Emergency Response Performance Measures Used in the Assessment of Risk to Human Health Due to the Accidental Release of Hazardous Chemicals

Rudi H.P.M. Arts
and
Frederick J. Weiland

Innovative Emergency Management
8555 United Plaza Boulevard, Suite 100
Baton Rouge, LA 70809, USA
tel. (504) 952 - 8191
e-mail: arts@ieminc.com

Abstract

The potential exists that the public may be exposed to a hazardous material if an accidental, relatively sudden chemical release into the environment occurs at locations where hazardous materials are stored and handled. At these locations, officials responsible for public protection need to evaluate the acute risk to public health from the presence and movement of these hazardous materials. Public risk depends upon several factors, chief among which are the probability of a hazard itself and the effectiveness of public protection and response measures. The public depends on local emergency response systems to provide them with the necessary protection and minimization of potential hazard, should an accidental release to the environment of potentially hazardous materials occur. The authors treat emergency response as a system that implements a process whose performance can be quantified, measured, and managed.

In the USA, emergency response systems are normally administered and managed by public officials and are publicly funded. Therefore, both the officials and the public are interested in being able to appropriately allocate resources to, and manage the performance of, response systems at more than one jurisdiction at a time. Selection of an appropriate set of system performance measures will enable decision makers to accomplish this. The objective of this paper is to describe the authors' work in developing such performance measures. The authors propose and describe appropriate performance measures and the emergency response systems to which they can be applied. Performance measures were developed as a preliminary step in building a simulation model. This model is the primary tool for assessing the small risk to public health due to possible atmospheric chemical agent releases. Though the emergency response process described in this paper is developed for potential responses to chemical agent releases to the atmosphere, the authors believe that the approach taken has a wider field of application, e.g. potential accidents in the chemical industry. Note that the viewpoints described in this paper in no way reflect official or unofficial viewpoints or positions of the US Army and Department of Defense.

Keywords: Performance Measurement; Emergency Management; Emergency Response; Risk Assessment; Public Risk; Hazardous Chemicals.

1. Introduction

The ability to measure the performance of any emergency response system, including information systems, people and communication equipment used, is important because it allows managers to gauge the level of emergency preparedness of the public and indicates ways to improve the preparedness and response capability provided. Performance measurement supports decision-making on potential capital expenditures aimed at increasing public emergency preparedness for hazardous materials releases. Performance measurement and management capability in the face of hazardous materials releases to the atmosphere is especially important because there is typically far less time available to respond, in the unlikely event that a response is needed, than in the event of hazards that develop more slowly, such as hurricanes. Emergency management of hazardous materials releases is further complicated by the fact that it can affect more than one civil jurisdiction at a time. The emergency response systems can vary significantly in detail among jurisdictions. This variation creates difficulties when analyzing response system performance among hazardous materials storage sites or before and after implementing systemic changes; yet the ability to make such comparisons is essential to managing system performance.

Risk is the product of the probability of some outcome and the cost, financial as well as non-financial, of that outcome. In this case, the two factors are the probability of a particular chemical hazard and the number (or proportion) of people who may be affected by that hazard, should it occur and should it be severe enough to leave the storage facility and be of a dosage that would exceed the dosage that the human body can handle without consequence. The term "hazard" is used to describe a possible accidental release of hazardous chemical agent to the atmosphere occurring under specific meteorological conditions.

Risk assessment provides information that can be used in emergency management. Before assessing risk, it should be determined what variables influence it and how to express it so that it supports the emergency management process.

2. Characterizing the Hazard, Population and Environment

A hazard is a combination of accident and meteorological circumstances. For chemical agent storage sites, a list of possible accidents is identified and a probability of occurrence has been determined [4] [5]. Should a jurisdiction be affected by a chemical release, its population will not be affected equally. Those people who reside closer to the source of the release will be at small but greater risk of achieving No Effects dosage than those who reside further away. Furthermore, population will not be distributed uniformly over the jurisdiction. One could divide the area up in small enough parts so that the assumption of a uniform distribution holds, but this introduces complexity. Alternatively, it could be assumed that the entire population resides at the geographical center or some other point in the area. However, this would introduce a bias based on whether the one particular point is affected by the cloud or not. Another complicating factor is the fact that the residential population moves around during the day. Furthermore, exposed people will be affected differently depending on the particular activity they are engaged in at the time of exposure. For instance, if they are actively working outdoors at the time of exposure, they will be affected more than when performing sedentary work indoors. This is called the time budget of households [3, p. 61]. Also, anatomical differences between people cause some to be more easily affected than others. Another influencing factor is how much skin surface is exposed, which relates to clothing habits and climatic conditions. Further, the air exchange rate of the particular structure in which a person resides at the time of impact of a chemical cloud, will influence how well sheltered that person is in that structure. Also, the people's timing of exit out of the shelter is of influence on the amount of exposure received in the unlikely case of a release. In conclusion, the number of variables influencing level of protection achieved by a given person in an affected area is large. Unless every individual possibly affected wears a chemical dosimeter at all times, it will be impossible to determine with certainty the number of people affected beyond a specific dosage due to a given release. The above describes the complexity of the emergency response environment in which performance measurement is needed.

3. Performance Indicators

A Performance Indicator is:

"a numeric value for an aspect of a (sub)process that isn't influenced by related processes and is representative as a measure for the effectiveness and/or efficiency of that aspect of the (sub)process." [1]

Management requires performance information to be able to control the processes. Information should bear on the state of the process, developments in it and the environments the function operates in. It focuses on the effectiveness and efficiency of the process, meaning its activities, organization and cooperation with other organizational units.

Performance indicators (PIs) are needed to give management quantitative information on the extent to which goals are reached and what actions to take to improve its operations. They are a means to achieve control, so that costs can be reduced, productivity can increase, safety of the process can be improved and environmental regulations can be fulfilled.

The absolute value of performance indicators can be compared to a norm (to be chosen beforehand) or a trend in this value can be used to glean performance levels. The following performance indicators are suggested for the assessment of risk to human health due to hazardous materials storage and handling:

Direction of goodness for each PI is indicated between parentheses.

1. Expected Number of People Affected beyond No Effects Dosage Per Year for an Area of Interest (minimize)

This provides an indication of the efficacy of the entire response system considering the potential hazards. The efficacy expresses the mean value of the population actually affected beyond a No Effects dosage in number of people rather than as a fraction of the population at risk. A No Effects dosage is a calculated dosage from a chemical agent release below which a toxicity level is not expected to have short-term adverse effects on healthy adults [2].

Applications for this PI include comparing response system efficacy for two or more areas of interest, evaluating trends in this measure to show degree of improvement for constant areas and populations, and comparing the chemical hazard consequences for a specific area to consequences from other hazards to the same area.

This PI is influenced by the probabilities of hazards, the particular accident set being considered, the number of people living near the storage area, the distribution of the population, the protective action decision-making policies, the time required to complete response tasks, the set of tasks and their relationships, and the response behavior of the potentially affected population.

2. Expected Fraction of the Population of an Area of Interest Not Affected Assuming that a Chemical Accident Occurs that will Affect that Area (maximize)

This PI provides an indication of the efficacy of the entire response system considering the actual hazards. The efficacy expresses the population not affected as a mean value of the fraction of the total population at risk. This PI is essentially equivalent to the quantity complement of the expected fraction affected beyond No Effects dosage, normalized to the all hazards probability.

Applications for this PI include comparing response system efficacy for two or more areas of interest and evaluating trends in this measure to show degree of improvement for constant areas and populations. Because this PI does not explicitly include the small probabilities of individual initiating accidents, it is not appropriate for comparing the chemical hazard consequences to consequences from other hazards, unless they have been similarly normalized to their respective "all hazards" probability.

Because this PI is expressed in terms of a *fraction* of the people not affected, it is a complementary measure to the expected *number* of people not affected. It compensates for the fact that the number of people not affected in one zone relates to the actual population present in the zone at the time of a release. This is especially important for sites whose population is not uniformly distributed or that changes significantly over time.

This PI is influenced by the probabilities of hazards, the particular accident set being considered, the distribution of the population, the protective action decision-making policies, the time required to complete response tasks, the set of tasks and their relationships, and the response behavior of the potentially affected population.

3. Expected Fraction of Population Affected Beyond No Effects Dosage Per Year (minimize)

This PI measure provides an indication of the efficacy of the entire response system considering the actual hazards. The efficacy expresses the mean value of the population affected, should an accident occur, as a fraction of the population at risk rather than as a number of people affected.

Applications for this PI include comparing response system efficacy for two or more areas of interest, evaluating trends in this measure to show degree of improvement for constant areas and populations, and comparing the chemical hazard consequences for a specific area to consequences from other hazards to the same area.

This PI is influenced by the probabilities of hazards, the particular accident set being considered, the distribution of population, the protective action decision-making policies, the time required to complete response tasks, the set of tasks and their relationships, and the response behavior of the potentially affected population.

The above-mentioned PIs provide performance information of the entire response system influencing a particular area of interest, e.g. a jurisdiction. In order to analyze possible problems indicated by these overall PIs, other, more detailed, PIs are needed that focus on specific parts of the emergency response system. Such indicators were omitted here as they fall outside of the scope of this paper. In order to understand how the PIs will be used, we need to analyze the emergency response environment to some degree. This requires that we determine emergency response tasks and milestones in a typical emergency response process itself.

4. The Emergency Response Process

It should be noted here that no standard model of the Emergency Response Process exists. Variations exist across jurisdictions. The model described here attempts to show an example response system for emergencies involving potential atmospheric releases of chemicals at military storage facilities. For this reason, only major milestones in the response process were given. *The deterministic time estimates between milestones are for illustrative purposes only and will vary between jurisdictions and events.*

Figure *1a* shows a flowchart of an example emergency response process that takes place at the Emergency Operations Center (EOC) at a depot of a chemical agent storage site, in the unlikely event that a chemical agent release occurs. Listed task durations are in minutes and are for illustrative purposes only.

Shortly after a chemical accident or incident (CAI) occurs, personnel will observe with the help of permanently installed detection equipment that a release occurred. This observation may be reported to the person in charge of security, e.g. the Directorate of Law Enforcement and Security (DLES), or another official. This person will attempt to obtain detailed information on what occurred. Though no standard dispersion modeling software exists in industry, the government has accepted the D2PC software as its standard. The dispersion modeling software D2PC will therefore be used in this example emergency response system to estimate the effects of the release under current meteorological (met) conditions. In order to be conservative, it is assumed that the accident was in fact the Maximum Credible Event (MCE) as determined for that day. This is the worst case scenario accepted for a certain day considering the planned materials handling of the chemicals for that day. A designated official, e.g. the Director of Operations (DO), then decides what emergency level should be declared. Offpost EOCs will generally only be alarmed in the rare case that the hazardous cloud is expected to threaten people residing outside of the fences of the depot. Offpost EOCs are those EOCs which are located in an area surrounding a military installation or facility. In case these offpost EOCs need to be warned, a Protective Action Recommendation (PAR) is made for the jurisdictions which are at risk, based on dispersion model output. A PAR will list for each jurisdiction potentially at risk what protective action (e.g. evacuation, shelter in place) is considered most effective and therefore recommended. This PAR information is then sent to the offpost EOCs in the jurisdictions potentially at risk from the release and/or other EOCs who might distribute this information in turn, based on agreements made between the military installation and its surrounding jurisdictions.

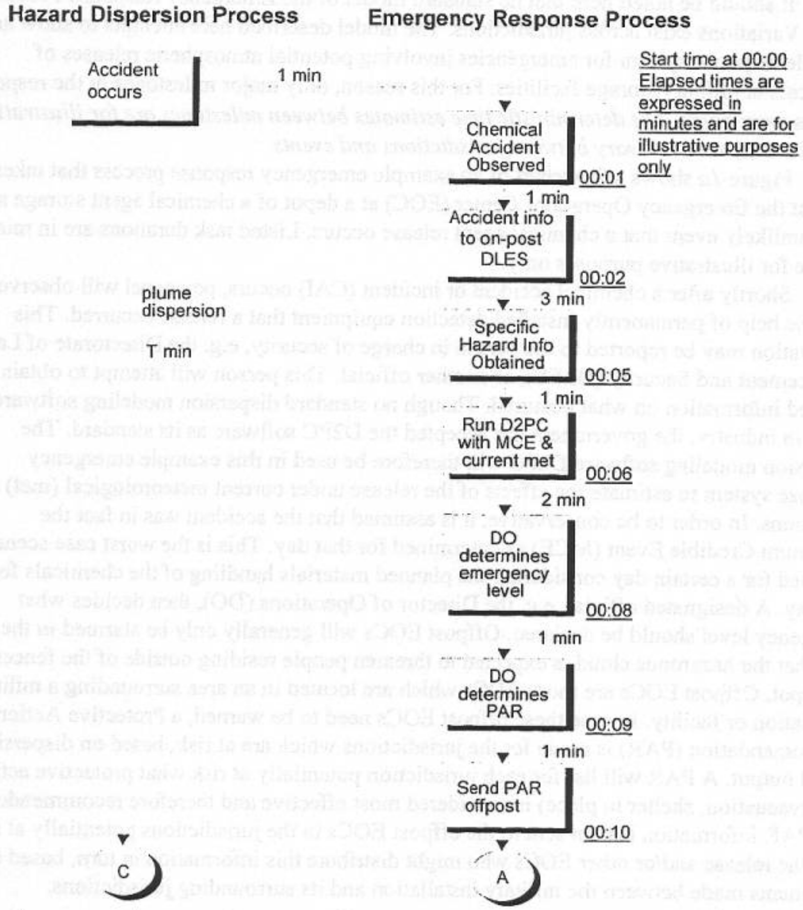

fig. 1a: Emergency Response Process at On-post Emergency Operations Center[1]

Figure 1b shows the emergency response process as it may apply to the offpost EOCs. As part of the daily management routine, offpost EOCs prepare a Protective Action Decision (PAD) for their jurisdiction should the Maximum Credible Event occur that day. This PAD might consequently be used in their reaction to the receipt of a PAR from the depot. Upon receipt, the recipient makes EOC personnel aware of the emergency and might call them to their stations. This is called an initial internal Emergency Management (EM) alert.

[1] Elapsed times are for illustrative purposes only and will vary by jurisdiction and event.

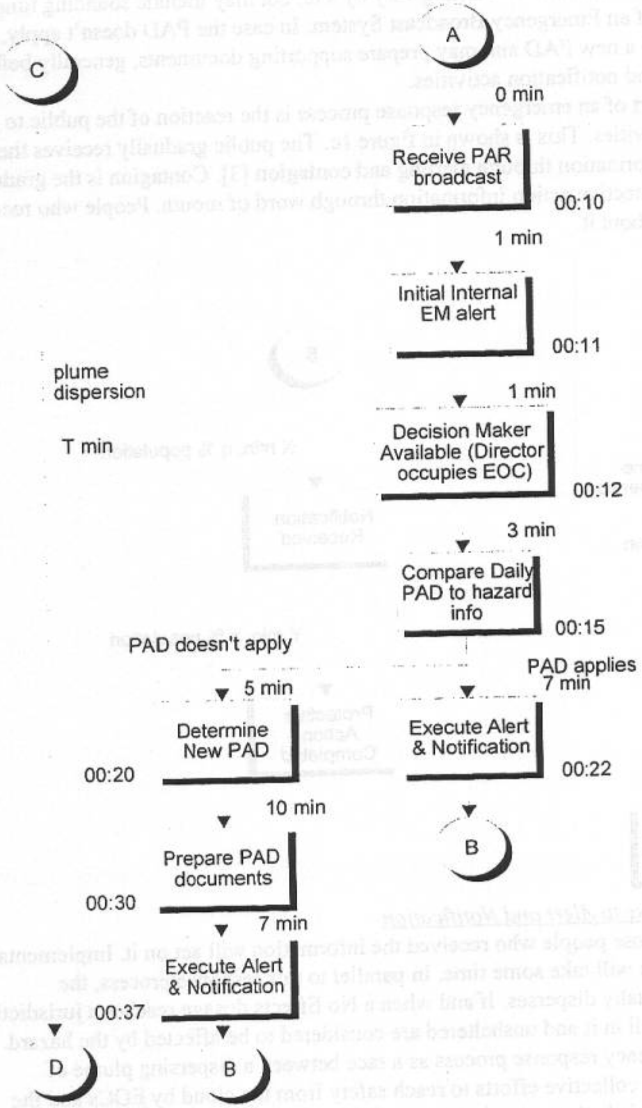

fig. 1b: Emergency Response Process at Offpost Emergency Operations Centers[2]

Shortly after this alert, the director of the EOC or other official authorized to make an alert & notification decision, arrives at his/her post or is contacted. Following his or her arrival or as soon as contact is established, the hazard information is compared to the Protective Action Decision (PAD) that was prepared for that day as part of the daily management routine. If the PAD applies, the EOC proceeds by executing its alert and

[2] Elapsed times are for illustrative purposes only and will vary by jurisdiction and event.

notification activities. Methods of warning vary by site, but may include sounding tone-alert radios and the use of an Emergency Broadcast System. In case the PAD doesn't apply, the EOC will determine a new PAD and may prepare supporting documents, generally before executing its alert and notification activities.

The third part of an emergency response process is the reaction of the public to alert and notification activities. This is shown in figure 1c. The public gradually receives the protective action information through alerting and contagion [3]. Contagion is the gradual dispersion of the protective action information through word of mouth. People who received the alert tell others about it.

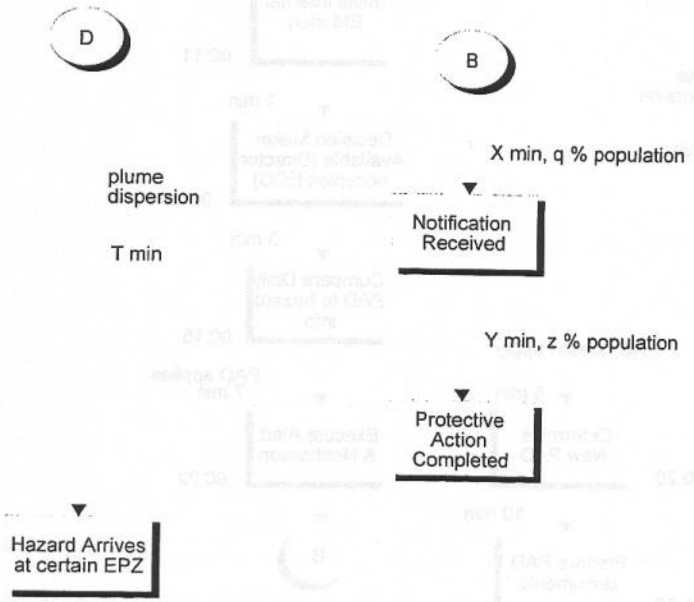

fig. 1c: Public Response to Alert and Notification

A portion of those people who received the information will act on it. Implementation of the protective action will take some time. In parallel to this response process, the hazardous plume gradually disperses. If and when a No Effects dosage reaches a jurisdiction at risk, those people still in it and unsheltered are considered to be affected by the hazard. One can consider an emergency response process as a race between a dispersing plume of chemical agent and the collective efforts to reach safety from the cloud by EOCs and the general public in the jurisdictions at risk. Its objective is to get people who might be at risk into safety before a dispersing plume can pose an immediate threat to their life and health.

5. Conclusions

The number of variables influencing the level of protection achieved by a given person in an affected area is large. Unless every individual possibly affected wears a chemical dosimeter at all times, it will be impossible to determine with certainty the number of people affected beyond a specific dosage due to a given release.

Performance measurement of emergency response processes is important in order to better manage them. Though the risk of chemical release to the atmosphere is minimal, and the potential of such a release being in concentrations that will pose a hazard to public very low, being able to measure it will help decision makers make wise investment decisions leading to a further reduction in risk.

6. References

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