrid Models

With this approach, a model structure is developed that will accommodate a variety of model types, each selected for its usefulness in its specific component of the evacuation process. It is expected that deterministic and stochastic models, models comprised of both of these factors, and models which explicitly deal with dependence, all can provide benefits to evacuation and emergency preparedness. The question then becomes on what basis should the enveloping structure be designed.

This leads to a broader issue, whether a single comprehensive model or model structure is practical. An outcome to be avoided is a significant level of effort in development of a combination of elegant models whose output is of little practical value because of difficulty in finding meaningful ways to analyze the results.

4.5 Models in Plan Evaluation

Perhaps the best near-term use of models in this process is in plan evaluation. That is, given a plan, develop a model that attempts to inform the users of likely outcomes and areas of high sensitivity. For the various components of the evacuation process, there could be a variety of model types.

In this use, then, the models are customized to reflect the plans that they evaluate. Given the variety to be expected in plans, a critical feature in a model type is its amenability to rapid development. Simulation again may find itself useful due to the interfaces of many simulation systems that lend themselves to rapid model development while maintaining the desired level of fidelity and providing meaningful output.

Given the issues and complexities discussed to this point, it is unlikely that a generic model could be developed for plan evaluation, especially in light of the degree of customization necessary for the facility. It is even less likely, then, for a generic model to be developed to support plan development.

5 CONCLUSIONS

The problem of developing a plan for regional hospital evacuation, and then testing, refining, and executing it, is a difficult one. There are a number of issues and complexities inherent in this process that have limited approach to this problem in a systematic way to development of models for component activities. This is complex in itself; Figure 1, a simplified decision flowchart for a segment of an evacuation plan, illustrates this. The remaining sections address these difficulties by describing the state of the art and approaches to extending it that have some feasibility.

5.1 Current State of the Art

The current status of planning in this context is one of a variety of plans using a variety of approaches. Some of these approaches are ad hoc, many are not based in sound

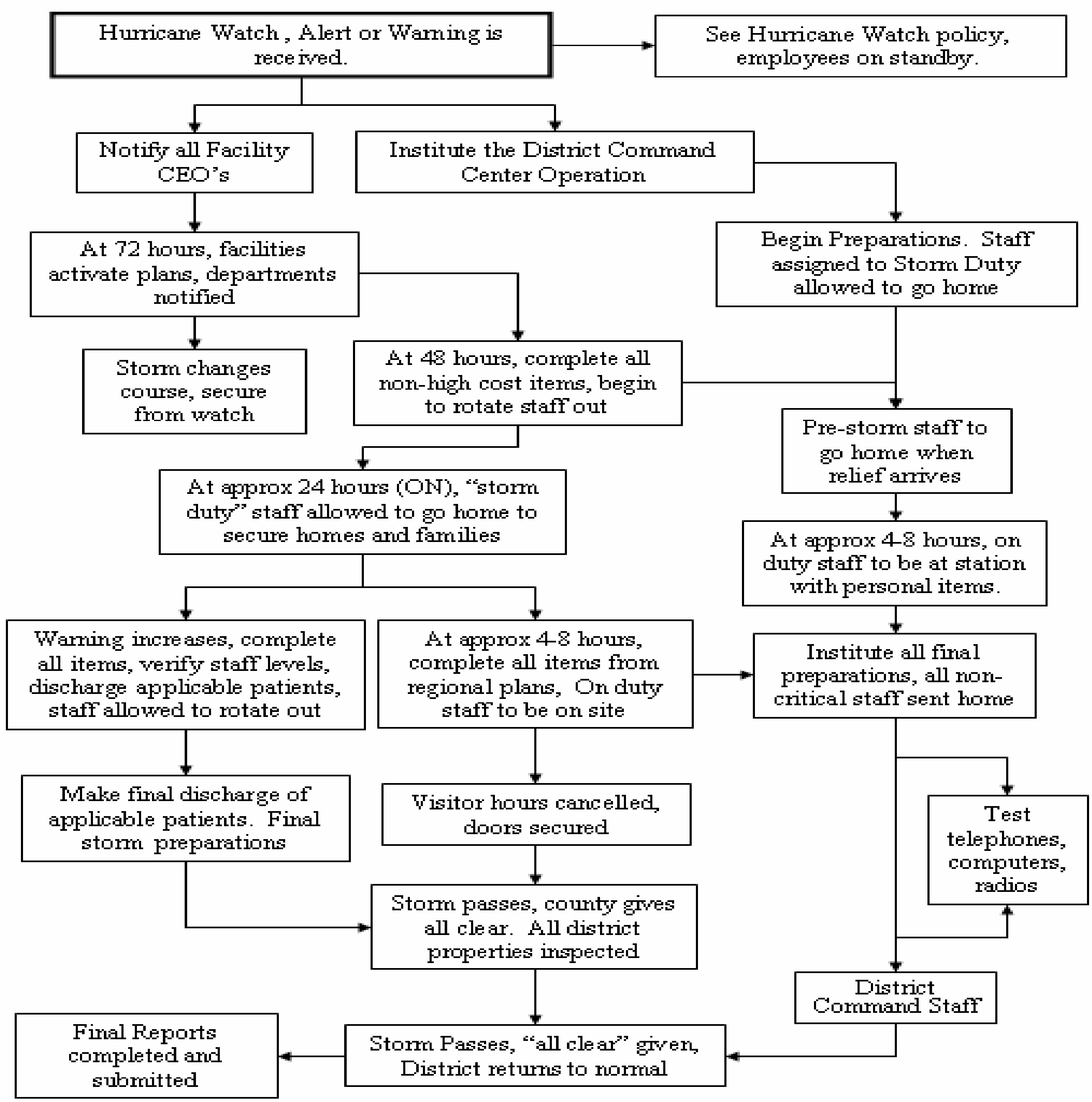

Figure 1 : Example Evacuation Decision Flow

analysis or modeling methods. The unique association of plans with facilities is common, and it should not be surprising that the best elements of these plans deal with the most familiar and easily modeled components of hospital evacuation.

Simulation is a viable modeling method for plan testing and refinement, and this finds its most frequent use. A growing activity is that of disaster exercises. Simulation can find a use here as well, in determining plan sensitivities, in developing risk probabilities, and in preparing for the physical exercise (a very expensive process) using a computer model (a much less expensive option).

5.2 Evacuation Decision Support System

The complexities inherent in this problem, and the all but impossible task of development of a comprehensive model structure, make the development of a decision support system attractive as a resource for plan development and execution. This approach lends itself to integration of a number of model types within it, where each is selected for the consistency of its capability with the needs of its component.

Simulations embedded within this structure could perform a number of different functions, and could become active at different stages. For example, some simulation models could be dedicated to providing information that other models require, while others might be dedicated to testing and evaluation.

The ability to encompass a number of model types in the decision support system allows customization. Customization will be required to deal with the facility dependence. It might also be an approach to a simplified plan that addresses a single threat. This would allow use of a system to begin while the larger system was still in development. A significant issue in development of this decision support system is definition of its structure.

5.3 Dynamic Data-Driven Systems

While one focus is to identify a methodology for modeling hospital evacuations, an ultimate goal would be to allow local hospitals the ability to monitor an evacuation currently in progress. Any combination of the modeling tools suggested in Sections 4 and 5 could be combined into a system that would physically reside in the local hospital.

A key future research area is determining how to feed a dynamic, data-driven simulation (or other decision support) model with data from real-time weather forecasting models, as well as wind measurement models, to provide real-time responses to evacuation plans. Such investigations into data driven systems has gained so much support that there now exists a Dynamic, Data-Driven Applications Systems (DDDAS) program, which NSF strongly supports as a key area for future research (Darema and Sen 2004).

5.4 Models for Plan Construction

While a decision support system (or part of one) can provide needed assistance in the short term, this approach does not address the issues of variation among facilities and the level of expertise in model development and use in those dealing with development of evacuation plans. This leads to the question of whether a different sort of system could or should be developed to support plan construction.

The evacuation plans for hospitals would be expected to vary with the hospitals' locations, patient mix, susceptibility to threat and other factors that lead to customized plans. However, they all have similar general goals. Given adequate definition of these goals and learning through development of a decision support system structure, a model (or set of models) for plan construction becomes possible.

Without such a resource, plans will continue to be developed with internal and external inconsistencies, customized to facilities, and possibly lacking in some important respects. Those developing evacuation plans may be highly skilled at what they do, but it is unlikely that they are equally adept at the quantitative and modeling issues inherent in this problem. This makes the creation of a plan development resource the desirable long term goal of this research.

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