A FRAMEWORK FOR ANALYZING SAFEGUARDS ALARMS AND RESPONSE DECISIONS

UCRL--86215

DE82 016784

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ABSTRACT

This paper describes a quantitative approach to help evaluate and respond to safeguards alarms. These alarms may be generated internally by a facility's safeguards systems or externally by individuals claiming to possess stolen Special Nuclear Material (SNM). This approach can be used to identify the most likely cause of an alarm--theft, hoax, or error--and to evaluate alternative responses to alarms. Possible responses include conducting investigations, initiating measures to recover stolen SNM, and replying to external threats. Based on the results of each alarm investigation step, the evaluation revises the likelihoods of possible causes of an alarm, and uses this information to determine the optimal sequence of further responses. The choice of an optimal sequence of responses takes into consideration the costs and benefits of successful thefts or hoaxes. These results provide an analytical basis for setting priorities and developing contingency plans for responding to safeguards alarms.

INTRODUCTION

Stolen special nuclear material (SNM) could pose a serious threat to public safety. When a safeguards system indicates that SNM may be missing, authorities must determine the likely cause of the alarm and respond appropriately. To assist in this process, we have developed a quantitative, decision-analytic model, called the Alarm/Response (A/R) Model.[1] This model can be used at the time of an alarm to help determine its cause and evaluate possible responses. Alternatively, it can assist in developing contingency plans before any alarm occurs. In addition, it can be used to analyze the benefits of more timely alarms and improved response capabilities. The model was originally developed to assist the Nuclear Regulatory Commission (NRC) in determining these benefits and in establishing appropriate regulations.

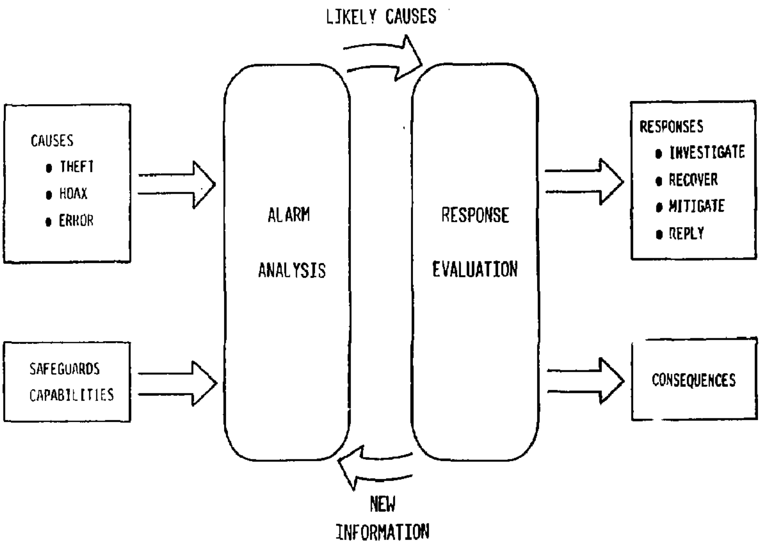
The A/R Model explicitly considers three possible causes of safeguards alarms: SNM theft, hoax, or error. SNM theft is limited to covert attempts by insiders. Hoaxes are deliberate acts intended to give the appearance of theft. Errors include bookkeeping mistakes and other innocent causes--such as process holdup--that lead to differences between the measured material inventory and the accounting records. One major use of the model is to help a facility analyze alarms by determining which of these causes is most likely. Another is to evaluate alternative responses to the alarm. These responses may include conducting investigations, initiating measures to recover stolen SNM, or replying to extortion threats from individuals claiming to possess SNM. The evaluation of alternative responses considers the likely causes of alarms as well as the ultimate consequences of successful thefts or hoaxes.

The data requirements of the A/R Model are similar to those of the Aggregated Systems Model (ASM),[2,3] a probabilistic risk analysis tool for nuclear safeguards, developed for the NRC and the Department of Energy (DOE). The data collection procedures used for the A/R Model are similar to those developed for the ASM. They have been applied successfully in support of many safeguards decisions, ranging from rapid on-site assessments of existing safeguards systems to detailed cost-benefit studies of new safeguards requirements.

THE STRUCTURE OF THE A/R MODEL

To analyze and respond to safeguards alarms, authorities must take several factors into consideration. These include possible causes of alarms, facility safeguards capabilities, response alternatives, and associated consequences. Figure 1 shows these factors as inputs when the model is used to "Analyze Alarms" and to "Evaluate Responses." The paragraphs below discuss these major uses of the A/R Model.

Figure 1. Structure of the A/R Model.



Analyzing Alarms

The first major use of the A/R Model is to analyze an alarm to determine the likelihood that it was caused by theft, hoax, or error. These likelihoods provide a convenient means to describe an alarm situation, and they aid in choosing an appropriate response.

Safeguards alarms may be generated internally, by a facility safeguards system, or externally by individuals claiming to possess stolen SNM. We refer to the latter case as a communicated threat since we assume the caller threatens some consequences if specific demands are not met within a given time. As indicated above, "errors" is a broad category that includes all innocent causes: measurement errors and inaccuracies; bookkeeping errors; misplaced SNM; and process holdup and losses.

As shown in Figure 1, the model uses data on alarm causes and safeguards capabilities to compute the likelihood of theft, hoax and error. These data include estimated frequencies of thefts, hoaxes, and errors and the probabilities that the safeguards system will generate an alarm for each cause.

The A/R Model displays the computed likelihood of each cause when an alarm is received as a point inside the triangle in Figure 2a. The diagram is constructed with unit base and height, so that the distances indicated in Figure 2a correspond to the likelihoods of theft, hoax, and error causes (0.14, 0.32, and 0.54, respectively). Note that the point lies closest to the vertex labeled "Error," which is the most likely cause in Figure 2a. This display gives decision makers a visual indication of the relative likelihood of each possible cause.

Using the A/R Model to analyze alarms is helpful throughout an investigation. For instance, if a large physical inventory difference occurs, the model assists by giving an initial determination of the likelihood of each cause. As the investigation proceeds, the A/R Model can be used to revise the relative likelihoods based on new information. This information is represented by the arrow from "Evaluate Response" to "Analyze Alarm" in Figure 1.

Continuing the same example, assume the the triangle in Figure 2a displays the initial likelihoods computed after the physical inventory alarm. Assume that authorities decide to conduct a more thorough "cleanout" inventory. This procedure will conclude either that all material is accounted for (MAF), which we define as having the books balance within normal error limits, or it will conclude that material is unaccounted for (MUF). Using a technique called Bayesian revision (discussed below), the model computes two new sets of likelihoods, as displayed in Figure 2b. One point displays the likelihood of each cause if the investigation concludes MAF; the other point is for the MUF outcome.

Bayesian revision combines two sets of input data: initial likelihoods of possible alarm causes (shown in Figure 2a), and assessments of the likelihood that the cleanout inventory will conclude MAF or MUF given the alarm was caused by theft, hoax, or error.

Figure 2a. Graphic representation of the likelihood of alarm causes.

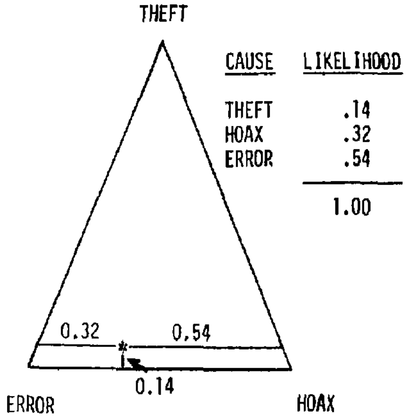
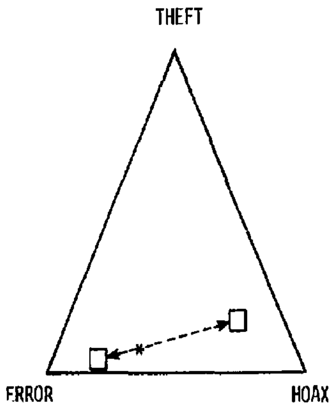


Figure 2b. Revised likelihoods based on MAF and MUF investigation outcomes.



As Figure 2b indicates, if the investigation concludes MAF, then the cause of the alarm is more likely an error (or holdup) than theft or hoax. However, there is still residual uncertainty because it is possible for the inventory to "account for" all material within normal limits of error, when, in fact, some SNM is actually misplaced or missing. If the investigation concludes MUF, then theft or hoax are more likely than they were before the investigation.

The type of information shown in Figures 2a and 2b assists decision makers in *understanding the current state of information* in an alarm situation and incorporating new information as it becomes available. Figures like 2b can show the degree to which a particular investigative procedure would change the current state of information, thereby to helping quantify the benefits of that procedure. The likelihoods shown in Figure 2 are useful inputs to decisions on how to respond to an alarm, whether the response is further investigation or a reply to a communicated threat.

The next section discusses using the model to incorporate the likelihood in alarm response decisions.

Evaluating Responses to Alarms

This A/R Model's capability to evaluate alarm responses builds upon its capability for analyzing alarms. Figure 1 shows the major factors involved in the choice of an appropriate response: the response alternatives; the likelihoods of possible alarm causes; and the consequences of each response depending on whether the cause is theft, hoax, or error.

Decision makers may have various options for responding to an alarm: conducting one of several investigative activities (called resolution procedures) to resolve whether the alarm was caused by a theft, a hoax, or an error; calling in law enforcement agencies or emergency response teams to recover stolen SNM; evacuating threatened areas to mitigate potential consequences; replying to any communicated threat, or ignoring the alarm. The number of available options depends on the type of alarm.

Some of these alternatives are extremely expensive, with no assurance of success. Furthermore, time limits imposed by an adversary may preclude some response options. Therefore, the choice of the best response may be quite difficult. The model provides a logical framework for examining the combined effects of the relevant factors for each alternative. In this way, it can help the decision maker consider the implications of each response. Further, the model can explore the trade-offs between immediate response costs and the effectiveness of the response in reducing public risk.

The A/R Model uses expected total cost as the criterion for evaluating response options. For resolution procedures or SNM recovery measures, expected total cost is the immediate cost of the investigation plus the long-term economic and non-economic cost to the public. For a reply to a communicated threat, the expected total cost is the extortion amount if the extortion demand is met and the expected public consequences if the demand is refused. Naturally, there are numerous uncertainties to be considered when determining these costs. The model explicitly incorporates uncertainties in expected costs and allows decision makers to *determine the effects of these uncertainties on* the choice of a response.

The response to an alarm may often include an entire sequence of actions. For example, suppose a routine physical inventory indicates missing SNM. A first step in response might be a quick check of records and SNM locations to ensure no error was made. If the conclusion is MUF (i.e. the missing material is not found), then a more thorough inventory might be conducted. If that fails to account for the missing SNM, a more exhaustive plant search may be appropriate, with notification of law enforcement and SNM recovery agencies if the outcome is MUF.

The evaluation of each response option must consider its possible outcomes as well as those of future responses. This is accomplished in the A/R Model through repeated use of the model's "Analyze Alarms" capability, that is, by calculating the likelihoods of the possible causes of the alarm for all combinations of responses and outcomes. This iterative procedure is represented by two arrows in the center of Figure 1, and it is used to determine an expected total cost for each alternative response. The model ranks possible responses in order of cost and indicates the one with the lowest expected total cost.

The potential public consequences of SNM theft are highly uncertain, and there are few data with which to quantify those risks. Nevertheless, alarm response decisions made in the public interest must consider those risks, even if the consideration is highly judgmental. With this in mind, the A/R Model has been designed to help decision makers examine the implications of various judgments and assumptions about the magnitudes of those risks.

APPLICATIONS OF THE A/R MODEL

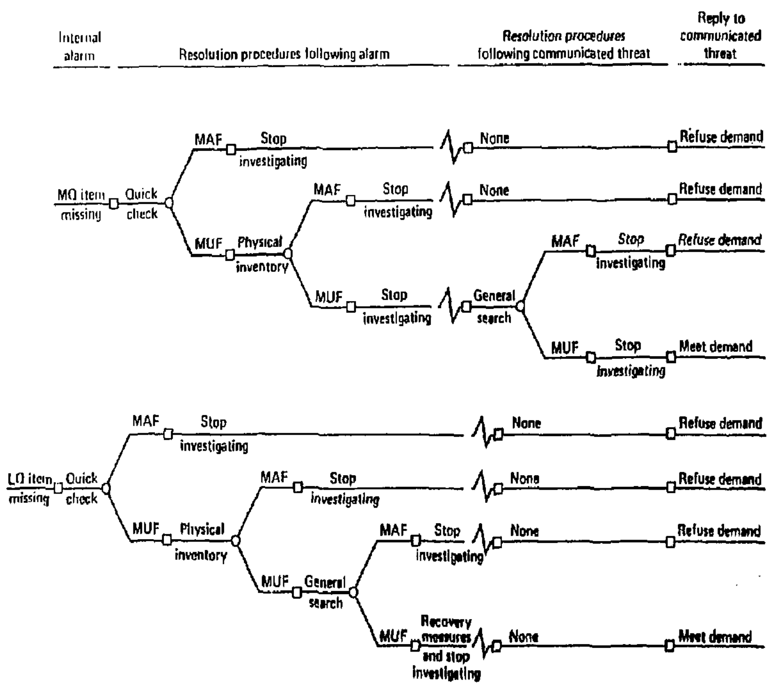
This section describes two applications of the A/R Model. First, we illustrate contingency planning for safeguards alarms with an example developed for a hypothetical facility. Second, we briefly summarize how the model can assist in establishing regulations for alarm and response performance.

Contingency Planning

As described in the preceeding section, the A/R Model can be used to identify the least-cost response to a safeguards alarm. The sequence of optimal responses to an alarm is called a contingency plan. To ensure timely action when an alarm does occur, these plans are developed in advance. They can be tailored not only to a particular facility, but to the type of alarm, the quantity of SNM involved, and whether a communicated threat is received.

Figure 3 shows two contingency plans for two types of alarms at a hypothetical facility. Both plans show the optimal sequences of responses to alarms indicating that uniquely identified items are missing. In the first case (the upper plan in Figure 3), the missing item contains a medium quantity (MQ) of SNM; in the second case it contains a large quantity (LQ). ("Large" and "medium" mean, respectively, weapon quantity of SNM or less.)

Figure 3. Illustrative contingency plans.



A decision tree format is used to display the contingency plan. At every square decision node is a branch that indicates the least-cost response. Circular nodes represent the possible outcomes of resolution procedures--MAF or MUF. The sequence of optimal responses includes a quick check of facility locations and records relevant to the alarm, a physical inventory of those areas, a general search of the facility and, if investigations fail to account for the missing item, initiation of SNM recovery measures. The trees also include replies to communicated threats.

Notice that the optimal sequence of responses can be different, depending on the quantity of material involved. The trees show that the LQ alarm is investigated more thoroughly than the MQ alarm. This result depends on the assumed costs and effectiveness of recovery measures and on the relative consequences of losing a medium and large quantity of SNM. These are judgmental factors, and the model can be used to evaluate how changes in these factors affect the overall contingency plan.

Regulation-Setting

The original motivation for the A/R Model was the need for a way to compare quantitatively different safeguards requirements. For example, this would allow decision makers to determine the value of a more timely alarm. Reducing alarm times is beneficial if it improves the ability to determine the cause of an alarm, facilitates SNM recovery, or reduces the likelihood of an incorrect reply to a communicated threat.

The model quantifies these benefits by comparing the expected total costs of responding to alarms under existing requirements with the expected total costs if alarms are more timely. The difference in expected total costs is a measure of the benefit of the more timely alarms. By comparing this benefit with the incremental safeguards cost to reduce alarm times, the A/R Model can help policymakers determine the appropriate performance level for safeguards systems.

CONCLUSIONS

Benefits and Limitations

The A/R Model provides a logical approach for *analyzing safeguards alarms* and *responding* to those alarms. It represents a first step toward the development of a systematic and quantitative decision-making framework to assist safeguards authorities in these situations. The model can be applied to a variety of safeguards decisions, ranging from developing contingency plans to real-time analysis and selection of responses to internal or external alarms. The model can also help determine the value of revised safeguards requirements, such as more timely alarms or more effective responses.

The model incorporates available data and expert judgment, analyzes that information systematically, and identifies its logical implications. In addition, it allows decision makers to quantify their degree of uncertainty regarding critical factors. The model also can help decision makers judge the adequacy of available information and determine whether it is best to gather additional data or to make a decision based on existing information.

The A/R Model is designed to supplement--not replace--the expertise and intuition of safeguards authorities. Often more important than the model's indication of a best response are the insights gained from sensitivity analysis and from studying the reasons behind specific model results. The model is motivated by the belief that such insights will improve the quality and consistency of safeguards decisions.

Further Development

Development of the A/R Model is continuing, focusing on data needs and computational aspects of the model. Data for the model's capability to analyze alarms are being gathered at operating facilities. The model capabilities to evaluate responses will require more information, especially regarding consequences and the effectiveness of recovery measures. The need for these data is an inherent aspect of the alarm/response problem. Even in the current environment, where safeguards decisions are made without the benefit of quantitative tools, such factors must receive, at least, implicit consideration.

Other current development efforts focus on streamlining the model for ease of use at the facility level. This involves simplifying the model in some areas to enhance its flexibility and to minimize computational requirements. We are also exploring other criteria for evaluating alternative responses. These could be used to evaluate response alternatives in lieu of explicit quantification of public risks.

REFERENCES

1. R. A. Al-Ayat, B. R. Judd, and R. K. McCord, Analyzing Safeguards Alarms and Response Decisions, Lawrence Livermore National Laboratory, Livermore, CA, NUREG/CR-2404, UCRL-53034 (July 1982).

2. R. A. Al-Ayat and B. R Judd, "A Model for Analyzing SNM Safeguards Decisions," Energy and Technology Review, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-52000-81-10 (October 1981).

3. R. A. Al-Ayat, J. M. Huntsman, and B. R. Judd, An Aggregated Systems Model for Nuclear Safeguards, Volumes 1, 2, Lawrence Livermore National Laboratory, Livermore, CA, NUREG/CR-1140, UCRL-52712 (June 1979).

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.