ANALYSIS AND EVALUATION OF EMERGENCY RESPONSE USING PROJECT MANAGEMENT AND SIMULATION TECHNIQUES

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ABSTRACT

This article describes how emergency response capabilities can be analyzed and evaluated using project management and simulation techniques. This evaluation approach is contrasted with traditional exercise-based evaluation strategies. Project and simulation models of response tasks are shown to be valuable tools for analyzing response times and variability in response times.

Project models are relatively easy to develop and provide revealing information on the interactions of the various players in the emergency response system, but they are limited because they are based on point estimation. The development of simulation models is somewhat more involved, but because the models use probability distributions rather than point estimates, they yield a more accurate representation of the potential behavior of the emergency response system.

These ideas and techniques were developed through application in the U.S. Army Chemical Stockpile Emergency Preparedness Program (CSEPP).

INTRODUCTION

Innovative Emergency Management, Inc. (IEM), has been providing plan evaluation support to the U.S. Army Chemical Stockpile Emergency Preparedness Program (CSEPP). The goal of CSEPP is the mitigation of the effects of any accident at the U.S. Army's eight mainland chemical weapons stockpile sites. The specific work discussed in this paper involves an effort to integrate the emergency plans of one of the Army stockpile installations with the plans of the state and the three closest counties.

An emergency response can be evaluated in terms of its speed, quality, and cost. However, these metrics only have meaning when analyzing the capability of an emergency response to support the response's ultimate goal: namely, the protection of life and property. Thus, emergency plans should be evaluated on how well and how quickly this goal is reached.

In this paper, we focus on the evaluation of response time, because speed is the easiest of the metrics to capture. Also, for applications with fast-moving hazards, such as chemical accidents, speed is often the most critical dimension.

In addition to the average speed of a response, consideration should also be given to the variability in response time. Variability in an emergency response is directly related to plan robustness. A plan is robust if it can effectively and efficiently handle a wide variety of operating conditions. The reduction of variability in emergency response is an important goal. In a response, a large number of complex, highly interrelated tasks must be performed, and unanticipated situations are almost guaranteed to arise. In such an environment, the ability of the response plans and procedures to handle non-ideal situations is of great concern. Improving plan robustness leads to a more easily managed emergency, and greater confidence in emergency responders.

To analyze the response time, two models of the emergency response processes were created: a project model and a simulation model. Both models accurately reflect actions that would be taken in a true emergency. The models focus on all the individual tasks necessary during a response, as well as their interrelationships. The project model uses discrete point estimates for all response task times, whereas the simulation model improves the realism of the analysis by defining a probability distribution for the time required for each response task.

The models were created through analysis of written plans and extensive interviews with local emergency responders. In addition, the models were verified and corrected, as much as possible, through monitoring of response exercises. This article presents examples of the modeling approach; however, to respect client confidentiality, the examples are fictional and serve only to illustrate the process.

The response models are valuable because they:

- focus on critical tasks and their interdependencies.
- allow rapid "what if" analysis.
- clearly document all response tasks and procedures.
- allow evaluation of response capability by focusing on the goal of response.

PROJECT MODEL

Using commercial, off-the-shelf project management software, we placed emergency response on a project timeline, scheduling the actions of response agencies during a chemical emergency. The technique allows emergency responders to see how their activities impact the rest of the response infrastructure. All dependencies between response tasks are defined explicitly, so that the contribution of each response position to the overall response is shown. The model also clearly identifies critical response tasks that constrain the time required to achieve the ultimate goal of the response.

The finished model consisted of nearly 400 tasks. Figure 1 illustrates the model using a small subset of these tasks. (The figures are at the end of the paper.) The figure shows the county response starting with initial notification and continuing through to activation of the sirens.

The first task, "Notify Staff," takes 12 minutes and starts immediately after the initial notification from the Army. Once the emergency staff have been notified, two tasks proceed simultaneously. The elected official reviews and approves the recommended protective actions, while other staff prepare appropriate siren messages. These tasks are modeled to take 20 minutes and 7 minutes respectively. Once both these tasks are completed, the sirens can be activated.

In this example, the county response takes a total of 47 minutes (12+20+15). Notice that, although activation of the sirens requires both the approval of the elected official and the preparation of siren messages, only the approval delays the activation of the sirens. This analysis suggests that all tasks are time critical except the preparation of siren messages, and hence that improvement efforts should focus on reducing the time needed for these critical tasks rather than reducing the message preparation time.

Project models provide a valuable analysis tool for evaluating response timeliness and the relationships between the parts of the response system. However, they have some limitations. Most significantly, project models do not reflect the variability inherent in an emergency response. One consequence of this drawback is that the models tend to be optimistic. The models are created largely through site personnel input. In our experience, when estimating the time required for specific response tasks, site personnel typically assume no unexpected circumstance will arise to foil their plans. For each individual task, this time estimate may be reasonable, but considering the large number of interrelated tasks performed during an emergency response, it is likely that some task(s) will take longer than expected. For a more detailed analysis – one that allows variability in task times – a simulation model is required.

SIMULATION MODEL

Simulation models were created using commercial, off-the-shelf spreadsheet and simulation software. For each task in the project model, we defined the range of possible response times and a probability function. The amount of variability introduced depended on the nature of the task. Allowing for variability increases the complexity of the model, but also improves the realism. The simulation model quantifies the variability in overall response times. Due to the variability in individual response tasks, the individual tasks that are time critical in any given response may change. As a result, the simulation model provides a broader and more realistic analysis of the current response's capability.

The finished simulation model contains approximately 50 of the most critical response tasks. Figure 2 illustrates how the response tasks used in Figure 1 may be modeled when variability is added. Notice that now each task time can vary. The plots by each task represent the probability density function (pdf) for the task time. The vertical line in each pdf shows the hypothetical response time for each task from one run of the simulation model.

Notification of staff takes between 10 and 20 minutes. Since little information was available regarding what time was most likely, a uniform distribution was used to model the variability in this task.

As in the project model, once the staff are notified two other tasks can be performed simultaneously. Approval by the elected official takes between 15 and 25 minutes. Since this task was fairly predictable and averaged 20 minutes, the variability inherent in this task is modeled with a normal distribution. The time required to prepare a siren message, on the other hand, has a large possible range of 4 to 45 minutes. In most cases, a fairly small amount of time is required because a prescripted message can be used. However, if the accident scenario does not fit the conditions described in the message library, a new message must be drafted which may take a significant amount of time. The gamma distribution models this type of situation very well.

Finally, the time required to activate the sirens is modeled as the sum of two normal distributions. The time required to activate the sirens averages either 15 minutes or 25 minutes depending on whether or not the primary siren activation system functions as intended.

Typically, preparing siren messages takes little time. However, if new messages need to be drafted, as modeled in Figure 2, preparing the message may take longer than the approval by the elected official. If this occurs, the critical path changes, since now preparation of messages now constrains the overall response. This example illustrates the advantages of the simulation model.

In building simulation models the tendency to make overly optimistic estimates for task times can be countered. In our experience, interviewees typically are able to offer reasonable estimates of the range of possible response times for individual tasks. For each task there is usually an easily determined minimum amount of time required that must be greater than zero. The maximum time required is more difficult to determine since long response times, due to special circumstances, are comparatively rare. However, by questioning the underlying assumptions, such as the assumption that primary response personnel will be available, an estimate of the maximum time can be obtained.

In this exercise it is important not to consider very unlikely events, but rather to focus on realistic conditions. Appropriate pdfs are typically right-tailed (like the "Prepare Siren Message" task in Figure 2), or are truncated on the left side. In any individual run of the simulation model, most tasks will have durations near the optimistic times used in the project model. However, due to special circumstances, some tasks may take significantly longer. As illustrated through Figure 2, this analysis can reveal useful information about the robustness of the response and the impact of unexpected delays in certain parts of the response.

The simulation model also allows time distributions to be correlated. For example, in the simulation model IEM created for CSEPP the time required to analyze the hazard is negatively correlated with the probability that the primary hazard analyst is available. This reflects the reality that alternate hazard analysts are not as familiar with the process, and typically take longer to analyze a hazard.

EVALUATING RESPONSE DIRECTLY AGAINST A HAZARD

To further evaluate the response capability, the emergency response models were combined with an analysis of the response of the civilian population, through either evacuation or in-place sheltering, and the progress of the hazard itself.

In our application, evacuation time estimates and in-place sheltering time estimates (the only two protective action decisions considered in CSEPP) were already available, and an analysis of the hazard itself was possible through the use of a chemical dispersion model. Running the dispersion model repeatedly with various combinations of credible accidents and realistic weather conditions created a profile of the hazard. In this way, the time necessary to protect the population, namely the Army and county response times plus the protective action implementation time, can be directly compared with hazard arrival times. From this comparison, it is possible to gauge under which accident scenarios the emergency response is likely to be sufficiently rapid.

COMPARISON WITH TRADITIONAL EVALUATION OF EMERGENCY PLANS

Traditionally, emergency plans are evaluated in a two step process. First, the plans are judged by higher authorities based on a thorough perusal of the plan, but not based on any demonstration of the plan's execution in a disaster environment. Second, response exercises are conducted.

Exercises place emphasis on achieving tasks in a manner consistent with an organization's formal emergency plans. Conformance to plan specifications is regarded as proof that an organization is fit to respond to disaster, since the plan has been approved by a higher authority. During this evaluation, each function in the response organization is considered separately, without evaluating how that function supports the overall response.

In the traditional analysis of plans, the ability to respond is never directly compared to the exigencies of disaster, and the ability of the response infrastructure as a whole system is never evaluated. Rather, each individual role in the emergency is evaluated against the written plan. This way, the contribution of each role to the overall mission – to protect lives and property – can too easily be forgotten. As such, some aspects of an emergency are not given appropriate emphasis by planners and plan evaluators.

In contrast, project and simulation models emphasize the need for a timely response to disaster. Success of a plan's execution is determined based on hypothetical lives saved, rather than conformance to the written plan. Furthermore, each function in the response organization is not assessed in isolation, but evaluated based on its contribution to the overall response goals.

CONCLUSIONS

Project and simulation models enable emergency managers to benchmark their capability against their organizational mission, which is to protect lives and property, instead of against the formal specifications of a written plan. Under traditional plan evaluation, there is no way to tell how one person's actions are dependent on others, or how one person's actions enable others to act. However, using project management and simulation techniques, planners can see how each aspect of response impacts the saving of life and welfare through the identification of response bottlenecks and critical response tasks. Planners can also gauge the ability of their plans to address changing operating conditions, and how changes in their plans improve response times. Since the actions of civilian populations are incorporated into the model, any improvement can be expressed in terms of saved lives.

These modeling techniques cannot supplant exercises as a tool for evaluating plans; exercises still provide uniquely valuable insight into the implementation of a plan. However, the use of project management and simulation can supplement traditional evaluation to improve the timeliness and robustness of a response. In addition, these techniques can be used effectively at a fraction of the cost of conducting an exercise.

BIOGRAPHY

Innovative Emergency Management, Inc. (IEM), is a research-based corporation specializing in emergency management and automation support. The company's expertise lies is five critical areas: emergency planning, computer services, management consulting, data and documentation services, and training. IEM has offices in Baton Rouge, Louisiana, and Salt Lake City, Utah.

Keith Alleman holds a B.S. in Quantitative Business Analysis from Louisiana State University in Louisiana, USA. He has worked with IEM for three years, focusing on response planning and plan analysis for the United States Chemical Stockpile Emergency Preparedness Program.

Stefan Steiner received his Ph.D. in Business Administration from McMaster University in Ontario, Canada. A former employee of IEM, he now holds a teaching position at the University of Waterloo in Ontario.

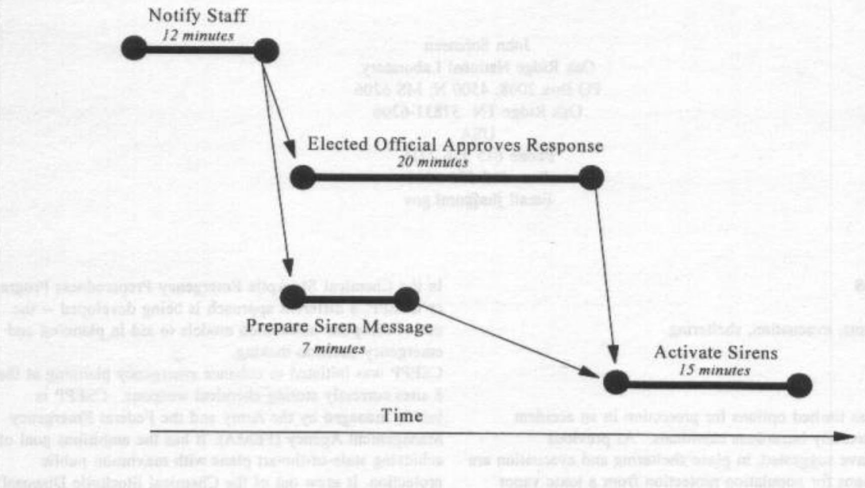

FIGURE 1: PROJECT-BASED RESPONSE MODEL

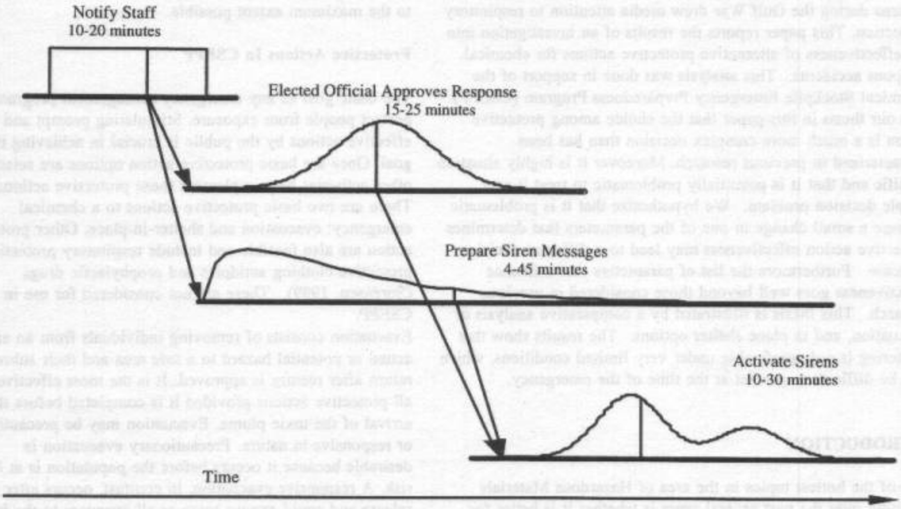

FIGURE 2: SIMULATION-BASED RESPONSE MODEL