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DECISION MAKING TECHNICAL SUPPORT STUDY FOR THE U.S. ARMY'S CHEMICAL STOCKPILE DISPOSAL PROGRAM: ENHANCING COMMAND, CONTROL, AND COMPUTER OPERATIONS AT ABERDEEN PROVING GROUND AND PINE BLUFF ARSENAL

David L. Feldman
Jerome E. Dobson

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FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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David L. Feldman
Energy Division

Jerome E. Dobson
Computing and Telecommunications Division

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ACRONYMS, ABBREVIATIONS, AND INITIALISMS

A&E	architectural and engineering
AFTOX	Air Force Toxic Chemical Dispersion model
ADSS	automated decision-support system
APG	Aberdeen Proving Ground, Maryland.
BZ	nonlethal, but incapacitating, chemical agent
CAD	computer-aided design
CAIRA	chemical accident/incident response and assistance
CAMEO	public domain system developed by the National Oceanic and Atmospheric Administration (NOAA) for use by fire departments
CONUS	continental United States
CPU	central processing unit
CRDEC	U. S. Army Chemical Research and Development Engineering Center, Edgewood Area, Aberdeen Proving Ground
CSDF	Chemical Stockpile Disposal Facility
CSDP	Chemical Stockpile Disposal Program
DBMS	Database Management System
DM	decision making
DOD	U.S. Department of Defense
DOS	disk operating system
D2PC	Computer program developed by U. S. Army's Chemical Research, Development, and Engineering Center to estimate downwind doses of nerve and mustard agents; assumes a Gaussian distribution of agent in vertical and cross-wind directions as agent disperses downwind
EIS/C	Emergency Information System Version C developed by Research Alternatives, Inc; Version C is designed for use at chemical facilities and operates on a personal computer DOS
EMIS	Emergency Management Information System
EOC	Emergency Operations Center
EPZ	Emergency Planning Zone
ER	emergency response
ERP	emergency-response personnel
FAX	facsimile
FEMA	U.S. Federal Emergency Management Agency
FRERP	Federal Radiological Emergency Response Plan
GB	chemical nerve agent, also called Sarin
GIS	geographic information system
h	hour
HAZMAT	hazardous material
IBM	International Business Machines
ICCB	Intergovernmental Consultation and Coordination Board
ICS	Incident Command System
IEMS	Integrated Emergency Management System
IRZ	Immediate Response Zone; 10-km zone surrounding CSDP sites representing areas of limited warning and response time in the event of a CSDP agent release

JIB	Joint Information Body
JIC	Joint Information Center
km	kilometer
LAN	local area network
lb	pound
LEPC	Local Emergency Planning Committee (see SARA Title III)
MACS	multi-agency coordination system for emergency planning; part of the incident command system (ICS) for emergency response developed by the U. S. Forest Service and other agencies
MB	megabyte
mg	milligram
MOU	memorandum of understanding
MSDS	material safety data sheet
NOAA	U.S. National Oceanic and Atmospheric Administration
NWS	National Weather Service
OCC	Operations Coordination Center; conducts incident command system planning
PAZ	Protective-Action Zone; 35-km zone surrounding each CSDP site (50-km zone at PBA) encompassing areas in which hazard distances are large enough to allow greater response time for decision making
PBA	Pine Bluff Arsenal, Arkansas
PC	personal computer
RAM	random-access memory
RDS	response data sheets
SARA Title III	Superfund Amendments and Reauthorization Act of 1986; Title III refers to the Emergency Response and Community Right-To-Know Act
SSAS	Surety Site Automation System; emergency management software developed at Aberdeen Proving Ground
USGS	U.S. Geological Survey
WATCH	Warning Against Toxic Chemical Hazards; software system being developed at Aberdeen Proving Ground

ABSTRACT

This report examines the adequacy of current command and control systems designed to make timely decisions that would enable sufficient warning and protective response to an accident at the Edgewood area of Aberdeen Proving Ground (APG), Maryland, and at Pine Bluff Arsenal (PBA), Arkansas.

Institutional procedures designed to facilitate rapid accident assessment, characterization, warning, notification, and response after the onset of an emergency and computer-assisted decision-making aids designed to provide salient information to on- and off-post emergency responders are examined. The character of emergency decision making at APG and PBA, as well as potential needs for improvements to decision-making practices, procedures, and automated decision-support systems (ADSSs), are described and recommendations are offered to guide equipment acquisition and improve on- and off-post command and control relationships.

We recommend that (1) a continued effort be made to integrate on- and off-post command, control, and decision-making procedures to permit rapid decision making; (2) the pathways for alert and notification among on- and off-post officials be improved and that responsibilities and chain of command among off-post agencies be clarified; (3) greater attention be given to organizational and social context factors that affect the adequacy of response and the likelihood that decision-making systems will work as intended; and (4) faster improvements be made to on-post ADSSs being developed at APG and PBA, which hold considerable promise for depicting vast amounts of information.

Phased development and procurement of computer-assisted decision-making tools should be undertaken to balance immediate needs against available resources and to ensure flexibility, equity among sites, and compatibility among on- and off-post systems.

1. INTRODUCTION

Effective emergency response (ER) in the event of an accidental release of chemical agent in the U.S. Army's Chemical Stockpile Disposal Program (CSDP) depends on sound command and control as well as rapid decision making (DM). This report reviews the adequacy of command and control systems being developed at the Edgewood area of Aberdeen Proving Ground (APG), Maryland, by the U.S. Army Chemical Research and Development Engineering Center (CRDEC) and at Pine Bluff Arsenal (PBA), Arkansas. These systems are designed to facilitate timely decisions that would provide sufficient warnings and protective responses to accidents. A period of 5 to 10 min after a release constitutes the maximum allowable time span in which emergency-response decisions should be made.

The two principal components of command, control, and DM that are examined are (1) institutional procedures that facilitate rapid assessment of, characterization of, warning of, notification of, and response to emergencies and (2) computer-assisted DM aids that provide information to on- and off-post emergency-response personnel (ERP). These components are equally vital to rapid response capabilities, which need to be implemented within 5 to 10 min of a chemical-agent release to save lives. The components are also mutually supportive: good information cannot be used effectively by ERP if they cannot digest, analyze, or disseminate it. Moreover, even institutions that are well prepared for disasters may be unable to respond effectively without clear, reliable, accurate, timely information.

This report describes emergency DM procedures used at APG and PBA as well as needs for enhancements to DM procedures and automated decision-support systems (ADSSs). Recommendations are also offered to (1) guide equipment acquisition and procurement decisions and (2) improve on- and off-post command and control relationships at CSDP sites.

On- and off-post command, control, and DM procedures need to be integrated to permit rapid DM in an emergency that could have off-post consequences. Thought should be given to methods by which the on-scene incident commander could recommend protective actions and issue an alert. Such responses by the incident commander would require enhanced capabilities for rapid accident detection and assessment, even if those capabilities did not permit precise accident characterization.

Inability to make timely decisions persists at APG and PBA because emergency-communications pathways are insufficient among on- and off-post officials and communities, and the responsibilities of and the chain of command among off-post agencies are unclear. To ensure unified command and control if a chemical-agent release occurred, potentially affected jurisdictions may need to jointly stipulate beforehand the specific roles and responsibilities to be performed by the various parties involved. An Incident Command System (ICS) that would encompass several jurisdictions and would be similar to that developed by state, local, and federal agencies for response to forest fires and other disasters might enhance responses by coordinating personnel and resources. However, ICSs have certain limitations that would affect their application to the CSDP: emergency-response resources may be unevenly distributed among potentially affected communities, a rapid-onset CSDP accident could necessitate a quicker response than ICS-type incidents have thus far, and barriers to institutional cooperation exist among off-post jurisdictions.

Disaster experience, organizational flexibility, and characteristics of individual decision makers under stress determine the adequacy of responses and whether DM systems work as intended. In an emergency, decision makers could not calculate all possible alternatives or make sweeping, comprehensive choices based on clear probabilities for success or failure. The decision makers would most likely have to respond to urgent, highly specific matters and would have to make judgments based on fragmented, incomplete information. Unless carefully prioritized and relevant to immediate needs, data generated by ADSSs may overwhelm decision makers. Thus, the development of ADSSs should be guided by institutional procedures and needs.

On-post ADSSs being developed at APG and PBA may be able to process vast amounts of information for emergency responses. Capabilities need to be improved for processing and displaying meteorological data, increasing user access and secure record-keeping, and optimally using state-of-the-art geographic information system (GIS) features. Integrating ADSS benefits with the needs of off-post communities adjacent to CSDP sites remains a formidable task.

We conclude that computer-assisted DM tools should be procured or developed in phases according to immediate needs (problems requiring resolution before the CSDP is implemented at any site), intermediate needs (problems that can be resolved as the CSDP commences), and longer term needs (problems that arise in early stages of operation). These needs should be balanced against available resources to ensure flexibility, equity among sites, and compatibility among on- and off-post systems.

Finally, although on-scene coordinators (in most cases, on-post commanders) are responsible only for mobilizing on-post resources and for warning off-post communities in an emergency (U.S. Army 1989a), the expectation in some CSDP communities is that the on-scene coordinator's recommendations following an accidental release of chemical agent will be closely followed. Thus, the on-scene coordinator may have *de facto* (actual), if not *de jure* (legal), authority for some off-post emergency-response actions, depending on his or her position and access to emergency information.

2. STRUCTURE OF THE REPORT

Section 3 follows an executive summary (Sect. 2.1) and reviews institutional factors important to emergency DM, including the role of individual thought processes, experience, and intuition; information constraints; and the effects of stress. Section 4 discusses features of an ICS designed to enhance flexible, integrated response to emergencies that has been widely adapted by state, local, and federal emergency-management agencies. The features of state-of-the-art ADSSs are compared in Sect. 5.

Section 6 depicts two sets of criteria for evaluating the adequacy of DM systems at APG and PBA: criteria that measure institutional performance and criteria that assess the performance of ADSSs. Section 7 assesses DM systems used at APG and PBA by applying these criteria to Emergency Operations Center (EOC) operations; to ADSSs; to on- and off-post command, control, and communications functions; and to emergency-notification schemata. Section 8 recommends enhancements to institutional decision support systems and ADSSs at APG and PBA that would hasten DM. Finally, Sect. 9 identifies major issues that may require examination and evaluation at other CSDP sites.

2.1 EXECUTIVE SUMMARY AND MAJOR FINDINGS

The major findings of this report are as follows:

- On- and off-post command, control, and DM procedures for ER should be integrated to link on-post ERP with off-post officials from several jurisdictions and functional commands.

  At best, no more than 5 to 10 min can elapse between detection of an incident with potential off-post consequences and the initiation of protective actions (Carnes et al. 1989). Some off-post officials believe that population density and warning-system limitations require that emergency-response decisions decisions be made within 2 to 5 min after a release. Thus, the on-scene incident commander may have to recommend protective actions as well as issue an alert and would therefore require better accident detection and assessment capabilities, even if those capabilities did not permit precise accident characterization.
- Integration of on- and off-post ERs has progressed at APG and PBA. Nevertheless, communications routes among ERP are inefficient, and responsibilities of and the chain-of-command among off-post agencies are unclear.

  Potentially affected jurisdictions may need to compose formal agreements to designate roles and responsibilities in the event of a chemical release to unify command and control and to facilitate quick, clear communication among on-post, EOC, and off-post officials. Improved communications can be facilitated in two ways. First, the on-post EOC closest to the chemical stockpile should be linked into communications systems of, and should be authorized to notify and issue a warning to, off-post officials (e.g., the Edgewood area CRDEC/EOC should be directly linked to Harford County). Second, employment of an ICS similar to that developed by state, local, and federal agencies for responding to forest fires and other disasters encompassing several jurisdictions may enhance response by coordinating and allocating personnel and resources. Many emergency planners have high confidence in ICS because it is designed to go into operation as soon as an emergency arises and to adjust itself to changes in needs and priorities so that data can be manipulated (Haney 1985; U.S. FEMA 1987).

- ICS has several drawbacks that need to be understood by potential users. These drawbacks include (1) the uneven distribution of ER resources in communities potentially affected by a CSDP agent release; (2) limited guidance for some rapidly occurring accidents that would necessitate a quick response; (3) lack of existing cooperation among jurisdictions, because a chemical release (unlike a forest fire) is not a periodically recurring emergency; (4) the likelihood that CSDP accidents require widely scattered, independently operating teams not typical of ICS experience; and (5) lack of formal evaluation by ICS proponents through comparison with other systems: periodic test exercises should be performed if an ICS is used in the CSDP.
- To improve formal command and control mechanisms on and off post, agency roles and responsibilities have been clarified and relevant environmental statutes at APG and PBA have been obeyed. However, institutional factors that determine response adequacy and whether DM systems work as intended should be attended to further.

  Such institutional factors include organizational flexibility and decision makers' capacities to rely on personal experience if information about an emergency were limited. In an emergency, decision makers may have to respond to small, pressing, specific matters; to make judgments about fragmented, incomplete information; and to abandon dispassionate reasoning and rely on personal experience and intuition (Simon 1983; Saaty 1982; Tversky and Kahneman 1974; Newell and Simon 1972). Decision makers' attentiveness to detail is likely to be minimal, yet stress is likely to be maximal (Keinan 1987; Gertman et al. 1985; Graham 1981). Thus, information generated by ADSSs may overwhelm decision makers unless carefully prioritized and directly related to immediate needs.
- On-post ADSSs being developed at APG and PBA may be able to process and depict vast amounts of information for ERs. However, the ADSSs also have limited capabilities for processing and displaying meteorological data, require greater user access and secured record-keeping capabilities, and need most-current GIS features. Integrating benefits of ADSSs with the needs of communities adjacent to CSDP sites remains a formidable task.

  In developing on-post ADSSs, efforts should be made (1) to ascertain off-post needs for information and access; (2) to depict information clearly and simply; (3) to ensure that emergency information is logged in a reliable, secure, tamper-proof manner in shared records databases; and (4) to compare and contrast alternative systems with those being developed before procurement decisions are made based on multiple criteria.

  Institutional procedures and computer operations should be developed simultaneously. Because ADSSs would relieve them of many computational and data-retrieval tasks, decision makers could spend crucial moments making judgments. If ADSSs were designed with no distinction between routine operations and critical emergency operations, managers and operators could be familiarized with the systems' hardware, software, and databases through routine surety tasks such as retrieving and viewing maps and floor plans, accessing chemical-inventory data, and estimating air-diffusion plumes.

  Ultimately, introducing innovations that require high levels of automation (such as artificial intelligence systems capable of initiating some decisions) may be feasible. However, the first priority at APG and PBA must be to accelerate the performance of routine, standard operating procedures. Computer scientists should collaborate closely with ERP to ensure that final designs are functional and efficient: some functions are easy to design and implement, but others are more difficult. Together, emergency managers and computer scientists could design an effective information system based on incremental enhancements to existing technology.

- Compatibility among on- and off-post ADSSs (both existing and likely to be acquired) is essential to ensure that information transfers are two directional during a CSDP emergency.

  Some on-post computer resources may need to be shared with off-post communities to facilitate warning, notification, and mobilization of response apparatus, but some off-post resources could be enhanced with on-post software and equipment if accessibility to off-post personnel were guaranteed.

- A GIS is essential to any ADSS, because a GIS can model 2- and 3-dimensional phenomena by storing and retrieving relevant spatial data.

  Deployment of IEMIS,* the Emergency Information System Version C (EIS/C), and other GISs has been debated considerably. To best aid decision makers, a GIS system should be able to depict population clusters, significant natural features, human-made structures that would help or hinder responses, transportation infrastructures, and environmental pathways (Dobson 1985). Ideally, a GIS should be linked to other information systems and should be adjustable to changes in needs and priorities to permit data manipulation.

- A phased, prioritized system for procuring ADSSs should be developed to best use resources that are limited at some sites; to ensure adequate time for training, proof testing, and equipment debugging; and to address urgent DM needs.

  Acquisition procedures should facilitate the purchase of computer-assisted DM tools in terms of immediate needs, resources, and availability of commercial systems. As resources permit, intermediate and longer-term needs should be addressed after basic tools are in place.

- Progress in developing ADSSs at APG and PBA should not constitute the sole criterion for adopting a particular type of system for the entire CSDP ER upgrade program.

  The appropriateness, cost, and overall effectiveness of ADSSs must be gauged by several criteria: user friendliness, accessibility, rugged construction (for off-post, mobile use), reliability (for enduring daily and emergency-use stresses), and ability to manage multiple data inputs. One means of meeting these criteria would be to adopt decision-support systems that incorporate features of systems developed for the armed forces in other contexts. Such models would provide a base line for comparing advantages and disadvantages of newer systems.

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*Integrated Emergency Management Information System, a software package developed by the U.S. Federal Emergency Management Agency (FEMA) to provide spatial data management that is linked to federal models, accessible to public GIS databases, and has been used in radiological emergency exercises.

3. THE IMPORTANCE OF INSTITUTIONAL COMPONENTS IN CSDP EMERGENCY DM: A LITERATURE REVIEW

The institutional components of command, control, and DM for ER consist of *organizational factors* and *social-context factors*. Organizational factors are the rules, procedures, and policies that govern an organization and ensure that it conforms with good organizational science. Social-context factors include interpersonal factors that lie outside the structure of an organization and that are less formal than organizational components. Although widely recognized as important elements of DM, social-context factors usually are not acknowledged explicitly in rules governing organizational procedures (Mitroff and Betz 1972).

In the CSDP, organizational factors are composed of those elements of on-post command and control and off-post civilian authority charged with emergency planning and response at the eight continental U.S. (CONUS) CSDP sites. These factors [depicted in the final programmatic environmental impact statement, in various support studies (U.S. Army 1988, vol 3: appendix L; Jacobs Engineering Group 1987), and in the most recent chemical accident/incident response and assistance (CAIRA) manuals (U.S. Army 1989a)] include federal, state, and local organizations that interact through prescribed statutes and regulations.

Social-context factors include organizational loyalty and morale, quality of leadership, charm or charisma, individual desire for achievement and reward, interpersonal legitimacy, and inter- and intra-group values (e.g., those held by co-workers as opposed to the formal values of an organization).

Institutional components are important to emergency DM for three reasons. First, practically speaking, organizations do not make decisions: people do. Organizations are composed of individual decision makers who possess limited knowledge, have a usually well defined role and explicit set of responsibilities, and constitute but one link in a hierarchical chain of activity that produces a collective response to an event (Simon and March 1958; Buchanan and Tullock 1962).

Second, every organization, regardless of its formal purpose, is composed of individuals who have goals and aspirations of their own. These individual goals may not always be harmonious with the larger goals of an organization. Reconciling organizational and individual needs can sometimes be accomplished by encouraging the individuals in an organization to internalize the organization's goals. An organization can prompt its members to internalize its goals by ensuring job satisfaction through flexibility in implementing nonemergency decisions, establishing routine procedures that minimize the need to reason during particularly stressful decisions, and by inculcating a sense of organizational loyalty and pride (Gertman et al. 1985; Kaufman 1968; Blau 1963; Simon 1948; Barnard 1936). However, some tension between personal and organizational goals will likely remain.

Third, although most organizations have some form of hierarchical command and control, achievement of organizational goals usually relies on individual perceptions of situations. Because of their field experience, personnel at lower levels of an organization often want to implement decisions selectively and to exercise discretion. Latitude for such judgment by experienced personnel may enhance organizational response to emergency situations (Simon 1983; Simon 1979; Kaufman 1968; Barnard 1936).

A considerable body of literature in the social and decision sciences has focused on the relationship among institutional components and effective command, control, and DM during situations analogous to rapid-onset emergencies. Four ⁱⁿ ues pertaining to how individuals in complex organizations solve problems when DM time is short and uncertainty is high have been studied: the role of emotion and nonlinear reasoning on DM; the impact of judgment, intuition, and experience on the quality of decisions; effects of having fragmented or incomplete data to evaluate a problem; and stress.

3.1 HOT AND COLD REASONING: SIGNIFICANCE FOR DECISIONS THAT MUST BE MADE QUICKLY

Decision theorists distinguish between *hot* and *cold* reasoning when describing the process of DM under conditions of uncertainty and time constraints. Cold reasoning (also termed cool, calculating, or linear reasoning) is the type of thinking employed when a decision maker approaches a complex problem with dispassionate, scientific detachment.

According to decision theorists, when presented with an incident such as a chemical-agent release, the decision maker in an EOC is likely to view the problem as if he or she were confronted with a set of clear contingencies or alternatives, each of which had a fairly predictable set of probabilities for success or failure. Under this cold reasoning scenario, the key to rendering a good decision (one that quickly and effectively mitigates the emergency or other nonroutine problem) is to focus on the means of identifying the single alternative likely to restrain the incident.

This DM approach assumes a well-defined set of alternatives to a problem, a decision maker who is well trained and able to quickly surmise the entire situation, and a reliable feedback mechanism that would continually provide information about a problem to correct and update data on unfolding situations (Linstone 1984; Simon 1983; Steinbruner 1974; Simon and March 1958).

Hot reasoning, on the other hand, assumes that decision makers sometimes react to problems with some emotion, passion, fear, and apprehension. Generally, hot-reasoning decision makers neither are highly trained nor need to be to react quickly to a critical situation. The principal mechanisms hot-reasoning decision makers rely on for clarifying a situation are their own experience as well as information about the event (Saaty 1982; Maslow 1968; Maslow 1954).

According to this hot-reasoning scenario, decision makers are not, nor can they ever be, entirely detached from or objective about a problem. In practice, decision makers' responses in an emergency are likely to range along a continuum from hot to cold reasoning. Few people are either absolutely hot or cold thinkers. Try as they might, they are unable to entirely remove emotion from DM, partly because of environmental factors such as upbringing and socialization. These factors shape and order priorities in a decision maker's assessment of a situation and determine if he or she will be optimistic or cautious and pessimistic about a hazard's consequences, even if the probability of a serious event is known to be low (Slovic 1987; Simon 1983; Berlinkir 1976; Maslow 1968; Maslow 1954). Some hot reasoning stems from subconscious, hereditary urges—impulses and instincts that no amount of learning or socialization can change entirely (Saaty 1982).

3.1.1 Implications for the CSDP

Consideration of hot and cold reasoning is significant for CSDP emergency DM for two reasons. First, in the event of a chemical-agent release, decision makers in on- and off-post EOCs would likely employ some combination of both types of reasoning. However, at some point decision makers would likely rely to a greater extent on hot reasoning. Cold DM requires that the decision maker digest information from ADSSs and telecommunications networks to dispassionately assess the situation and weigh the comparative benefits and costs of certain responses. Hot DM processes information and alternatives through a filter of experience and subconscious impulse. The more complex a situation becomes, the greater the amount and range of information that decision makers must digest; and as the decision maker attempts to quickly digest information displayed on a computer terminal, transmitted via a radio, or received from other sources, the filter of experience and subconscious response is likely to exert a stronger influence on his or her reaction (Berlinkir 1976).

The reason for a decision maker's changing from cold to hot reasoning may be explained in this way: as the possible consequences of an event become increasingly apparent, decision makers become less inclined to compute the probabilities of a serious incident and more attuned to identifying mechanisms to avert catastrophe (Linstone 1984; Berlinkir 1976). Studies of crisis DM have shown that this search for mitigating mechanisms serves to filter out some external sources of information because, at the point at which the gravity of an event becomes apparent, the decision maker no longer needs to understand its linear causes. Instead, he or she is more likely to want to know how to control the consequences of costly errors (Steinbruner 1974). The more complex the situation becomes, the less a decision maker is likely to rely on cool, linear, or logical thinking (Tversky and Kahneman 1974).

A second reason that consideration of hot and cold reasoning is important for emergency DM is because hot reasoning can never be entirely controlled by cool, dispassionate thinking. Studies of risk taking in the behavioral sciences have shown that in some situations, new evidence may have little influence on preformed opinions. This would appear to confirm current theories that maintain that individuals often search through only a small fraction of information before responding (Tversky and Kahneman 1974; Simon 1979). Moreover, in the opinion of some analysts, using only cold reasoning could hamper DM in an event requiring a quick response (Simon 1983; Simon 1979).

Cold reasoning digests facts logically and orderly, but hot reasoning can recognize important values necessary to evaluate the consequences of rapidly developing situations. One such value is the recognition that some facts are more important than others and should take precedence when decisions are being made. Although facts can be weighted and prioritized through cold reasoning, linear reasoning alone cannot explain which probabilities are likely to be computed or what aspects of a decision maker's experience will be accessed. Emotion plays a large part in this process, especially as regards the order in which facts are presented.

For instance, because reaction to chemical-agent exposure is dose driven, the concentration of agent through time as well as the cumulative amount of agent to which people would probably be exposed are more-important facts for making decisions on warning and protective actions than is merely the amount of agent released (Carnes et al. 1989). Likewise, determining that some events should be classified as one category of problem or another [e.g., a level 1 as opposed to a level 2 emergency (see Table 3.1)] and being aware of the potential errors inherent in drawing conclusions from limited mathematical data may paralyze the judgment of the decision maker (Simon 1983; Tversky and Kahneman 1974). In short, a purely cold reasoner could be overwhelmed by data.

3.2 JUDGMENT AND INTUITION: WHY EXPERIENCE IS INVALUABLE IN RAPID-ONSET EMERGENCIES

Some decision makers can surmise the scope of an emergency, even when only a paucity of information is available, and can intuitively calculate its seriousness. They quickly comprehend the likely prognosis of an unfolding situation by focusing on certain cues or stimuli that have become familiar to them through experience (Simon 1983; Tversky and Kahneman 1974; Newell and Simon 1972). Such cues or stimuli are referred to as heuristic rules (Tversky and Kahneman 1974; Newell and Simon 1972).

Instead of segregating all the components of a situation into finely structured problems, such decision makers draw analogies among their immediate and past experiences (Sage 1981). In the case of a CSDP chemical-agent release, cues, stimuli, or heuristic rules could include sensitivity to the inflection of a voice on the telephone, the ability to judge whether a delay in the processing of routine information should be a cause for concern, and guarded skepticism toward the accuracy of a computer-calculated release size because a particular meteorological tower was imperfectly calibrated.

These heuristic rules could also include recognition that an emergency may not remain well structured and predictable in its development and that all predictions based on incomplete data would be erratic and could result in important consequences. Finally, these decision makers are likely to resist being guided entirely by objective probabilities. They are likely to employ subjective probabilities—the determination that different levels of risk are acceptable based on prior familiarity with a hazard (Tversky and Kahneman 1974). The role of subjective probability in emergency DM can be partially appreciated by comparing the warning notification systems of APG and PBA and those systems' criteria for classification (see Table 3.1).

3.2.1 Heuristic Rules in CSDP DM

Heuristic rules are important for CSDP emergency DM for three reasons. First, CSDP decision makers could not calculate all possible actions or rely on a well-defined set of alternatives to avoid a possible disaster in the event of a rapid-onset chemical-agent release. The decision makers may have to make judgments about the accuracy of fragmented, incomplete information in a short period of time. Thus, ADSS-generated information may overwhelm decision makers unless they are able to quickly prioritize it and place into perspective its relevance to immediate needs. In short, too much information can overload a DM system and become unusable (Benbasat and Taylor 1982; Katz and Kahn 1974). Receiving too much information at once may also cause decision makers to accentuate the possibility of a negative, catastrophic outcome because they have so little time to process the information (Ben Zur and Breznitz 1981).

Second, heuristic rules of judgment play an important role in risk assessment of a CSDP emergency. Considerable effort has been devoted to specifying the likely consequences of a CSDP accident based on information developed in the CSDP risk analysis (Carnes et al. 1989; MITRE Corporation 1987). Although this risk analysis has

Table 3.1. Comparison of CAIRA, APG, and PBA emergency notification classification systems

	CAIRA	Pine Bluff Arsenal	Aberdeen Proving Ground
Levels of alert	3 (alert, site area emergency, off-site consequences emergency)	6	4
Defining characteristics	Events occurring or likely to occur that (1) are confined to storage area, (2) are dispersed beyond storage area but no farther than site boundary, (3) present danger beyond site boundary	Agent releases occurring or potentially occurring that (1) require worker protective measures in storage or exclusion area but no farther than site boundaries; (2) disperse beyond exclusion area but no farther than site boundaries; (3) disperse beyond site boundaries to IRZ[a], with fatalities confined to IRZ; (4) disperse beyond site boundaries with, fatalities confined to IRZ; (5) disperse beyond IRZ to PAZ[a], with protective actions on post and in IRZ/PAZ; (6) disperse to PAZ with PAZ fatalities	(1) Abnormal, but no off-post consequences—a news-worthy event; (2) unplanned agent release requiring protective measures in chemical-storage area; (3) event requires protective measures outside storage area but will not affect off-post populations; precautionary measures recommended off post; (4) actual or potential release that may transcend installation boundary
Recommended actions	3 levels. (1) bringing IRZ officials into enhanced level of readiness, (2) mobilization of IRZ response and widespread notification to PAZ and state officials, (4) mobilization and alert throughout PAZ	6 levels. (1) contact to NCTR[a] and Jefferson County; (2) same as 1 + state officials; (3) same as 2 + mobilization of Jefferson County EOC[a] & mobile unit; (4) same as 3 + schools establish personnel-processing points; (5) same as 4 + mobilization of adjacent counties; (6) same as 5 + protective actions in PAZ	4 levels. (1) notify county officials and news media; (2) notify/brief EOC officials, emergency communications officials notify volunteer fire depts., establish communications and alert watch; (3) activate EOC incident commander, who activates route alert; close outdoor recreation areas; and issue news statements in JIC, receive evacuees; (4) everything in 3 + provide health advisories

Table 3.1. (continued)

	CAIRA	Pine Bluff Arsenal	Aberdeen Proving Ground
Distinguishing characteristics	Simplicity, stress upon likelihood that an event will pose a danger. Distinguishes between on- and off-post impacts	Greater level of detail; specific parameters for notification and alert; driven by need for protective action and likelihood of fatalities. Distinguishes among on-post/IRZ/PAZ impacts	Not quite as detailed as PBA; parameters for alert-driven likelihood of off-post hazard. Incorporates references to managing media and employment of JIC. Significant detail pertaining to special facilities/special populations
Positive points/advantages	Allows change or expansion in classification levels as accident information becomes available	Established by PBA and off-post officials in response to current accident information	Established by APG[a] and Harford County; geared to established alert proceedings for Peachbottom nuclear plant. Under level 3, off-post response is practically geared to a full alert
Potential points/disadvantages	Current classifications leave considerable room for judgment and discretion in accident characterization—e.g., not anticipated to present a danger to public; specific nature of danger not clear; composition of IRZ response organization and other off-post components unspecified; character of protective actions not specified. Pathway of alert/notification unclear	Current classification assumes precision in accident characterization that nay not be possible. Character of protective actions not specified. Pathway of alert and notification unclear	Recommend early notification of media, which could be problematic; responsibilities of off-post responders for evacuation, route control, etc. not explicit

[a]IRZ = immediate response zone; PAZ = protective action zone; EOC = emergency operations center; JIC = joint information center; PBA = Pine Bluff Arsenal; APG = Aberdeen Proving Ground; NCTR = National Center for Toxicological Research located at PBA.

Sources: *Draft Jefferson County Emergency Response Plan for Chemical Accidents at Pine Bluff Arsenal*, June 1, 1989; *Draft Harford County, Maryland Emergency Response Plan for a Chemical Emergency at Aberdeen Proving Ground*., *Appendix B*, April 1989; and U.S. Department of the Army, *Nuclear and Chemical Weapons and Material, CAIRA*, March 31, 1989.

helped define a range of probable releases, it is impossible to predict all the accidents that could occur during operation of the CSDP. As a consequence, reliance on a formal fixed set of procedures dictating how to respond under certain accident scenarios simply is not viable. Instead, decision makers should be aware of possible accident scenarios that would be difficult to predict.

Emergency experience in the nuclear industry, for example, reveals that the type of accident likely to occur in a complex technology may be far different in character from the type that might be depicted in a probabilistic risk assessment. The possibilities of bizarre mechanical failures or errors in human judgment, compounded by the breakdown of redundant common-mode safety systems, operator inexperience, stress (see Sect. 3.4.), and misinterpretation of equipment output, should not be categorically ignored in the CSDP any more than in other complex technologies (Perrow 1984; Ford 1984). Because of people's inabilities to logically evaluate all contingencies in complex technologies, a decision maker's intuition, judgment, and experience play a large role in DM. Subsequently, a third and final point is that people who have good judgment and intuition tend to make good decisions in an emergency. Good judgment and intuition are gained by experience within an organizational structure that rewards demonstrated proclivities for sound DM (Simon 1983; Saaty 1982; Tversky and Kahneman 1974; Newell and Simon 1972). Obviously, a decision maker has no time to develop good judgment and intuition during an emergency.

3.3 INFORMATION CONSTRAINTS ON RATIONAL DM: THE PROBLEM OF BOUNDED RATIONALITY

Uncertain data and time restrictions impose information constraints on DM. Many of these information constraints can be managed effectively by ADSSs, which are particularly useful for sorting factual information into logical categories to which decision rules can be applied. Studies of the usefulness of ADSSs to emergency managers have shown that a well-designed ADSS can graphically enhance the display of relevant facts and can prompt emergency managers to be more attentive to critical variables (Belardo, Karwan, and Wallace 1984).

However, some information constraints on decision makers transcend the aggregation of facts. Rendering value judgments is an equally serious need for decision makers. ADSSs can help with this problem but cannot totally mitigate it. The symbols processed by a computer do not have meaning for the machine: the machine is programmed to simulate a learning process, not duplicate social reality (Searle 1982). Thus, decision makers must still be able to render judgments.

DM in an emergency requires difficult choices concerning (1) which issues should demand the immediate attention of an on-scene commander and which issues can be delegated to others; (2) how to allocate scarce yet essential resources; and (3) whether personnel should be ordered into a contaminated area to assess damage, evaluate an emergency, and monitor its prognosis. Decisions are almost always critiqued after a crisis passes (Simon 1983) because possibly the decision maker could have made better decisions using rules other than those employed during the emergency (Simon 1983). Making difficult value choices under information constraints requires an understanding of the concept of bounded rationality.

Bounded rationality stipulates that decision makers do not make sweeping, comprehensive choices in emergencies or other rapid-onset crises; instead, they respond to small, pressing, specific matters (Agnew and Brown 1986; Simon 1983) such as how fast a plume is moving, the direction in which it is moving, and the disposition of response forces.

These small, pressing matters pre-empt the need to make some decisions. In an emergency, the decision to act is essentially preformed. Certain response actions are automatically initiated and certain checklist functions in an EOC are automatically actuated. ADSSs can page ERP [a process under development at APG (see Sect. 7.1)], transmit plume data, and actuate communication and warning systems. The role of the decision maker in such circumstances is to prioritize the most important response tasks based on such preeminent values as the preservation of life and property. According to students of bounded rationality, prioritizing tasks involves both cold and hot reasoning (Agnew and Brown 1986) and can be performed in two ways.

First, making good decisions in an emergency often depends more on the adequacy of a predictive model, such as a chemical downwind hazard model, and the data supporting it than on the ability to compute a maximizing value (such as the exact trajectory of a plume). Discrepancies between available and desired information in emergency planning are expected by ERP (Comfort and Cahill 1988). Thus, EOC staff should have means to convert a general, abstract, intractable problem such as saving lives or minimizing property loss into a specific, tractable one that could be broken down into smaller components for exercises and readiness assessments. Goals should be defined in tangible and, if possible, quantifiable ways, such as moving a certain number of responders into an area or evacuating people from the Immediate Response Zone (IRZ) within a specified period of time. In this way, the performance of a DM system could be compared with some ideal set of performance standards (Simon 1979).

Second, decision makers should encourage and nurture organizational settings in an EOC that maximize the input of diverse points of view and ranges of experience and minimize the number of people participating in emergency DM (Allison 1971; Allison 1969). One strategy that has been suggested for achieving such settings is pairing different specialists to work on some pre-emergency task such as communications, logistics, or planning. The work of these specialists can be coordinated by means of a coherent management structure and communications system. This pairing system would help prevent a particular group's dominating DM (Cyert and March 1963).

3.3.1 Risk Discounting and Bounded Rationality

A final issue related to bounded rationality is *risk discounting*. Risk discounting refers to the fact that the further one gets from a crisis event, or the longer routine, noncrisis conditions prevail in an EOC, the more complacent one is apt to become toward the possibility of a serious accident (Linstone 1984; Searle 1982). One method that has been employed by some agencies to minimize decision-maker complacency requires field personnel to constantly report to higher-level officials during both routine, nonemergency periods and during crises. Lower-level personnel must keep a log of activities that is reviewed by higher-level personnel to identify problems or evaluate performance deficiencies.

Periodic performance assessments to ascertain how well personnel know the programmatic and installation CAIRA manuals may be useful for building supervisors' confidence in subordinates and may ensure that the subordinates are able to perform routine decisions (Kaufman 1973; Kaufman 1968), especially if the performance assessments are designed to rapidly detect and correct errors (Argyris 1976). The obverse of risk discounting is risk inflation, which is likely to occur during periods of high stress caused by emergencies. The management of stress under emergency conditions is discussed in Sect. 3.4.

3.4 DM UNDER STRESS

A chemical-agent release, or its imminent possibility, in the CSDP would likely stress personnel in on- and off-post EOCs and Chemical Stockpile Disposal Facilities (CSDFs). For crisis situations, stress may be defined as an unusually severe anxiety caused by a frightening or horrifying event. This reaction would likely be experienced by personnel responsible for monitoring, controlling, preventing, or responding to an accident (Mitchell 1988).

Stress is an important factor in CSDP emergency DM for two reasons. First, in a CSDP accident, a variety of stress-induced traumas or disorders may occur among personnel in the on-post EOC as well as among ERP who must contain the accident (Tushman and Nadler 1978; Huber, O'Connell, and Cummings 1975; Monat, Averill, and Lazarus 1972). Stress may prevent decision makers from making optimal choices or assessing a situation accurately. Studies of DM in situations characterized by extreme uncertainty and stress indicate that decision makers are sometimes likely to perform poorly, to misunderstand usually well-understood cues, and to make poor judgments unless some stress is alleviated (Tushman and Nadler 1978; Huber, O'Connel, and Cummings 1975; Monat, Averill, and Lazarus 1972).

Second, in some instances, stress may actually enhance ER by compelling decision makers to initiate a vigilant problem-solving process—particularly if the survival of the organization were at stake or if the ethical values important to decision makers could be violated if action were not taken (Janis 1989; Janis and Mann 1977). Whether stress would enhance or detract from ER performance is partly a function of the degree to which an organization nurtures coping mechanisms such as DM shortcuts and novel strategies for processing information (Zakay and Wooler 1984; Wright 1974).

3.4.1 Stress and DM Within the CSDF

Although no one can predict the type of accident that might occur in the CSDP, it appears reasonable to assume that if a chemical-agent release occurred, it would likely result from equipment failure or human error, or both, in a CSDF or nearby storage area. Such an incident would be discovered first by operators in the vicinity of the CSDF. Personnel training programs are designed so that the normal-operation and emergency-situation duties of CSDF workers become so engrained that workers could perform standard operating procedures at 100% effectiveness during an accidental agent release (*JACADS O & M Training Philosophy* 1989). Ways in which stress may affect workers' performance during such an emergency should be considered.

Studies of the impacts of stress on the operators of complex technologies such as nuclear reactors (which, like CSDFs, are highly automated) indicate that stress affects decision makers through

- perceptual narrowing, which restricts an operator's understanding of stressful conditions and appropriate responses to them (Keinan 1987; Gertman et al. 1985);

- cognitive rigidity, which restricts the capacity of an operator to analyze, evaluate, and plan alternative courses of action to alleviate a problem (Keinan 1987; Gertman et al. 1985);
- changes in the nominal correctness of judgment, which cause an operator to predict negative instead of positive outcomes (Wright 1974);
- information distortion about the consequences of stress, which causes an operator to discount the impact of stress on his or her judgment; and
- response preservation, which causes an operator to repeat ineffective actions or to make inappropriate responses to the stress (Gertman et al. 1985).

Results of stress-inducing experiments on nuclear-reactor operators reveal that operators under stress perform better if their work loads are lightened. These results suggest that in a CSDF setting, work loads must be carefully monitored, especially during periods of stress, when accidents are likely to be caused by human-judgment errors (when the facility is started or shut down, for example). ADSSs may be able to monitor this CSDF work load at CSDP sites.

The availability of detailed procedures may also enhance operator performance and DM, even in the presence of conflicting information. Additionally, if operators are made to clearly understand that they will be rewarded for performing well under stress, they are likely to perform better, as are operators who have coped successfully with previous stressful experiences.

Compensatory measures can be provided to ensure that these favorable conditions are optimized. Such measures could include internalizing prior training to such a degree that the need to think through appropriate responses under an abnormal event is minimized; providing special drills and simulations to manipulate various stress-causing situations (Zakay and Wooler 1984); presenting effective displays of critical information in the control room; providing procedures compatible with restricted cognitive and problem-solving processes, such as ergonomically designed lighting, a well-planned physical layout of the EOC, good acoustics, small rooms connected to the main EOC to facilitate small-group conferences or consultations (Nunamaker, Applegate, Konsynski 1988; Robinson 1982); and centralizing authority within a control room (Gertman et al. 1985; Bronner 1981).

3.4.2 Stress and DM Within the EOC

A chemical-stockpile accident would greatly stress ERP, who may discount the impact of stress on their abilities to respond to an unfolding emergency (Mitchell 1988; Linstone 1984; Simon 1983; Steinbruner 1974; Simon and March 1958).

Emergency management personnel are likely to discount stress by psychologically blocking it, by projecting a strong image of toughness, or by hiding their true feelings from co-workers (Mitchell 1988; Graham 1981; O'Brien 1979). The significance of this tendency to discount stress often results in a wide range of physical, cognitive, and emotional disorders (Mitchell 1988).

These disorders may produce effects such as traumatization (the inability to think clearly) (Sorokin 1942); a tendency to make erratic judgments by relying on less rather than more information (Rothstein 1986); and perceptual narrowing and cognitive rigidity. The discounting of stress may induce decision makers to render premature judgments and to scan disaster-mitigating alternatives in a nonsystematic or even sloppy manner (Keinan 1987).

Thought should be given to means of extensive pre-incident training on stress and its effects, clinical intervention shortly after the emergency, and other means of stress mitigation. One example of stress training is *stress inoculation*. Stress inoculation involves practicing responses to stressful situations so that workers are not as stressed during emergencies (Meichenbaum 1983). Most important, decision makers need to have information presented to them in a useable format. Studies indicate that the appropriate method for presenting information to a decision maker depends on its context. Problems for which sure, plentiful information is available lend themselves to precise mathematical formulation. Situations characterized by high uncertainty and little information may benefit from ADSSs such as those discussed in the next section, from expert systems, and from some form of artificial intelligence (however, present artificial intelligence systems may not be able to deal well with these problems (Cosier and Dalton 1988).

4. THE ICS: AN INSTITUTIONAL APPROACH TO CSDP DM

This section focuses on the ICS, a state-of-the-art institutional model designed to integrate several jurisdictions into a coherent ER network. Another institutional state-of-the-art model considered for detailed examination was the Federal Radiological Emergency Response Plan (FRERP). FRERP was developed after the Three Mile Island nuclear-power-plant accident in 1979 to expedite federal-agency-coordinated responses to radiological emergencies. Composed of a master plan and several subsidiary components, the FRERP was designed to designate a lead agency after an accident, define subsidiary agencies' on- and off-site responsibilities, and initiate a series of exercises to ensure that joint response plans among federal-, state-, and local-agency responders work as intended (FRERP 1985; Radiological Emergency Planning and Preparedness 1982; National Radiological Emergency 1980).

Although FRERP is an important model for coordinated, rapid response, its design is based in part on ICS criteria—particularly as regards planning and operational control, designation of a lead agency, and compatibility with other federal-agency emergency-contingency plans and procedures. ICS and ICS variants have been adopted by several federal, state, and local ER agencies under the broad title *Integrated Emergency Management System*, or IEMS (Bragdon, Moreland, and Le Blanc 1988). IEMSs are tailored to the specific requirements of communities nationwide through FEMA's Hazard Analysis/Capability Assessment Guidance (Bragdon, Moreland, and Le Blanc 1988). Moreover, ICS is now a major component of the National Interagency Incident Management System as a result of the efforts of the U.S. Fire Administration and National Fire Academy (Haney 1985; Franklin 1989). Thus, a thorough understanding of ICS will provide insight into the operation of other institutional models of coordination.

ICS is designed to ensure that emergency-management agencies from jurisdictions throughout a wide area are preprogrammed to integrate their responses to accidents. Integrated responses are achieved by obtaining agreement on a set of management objectives developed by officials from each jurisdiction who represent different functional areas of responsibility. To implement and support these emergency-management objectives, a centralized command and control system, subdivided into five areas—command, operations, planning, logistics, and finance—supports incident command (*Incident Command at Hazardous Materials Incidents* 1989; FIRESCOPE Hazardous Materials (HAZMATs) Specialist Committee 1989).

Under these functions of the ICS, personnel from different jurisdictions serve together. In theory, anyone can perform any function as long as he or she has been trained to do so. The important criterion in filling a position is qualification, not role or formal responsibility requirements within one's respective jurisdiction (*Incident Command at Hazardous Materials Incidents* 1989). Managing multiple disciplines and different levels of government under crisis conditions is possible by relying on an incident commander to supervise and coordinate each component. The ICS is designed to begin operating as soon as an emergency arises and to involve either more or fewer agencies and personnel as an emergency becomes either more or less serious (Schneider Engineering 1989b).

4.1 ORIGINS OF ICS: RELEVANCE TO THE CSDP

The ICS was developed in the 1970s to correct organizational weaknesses (such as lack of common organization, poor on-scene and interagency communication, lack of multifrequency and scanner capabilities, inadequate joint planning, lack of timely and valid intelligence, inadequate resource management, and limited prediction capabilities) in ERs to forest fires (Irwin 1989). ICS was later incorporated into other ER plans after experience proved it to be effective.

ICS comprises two components: a multi-agency coordination system (MACS) for emergency planning and an ICS for ER. Ongoing planning within the MACS takes place in an Operations Coordination Center (OCC), which collects, processes, and disseminates information useful for crisis management. OCC serves as a nexus for information from all agencies and jurisdictions; provides situation summaries to cooperating agencies, the mass media, and others; and operates full time and with different readiness levels (i.e., normal, nonemergency conditions; precautionary conditions; or emergency or *red alert* conditions).

The ICS component provides an integrated emergency-management organization that features standardized terminology, uniform procedures, enhanced communication, and mutual assistance by various jurisdictions. Four separate but interacting levels of response command are managed by an executive coordinator, as shown in Table 4.1.

The executive coordinator is at the top of a hierarchical chain of command. Pre-emergency planning is highly democratic. Issues involving operations and management of MACS and ICS may be identified at any level, by any group or individual (U.S. FEMA 1987).

MACS, the managerial element of the ICS system, has no independent operational authority. It is dependent on the voluntary cooperation of member jurisdictions, is an extension of the formally defined command function of member agencies, user managed and service-oriented, and does not compromise or usurp established agency authority or practices (U.S. FEMA 1987). Because many state and local emergency-management agencies have interagency agreements for emergencies that cross jurisdictional boundaries (Pine 1988; Pine 1989), the leap from established interagency patterns of cooperation to ICS need not impose unusual demands, at least from the standpoint of unified management.

Finally, MACS has four operational modes (similar to levels of alert under CAIRA). The requirements of the highest mode (level 4, a full regional alert) are clearly depicted and understood. MACS situational teams meet periodically and plan such ongoing tasks as agency radio purchases; vehicle procurement; standardized, clear, plain language text for radio messages; and a matrix for the sharing of radio frequencies (U.S. FEMA 1987).

4.2 ICS AND ESTABLISHED CAIRA PROCEDURES

ICS practices and Army procedures depicted in the current CAIRA manual for nuclear and chemical incidents share many features. Like CAIRA, ICS recommends employment of a common terminology for ER; prescribes a modular organization with limited, manageable span of control under a clear chain of command; urges integrated communication, unified command structure, a consolidated action plan, and predesignated incident facilities [such as an EOC and a Joint Information Center (JIC)]; and prescribes comprehensive resources management (Franklin 1989; U.S. FEMA 1987). Moreover,

Table 4.1. Incident Command System formal structure and responsibilities

Level	Function
(1) Board of directors	Set goals and objectives Make final decisions Establish policy Adopt policies for own agency
(2) Operations team	Recommend policy Prepare action plan Decide operational issues Set direction and goals for task force
(3) Task-force elements	Develop multi-agency coordination system and incident command system functions Establish appropriate organizational Develop procedures Provide nontechnical direction to specialist groups
(4) Specialist groups	Perform specialized assignments in appropriate functional areas

Source: adopted from U.S. Federal Emergency Management Agency, National Emergency Training Center, Emergency Management Institute, *Exemplary Practices in Emergency Management*, February 1987.

ICS systems established in many states are patterned after military-style command and control systems (Haney 1985).

The scope of incident command authority prescribe ICS has largely been adopted by the Army. During the early stages of a CSDP i t, the immediate response-force commander retains on-scene command so lo immediate response force under his or her authority is deemed capable of managing the incident (U.S. Army 1989a). On-scene local officials are relied on under ICS because of the assumption that out-of-state, distant teams do not possess intimate knowledge of the characteristics of the affected area (*Incident Command at Hazardous Materials Incidents* 1989).

Under ICS, all terminology is predefined and understood by all participants regardless of discipline or jurisdiction (Bragdon, Moreland, and Le Blanc 1988). When agencies use the same terminology, few differences are likely to occur among methods of operation. Clear terminology identifies resource elements and facilities, delegates management authority, and facilitates uniform planning by clearly defining objectives. When applied to radio communication practices, it ensures that messages are transmitted in clear text, free of potentially misleading codes, so that people can say exactly what is on their minds (Exemplary Practices 1987).

One difference between ICS theory and Army practice, however, is in the area of emergency-classification terminology, which will be discussed in Sect. 7.3. Differences among APG, PBA, and CAIRA terminology regarding emergency classification pose a potential operational problem for which an ICS terminology standard could be beneficial.

4.3 ADVANTAGES OF ICS: SOME LESSONS FOR OPTIMIZING CSDP EMERGENCY DM

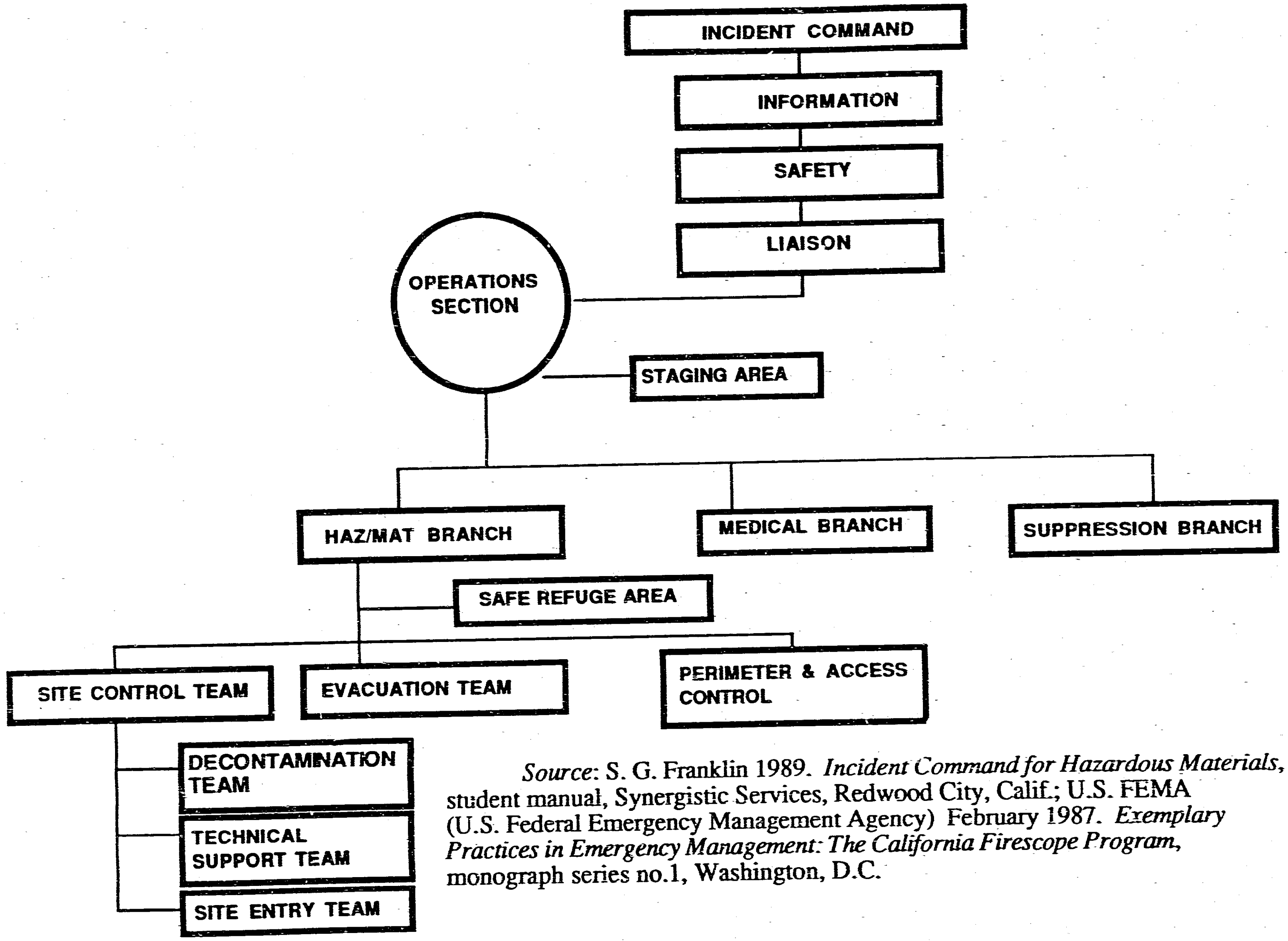
Despite similarities between ICS practice and CAIRA, some advantages of ICS have not been fully incorporated into CSDP emergency DM. First, greater regard for span-of-control (i.e., the number of people reporting to a single supervisor) considerations should be encompassed by on-post emergency planners. Under ICS, span-of-control considerations are determined by management needs and ERP safety considerations. Generally, span of control of any individual charged with emergency-management responsibility should range between three and seven people, with five being optimum (Franklin 1989). If a group exceeds seven people, its effectiveness deteriorates. Optimal span of control allows each emergency responder to concentrate on a primary assignment, not be distracted by other responsibilities, and not hinder others performing the same task.

Second, ICS philosophy contends that good communications among on- and off-post EOCs depend on such relatively simple logistical considerations as shared procurement of radio systems, interjurisdictional determination of radio equipment needs, the assignment of exclusive interagency frequencies for use by responders, and ensuring that maximum use is made of all assigned communications capabilities. ICS guidance prescribes shared procurement systems, assurance of equipment compatibility through compliance with special needs-analysis procedures before equipment procurement is approved, and through the employment of common communication codes (U.S. FEMA 1987; Haney 1985). During an emergency, responders should use the radio system they would employ under normal, nonemergency conditions to minimize having to learn new procedures or to familiarize themselves with strange equipment. This also minimizes chances for communication breakdowns and ensures the best possible integration of available communications equipment. Secured communications systems are yet to be developed at APG and PBA. Consideration should be given to the incorporation of ICS experience and philosophy in system development.

Third, there is a need for greater off-post coordination among key jurisdictions at CSDP sites. ICS provides some practical insights into how to achieve this coordination with minimal impact to established procedures and emergency protocols. Unified command structure under ICS allows for considerable flexibility among jurisdictions and agencies.

Figure 4.1 depicts how an ICS system for the CSDP might work. The most significant feature of this configuration is that the three main branches of operations (HAZMATs, medical, and accident suppression) report to an operations section in the field. This operations section, in turn, reports to an off-post EOC within which the ICS is housed. Site control, evacuation, and perimeter and access control teams report to the HAZMAT branch.

The justification for this configuration is that incident-command authority is most effective when dedicated to supervising major response functions rather than the



Source: S. G. Franklin 1989. *Incident Command for Hazardous Materials*, student manual, Synergistic Services, Redwood City, Calif.; U.S. FEMA (U.S. Federal Emergency Management Agency) February 1987. *Exemplary Practices in Emergency Management: The California Firescope Program*, monograph series no.1, Washington, D.C.

Fig. 4.1. Possible configuration of an Incident Command System for a Chemical Stockpile Disposal Program emergency.

micromanagement of field tasks. Field-based personnel should practice implementing functions pertaining to decontamination, technical support, and site security and entry. Figure 4.1 demonstrates that, because the qualifications and training of people selected to fill each position are more important than the role each person plays in ensuring functional specificity, a local expert in safety issues could serve immediately under the incident commander and could supervise emergency-responder safety during a CSDP incident, and a state official less qualified for command might be assigned perimeter-access-control duties in the field. Thus, depending on the scope of a CSDP emergency, incident command could require the availability of a key responsible individual from each jurisdiction in a multijurisdictional situation or could be composed of several functional departments within a single political jurisdiction (Haney 1985).

Incident command can be configured in a variety of ways. During a recent Colorado forest fire, two on-scene incident commanders coordinated DM. The first, a federal official, was charged with overseeing ER activities on federal lands, and the second, a local official, supervised incident response on nonfederal territory (*Incident Command at Hazardous Materials Incidents* 1989). Thus, each CSDP site could select the configuration best suited to its needs, including a dual incident-commander system, if appropriate.

The greatest advantage of ICS, according to its proponents, is that it enables agencies to work together more effectively with increased trust and confidence in one another's capabilities. This is accomplished by the ICS planning process that stresses expansibility from simple daily activities to the demands of a major emergency. Policies and priorities are set by command, and the organizations established to meet these priorities are tailored to the needs of operations personnel. Financial constraints on some communities are taken into consideration in allocating ICS responsibilities (Irwin 1989). Thus, less-affluent communities may contribute to the integration of emergency command by in-kind contributions of personnel or equipment rather than through monetary contributions. ICS also displays considerable flexibility during the re-entry phase of an emergency (in ICS terminology, *stand down*). ICS is capable of rapid stand down and relinquishment of authority to local officials. As an emergency becomes either more or less serious, various ICS functions and branches are disbanded, allowing for the retention of command authority in critical areas and a simultaneous return to normal operations because some personnel can return to their regular roles.

4.4 LIMITATIONS OF ICS: A CRITICAL REVIEW

There are two broad sets of problems involved in applying ICS to the CSDP. These are (1) possible disruption of existing ER procedures and (2) possible misapplication of ICS procedures to the CSDP. From the standpoint of disruptiveness, the implementation of an ICS system should impose the least possible change on existing emergency-management systems at CSDP sites. Unless established jurisdictions can retain control of their legal and fiscal responsibilities, roles, and procedures, they are unlikely to approve of the system and may resist or subvert its implementation (Franklin 1989). To ensure minimal resistance, strict boundaries of incident command should be agreed on beforehand.

Moreover, during an emergency, incident command should not be automatically transferred to a higher-level officer or political official who arrives on the scene. Before command is transferred, the newly arrived individual should be fully apprised of the situation and informed of what actions have been taken. Command transfer should be done face to face (U.S. FEMA 1987).

A second source of possible disruption is the adoption of common terminology and standards in planning documents, training programs, and operational procedures. In actual experience, ICS has generated considerable resistance among response agencies in states and communities that have little experience in rapid-onset emergencies. Some resistance to ICS was displayed by the Forest Service, for whom it was initially developed (U.S. FEMA 1987). Imposing uniform terminology and standards compels agencies to change established habits and procedures. One reason ICS may have been adopted in California sooner than in other states was the relatively long history of coordination among local jurisdictions and state agencies in emergency planning for forest fires, earthquakes, and other disasters (U.S. FEMA 1987). To ensure that it works as designed, ICS must be proof tested through periodic simulated and full-scale exercises (U.S. FEMA 1987). Those experienced in ICS training suggest that ICS constitutes a form of technology transfer that gradually enhances participants' ability to contribute to integrated ER. Eventually, common training and gradual operational implementation should reduce political resistance (U.S. FEMA 1987).

After they are implemented, ICS procedures provide response personnel with significant room for discretion and flexibility. The most important decisions within ICS are *not* preprogrammed; they are formulated through open communication among lower-level and management personnel. Constant contact and communication among on-scene incident commanders and field-management teams is encouraged. On-scene commanders often defer to the judgment of field personnel who, by virtue of their functional specializations, have earned the respect of supervisory personnel (*Incident Command at Hazardous Materials Incidents* 1989).

The overall relevance of ICS to a CSDP chemical-agent release is more problematic for two reasons. First, an integral assumption of ICS philosophy is that every jurisdiction potentially affected by an emergency has certain resources it can offer in responding to it. Although each community potentially affected by a CSDP release has resources that can be mobilized, an emerging consensus among CSDP sites suggests that in the event of a chemical accident with rapidly developing off-post consequences, principal responsibility for warning, notification, and, to some degree, coordinated off-post response, would fall to the Army (Schneider Engineering 1989b). Although ICS proponents claim that nonmilitary experts can be incorporated easily into the management of an emergency (U.S. FEMA 1987), it is not entirely clear how this could be done during a rapid-onset chemical-agent release. Moreover, the unique logistical needs of a CSDP accident may impose resource requirements that many communities simply cannot bear without significantly enhancing their ER capabilities.

Second, many of the planning criteria for ICS are geared to a potentially large incident that extends over a broad area and for which adequate time for preparation is usually available (U.S. FEMA 1987). No known studies have compared the relative response times of ICS with non-ICSs.

Despite these limitations, ICS is likely to optimize a timely response to a rapid-onset emergency for three reasons. First, ICS experience in HAZMAT incidents has shown that it is capable of coordinating responses among a complex array of federal, state, and local agencies in the absence of clear-cut responsibilities for given tasks (Franklin 1989). The integrated planning process of ICS allows for early identification of potential organizational problems likely to interfere with optimal response, especially for organizations that work for the sponsor of a given task (Franklin 1989).

Second, the predetermination of functional areas of responsibility under ICS minimizes confusion and overlapping of personnel during ER. This minimizing of confusion makes it relatively easy for jurisdictions to negotiate with one another for various forms of assistance and logistical support under accident scenarios, thereby further optimizing timely response.

Third, within an ICS, each responder arrives on the scene with a specialized knowledge and background in some aspect of an emergency (U.S. FEMA 1987). Thus, little time has to be spent on acquainting responders with special precautions and characteristics associated with a CSDP release because their training and operations planning will have equipped them with that knowledge.

A final problem in applying ICS to a CSDP accident is that most ICS experience has been concentrated in well-understood, recurring emergencies (forest and brush fires) that, gradually, have prompted cooperation among political jurisdictions. Such interjurisdictional cooperation may not exist at most CSDP sites to the same degree. CSDP communities have had little experience, for example, with major interjurisdictional ER. Related to this is the fact that ICS stresses small teams of responders able to operate in widely dispersed units where independence of action is both necessary and appropriate (U.S. FEMA 1987). Such independence of action is likely to be less appropriate in a rapid-onset CSDP emergency.

4.5 CONCLUSIONS: HOW TO IMPLEMENT AN ICS

As a result of this review of the strengths and weaknesses of ICS, suggestions can be offered for its use in the CSDP. First, development of an ICS should utilize established ER protocols and methods of interjurisdictional assistance available in off-post jurisdictions. At APG, for example, it may be possible to use the authority of county sheriffs for integrating off-post command and control. At PBA, Jefferson and Grant counties could develop an ICS-type system based on established protocols that have been used to respond to train derailments and other emergencies.

In almost all cases, CSDP communities should be able to adopt ICS features such as an optimal span-of-control system (three to seven people per responsible individual) to allow each emergency responder to concentrate on a primary assignment. In addition, strategies can be developed among CSDP communities to allow less-affluent jurisdictions to make in-kind contributions to an integrated ER system. Finally, potential off-post organizational problems likely to slow coordinated response can be investigated and meetings among communities and the Army held to resolve some of these institutional problems through delegation of specific responsibilities to minimize overlapping and confusion.

5. ADSSs: A GUIDE TO COMPARATIVE FEATURES

Increased public support for emergency preparedness in CSDP communities, as well as increased public awareness, has led on- and off-post emergency managers at CSDP sites to broaden their technological perspectives. These changes reflect a growing nationwide concern about technological hazards (U.S. Congress 1983).

A variety of emergency-management programs are now offered commercially. Existing hardware, software, and databases cover a wide range of functions from database management to graphics (see Tables 5.1 and 5.2). Unfortunately, no vendor incorporates into a single system all of the functions required for rapid DM. Some systems are well-suited for storing and retrieving material safety data sheet (MSDS) data or chemical-stockpile inventory data; others are reasonably good at handling maps and floor plans, and still others are particularly adept at calculating plume models.

The ideal automated system would incorporate all of these functions along with GIS features. However, no such system has yet been introduced in commercial or public-domain offerings. A review of current systems depicted in Tables 5.1 and 5.2 illustrates this point. An additional compatibility problem is that current systems are limited to specific computer architectures and operating systems. This reduces the choices available to CSDP installations as well as to off-post EOCs because of previous commitments made to a particular computer system.

This state-of-the-art review encompasses a wide range of software including systems specifically designed for emergency management at chemical manufacturing and storage sites and other systems with generic capabilities that may support emergency-management needs but that are not specifically designed for that purpose. Numerous data-retrieval systems describing HAZMATs are available, but these existing systems fall far short of meeting the needs of CSDP sites for timely response to a chemical-agent release.

The greatest shortcoming of existing emergency-management information systems (EMISs) is their treatment of geographic information. Conversely, none of the commercial GIS systems is well endowed with emergency-management functions such as those offered by the leading EMISs. It is important that the system ultimately deployed at a given CSDP site be capable of accepting digital cartographic and geographic data regarding chemical-stockpile storage and demilitarization areas. It is recommended that the maps and floor plans normally maintained by civil engineers at military installations be the official database on which all emergency operations depend for cartographic information about on-post activities. Maintenance of such maps and floor plans is a standard operating procedure at all CSDP sites. At most CSDP sites, these documents exist as a collection of hard-copy drawings or blueprints. However, numerous installations now have digital cartographic files or computer-aided design (CAD) files representing the content of the hard-copy maps. Development and maintenance of such files adds a sophisticated computer-science task to what is already a difficult and expensive information-management task.

5.1 HAZMATs DATABASES

CSDP requirements are different from those of most industrial facilities in that chemical agents to be destroyed are the only important substances to be managed. Hence, the MSDS and response data sheets (RDS) capabilities of commercial EMISs could be

Table 5.1. Emergency Management Information Systems (EMISs) software evaluated for Chemical Stockpile Disposal Program (CSDP) requirements

Name	MSDS retrieval system	MSDS database (no. of records)	Atmospheric dispersion model	Inventory database	Mapping	GIS Raster	GIS Vector	Misc. risk models
EIS	X	X (2,629–CAMEO)	X	X	X			
CAMEO	X	X (2,629)	X	X	X			
GENESIS/HEXXIS	X	X (1,400–CHRIS)			X		X	
CHEMTREC/CHEMNET	X	X (>90,000)						
HAZARDLINE	X	X (>80,000)		Info not available				
Digital HAZMAT	X	X (>28,000)						
CHEMDATA	X	X (18,000)						
FLOW II GEMINI	X	X (16,000)						
HMIS	X	X (15,000)						
OHS MSDS	X	X (>7,000)						
Phoenix Fire Department		X (6,000)			X			
CERIS	X	X (3,700)						
CHEMTOX	X	X (>3,500)						
CHIT/TOXIC ALERT	X	X (>1,500)		X				
SAF-T MANAGER	X	X (>1,500)		X				
FIRSTsystem MicroCHRIS (USCG) MicroOHM/TADS (EPA)	X	X (>1,400)						
MSDS Inc.	X	X (>1,000 Northridge)		X				
SAFECHEM II	X	X(>1,000)		X				
AHMRTS	X	X (unknown)		X				
TOXNET	X	X (Toxic only)						
HAZMIN-C	X			X				
HazKNOW	X			X				
FireSoft	X							
HASTE			X		X			
SAFER			X		X			
PC MIDAS			X		X			
CHARM			X		X			

Table 5.1. (continued)

Name	MSDS retrieval system	MSDS database (no. of records)	Atmospheric dispersion model	Inventory database	Mapping	GIS Raster	GIS Vector	Misc. risk models
MESOCHEM			X		X			
AFTOX			X		X			
HARM			X		X			
DEGADIS			X		X			
ARAC			X		X			
DWNWND			X					
BREEZE HAZ			X					
D2PC			X					X
SAFETI AND WHAZAN								X
FRES								
CHEMIS (Materials unsuitable for evaluation)								

Source: Information and demonstration software provided by vendors listed below:

EIS	IBM PC computer compatibility
CAMEO	Apple computer compatibility
GENESIS/HEXXIS	Wang computer compatibility
CHEMTREC/CHEMNET	N/A (dial-up)
HAZARDLINE	
Digital HAZMAT	IBM PC computer compatibility
CHEMDATA	IBM PC computer compatibility
FLOW IT GEMINI	IBM and VAX computer compatibility
HMIS	IBM PC computer compatibility
OHS MSDS	IBM PC computer compatibility
Phoenix Fire Department	PDP-11 computer compatibility
CERIS	IBM PC computer compatibility
CHEMTOX	IBM PC computer compatibility
CHIT/TOXIC ALERT	IBM PC computer compatibility
SAF-T MANAGER	IBM PC computer compatibility
FIRSTsystem	IBM PC computer compatibility
MicroCHRIS (USCG)	
MicroOHN/TADS (EPA)	
MSDS Inc.	IBM PC computer compatibility
SAFECHEM II	IBM PC computer compatibility
AHMRTS	IBM PC computer compatibility
TOXNET	N/A (dial-up)
HAZMIN-C	Apple computer compatibility
HazKNOW	IBM PC computer compatibility
FireSoft	IBM PC computer compatibility
HASTE	IBM PC computer compatibility
SAFER	N/A (microcomputer part of system)
PC MIDAS	IBM PC computer compatibility
CHARM	IBM PC computer compatibility
MESOCHEM	IBM PC computer compatibility
AFTOX	Zenith computer compatibility
HARM	VAX computer compatibility
DEGADIS	VAX computer compatibility
ARAC	Vax computer compatibility
DWNWND	PDP-10 computer compatibility
BREEZE HAZ	IBM PC computer compatibility
D2PC	IBM PC computer compatibility
SAFETI AND WHAZAN	IBM PC computer compatibility
FRES	IBM PC computer compatibility
CHEMIS	Information not available

Table 5.2 Geographic Information Systems (GISs) software meeting minimum Chemical Stockpile Disposal Program requirements*

Name	A Supports map digitization	B Referenced to lat/lon	C Convert map projection	D Topology	E Raster (R) and vector (V) or R/V conversion	F DBMS	G Mensuration	H Mathematical operations	I Polygon geometry	J Terrain analysis	K Network analysis	L Geometric analysis
ARC/INFO	X	X	X	X	X	X	X	X	X	X	X	X
Deltamap	X	X	X	X	X	X		X	X	X	X	X
Earth One	X	X	X	X	X			X		X	X	
GeoVision	X	X	X	X	X	X					X	X
GeoVision WOW	X	X	X	X	X						X	X
GRASS	X	X	X	X	X		X	X		X	X	X
IGDS/DMRS	X	X	X	X	X	X		X		X	X	X
Laser-Scan	X	X	X	X	X	X						
Manatron GIS	X	X	X	X	X	X		X				
MicroStation GIS	X	X	X	X	X	X		X				
Pamap GIS	X	X	X	X	X	X	X	X	X	X	X	
SICAD	X	X	X	X	X	X	X	X	X	X	X	X
SPANS	X	X	X	X	X		X	X	X			
STRINGS	X	X	X	X	X	X					X	X
TIGRIS	X	X	X	X	X			X				
Ultimap	X	X	X	X	X	X		X			X	

*The 16 systems listed above were selected from 63 systems responding to a survey administered by *GIS World*. All systems claiming features A through E are included in this list.
Source: "GIS Technology '89: Results of the 1989 *GIS World* Geographic Information Systems Survey," July 1989. Special Report, pp. 1–16 in *GIS World*, Inc., Fort Collins, Colo.
A list of system vendors is as follows:

ARC/INFO	Environmental Systems Res. Inst.
Deltamap	Deltasystems
Earth One	C.H. Guernsey and Company
GeoVision	GeoVision Corporation
GeoVision WOW	Geovision, Inc.
GRASS	U.S. Army construction Engineering Laboratory
IGDS/DMRS	Intergraph Corporation
Laser-Scan	Laser-Scan Limited
Manatron GIS	Manatron, Inc.
MicroStation GIS	Intergraph Corporation
Pamap GIS	Pamap Graphics Ltd.
SICAD	Siemens p/c
SPANS	Tydac Technologies Corporation
STRINGS	GeoBased Systems
TIGRIS	Intergraph Corporation
Ultimap	Ultimap Corporation

important because of the structure they provide for special response information rather than for their pre-existing data content that is not relevant to this program. Pre-existing data on commercial materials could, however, be important for other functions for which the on-post EOC is responsible.

All manufacturers, distributors, and users of HAZMATs are required to provide a prescribed list of information describing each substance in terms of flammability, reactivity, and health characteristics; special precautions; protective clothing and equipment handling or containerization requirements; and ventilations requirements. These MSDSs are available in digital form. MSDSs are the basis for all of the thematic database systems evaluated in this report. RDSs are similar but generally contain more information about remedial actions, protective clothing, and other factors related to response.

The various systems differ primarily in the lists of materials included in their databases, as well as in the procedures used to access MSDS records. The MSDS record lists only hazardous chemicals in their pure forms. Hazards associated with chemicals' coming into contact with one another during a fire or explosion are recognized as important in the CSDP. Unfortunately, no current system deals with the problem of chemical mixtures.

The total number of MSDS records is quite large. Most automated systems limit their coverage to a few thousand records to optimize efficiency and focus on substances appropriate to a particular facility. A total of 18 different MSDS databases were evaluated for this report (see Table 5.1). These ranged from the CHEMTREC/CHEMNET database, which contains more than 90,000 substances, to the SAFECHEM II database, which contains approximately 1,000 substances.

The EIS/C database contains 2629 substances. The EIS/C list is identical to that contained in the CAMEO system—a public-domain system developed by the National Oceanic and Atmospheric Administration (NOAA) specifically for use by fire departments.

We recommend that the MSDS database be a resident database on digital-storage medium. However, in all cases, chemical agents at each CSDP site will have to be added to these databases.

5.2 INVENTORY DATABASES

Two inventory databases relevant to CSDP emergency DM were identified: *HAZKNOW* and *Property*, both of which were designed specifically to manage inventory information pertaining to storage facilities and their locations and contents. Although each of these database systems may function quite well as a stand-alone system (i.e., one that is not part of a larger computer system), none provides a distinct advantage over inventory database systems that are already integrated into more comprehensive emergency-management systems.

5.3 EMISs

EMISs are highly specialized application systems that encompass several different information technologies. As shown in Table 5.1, only two microcomputer workstations (as might be found in an EOC, for example) offer a significant subset of features essential for emergency management: the CAMEO system, developed by NOAA, and the EIS/C system, developed by Research Alternatives, Inc.

The two systems are very similar because EIS/C is a commercially-modified version of CAMEO. EIS/C was modified to run on International Business Machines (IBM) personal computers. CAMEO, on the other hand, was designed primarily to operate on the Apple family of personal computers.

The GENESIS/HEXIS system [not to be confused with the *Genisys* event log program in current use at PBA (see Sect. 7)] has been implemented at Tinker Air Force Base in Oklahoma, where it is used by the base fire department for emergency-management purposes. GENESIS is an Air Force–modified version of the commercial HEXIS system that adapts a general-purpose GIS for a specific emergency-management application. The resulting system runs on Wang *minicomputers* but is not compatible with the Wang family of *microcomputers*. GENESIS/HEXIS is expensive because of the higher initial cost of minicomputers vs microcomputers. GENESIS/HEXIS does not include an air-diffusion model, and its emergency-management features are neither wide ranging nor user friendly. The 15 remaining systems specialize in MSDS management, inventory management, or air-diffusion modeling. Their limited range of capabilities makes them unsuited for the comprehensive emergency-management needs of the CSDP.

5.4 GISs

Essential to any ADSS is some type of GIS that would allow for the representation of 2- and 3-dimensional phenomena in a manner that would facilitate the depiction, storage, and retrieval of spatial data relevant for emergency DM. At APG, such a system is being developed. Studies of GIS experience in emergency management indicate the following advanced capabilities by which the effectiveness of such systems can be evaluated (Dobson 1988):

- data capture, including data conversion, digitizing, editing, and image processing;
- data storage, retrieval, and management;
- data integration;
- mensuration and statistical summary;
- data manipulation and analysis;
- modeling (including meteorological modeling);
- linkage to other geographical and nongeographical systems; and
- graphical output and display.

In addition, the software must be capable of representing the location, geometric form, and spatial relationships of cartographic objects. Buildings, streets, and other installation facilities must be converted from analogue drawings (such as would be found on blueprints or topographic maps, for example) to digital spatial databases with geometry, topology, and other attributes.

In a GIS system, analytical software must be able to represent the distribution of each geographical object, spatially registering geographic distributions from different sources, and identifying coincident locations on multiple databases (Green 1988). For example, in the CSDP, it essential to be able to determine the location of a spill, fire, explosion, or other source of a chemical-agent release. It is also necessary to be able to depict IRZs, Protective-Action Zones (PAZs), and smaller subzones within the response zones as well as to be able to define a no-deaths or no-effects distance for an agent release. Finally, the intersection of each of these zones with the location of a chemical-agent release and the area within which a population would be at risk from the release are all available through the use of a GIS.

The most important GIS function is the conversion and transfer of data from an installation's engineering and chemical surety database (e.g., floor plans, utilities, other facilities) to the on-post EOC and its attendant microcomputer workstation.

CSDP requirements may be divided into four distinctly different, but integrally related, activities: database and scenario preparation; real-time, routine operations; real-time, emergency operations; and real-time operations during the recovery phase following a chemical accident/incident. Activities 1 and 4 are similar in that comprehensiveness and accuracy are more important than speed. During an emergency (activity 2), speed is crucial, but comprehensiveness and accuracy depend on preparation that has been done ahead of time (activity 1).

Routine operations are similar to emergency operations, except that the requirement for speed is not quite as stringent. These combined activities force trade-offs among speed, accuracy, and comprehensiveness that can be resolved only by employing one type of system during the preparation and recovery phases and another type during emergencies and routine operations. Paradoxically, the two systems must be so integrally linked that they can function almost as one system when data are being transferred between them.

Once the database is complete, analysis can be greatly enhanced by the particular analytical characteristics of the GIS. The selection of an appropriate GIS for the CSDP must necessarily focus on functional characteristics (see Appendix B). Table 5.2 and Appendix D depict the results of a survey of 63 GIS and related systems. This survey was administered by *GIS World*. The data are derived from a 1989 survey of GIS systems (GIS Technology 1989), and the analysis is also derived from an article in preparation by H. D. Parker, editor of *GIS World*, and J. E. Dobson (Parker and Dobson, 1990—to be published). In the survey (from which Tables 5.1 and 5.2 were derived), an attempt was made to contact all manufacturers of GIS systems to provide a broad, systematic comparison of features. There were no preselected criteria for including or excluding any system. Thus, the only limiting factor in the *GIS World* survey was that some companies did not respond. Systems listed in Table 5.2 were selected from the group that responded to the survey on the basis of five exclusionary criteria: map digitizing capability, reference to latitude/longitude, topology, raster and vector integration, and map projection conversion capability.

At this formative stage of GIS development, some vendors offer excellent GIS products, but many apply the term spuriously to software that will do little more than digitize maps and display graphic images. Conversely, some systems that are marketed under other names [such as automated-mapping (AM), facilities-management, or image-processing systems] offer a substantial subset of GIS features that may be useful for emergency management. Of 63 vendors responding to the *GIS World* survey, 51 considered themselves to be offering a true GIS. Ten characterized their products as AM software. An equal number considered their product to be for facilities management. Only 5 vendors characterized their products as image-processing systems, although 15 reported remote sensing image-analysis capability. Four vendors used the term *desktop mapping* to characterize their systems, and two characterized theirs as CAD. The specific characteristics of these systems are discussed below.

5.4.1 Data Structures

Until recently, most GIS systems operated under a single data structure—raster or vector—and conversion between rastor and vector structures was poorly supported. In general, raster structures dominate the image-processing arena because data acquired through regular sampling (as, for example, in a rectangular grid) can be best represented in raster form. Most of the satellite sensors used to acquire land-cover data operate on this principle of regular sampling. Automatic scanning devices used to convert analogue (hard-copy) maps to digital data also operate in this manner. Vector structures dominate the CAD arena because points, lines, and polygon boundaries can best be represented in vector form. Maps can be represented in either form, but comprehensive geographic analysis requires both structures.

Of the single data structure systems, vector systems outnumber raster systems by more than 2 : 1. A growing number (24 at present) of vendors offer a combination of raster and vector data structures, and vector-to-raster conversion capabilities are available on 32 systems, and raster-to-vector conversion capabilities are offered on 24 systems.

5.4.2 Topology

Topology indicates spatial relationships among entities (left, right, above, below) and is a key feature that distinguishes graphics systems from geographic systems. If the primary purpose of a system is to produce graphic images only for display and visualization, topology may not be necessary. If, however, the purpose of the system includes the intersection of two or more geographic distributions in space, then topology is essential. The CSDP will likely require this type of integrative analysis during the planning and recovery stages of emergency management. Real-time operations during an emergency might not depict topological features so that graphic images could be processed more quickly. However, such images will derive from the analysis conducted during the planning phase.

According to the *GIS World* survey, 34 systems claim topological capabilities, but 12 do not. Topology is an enduring problem for many vendors. Many of them simply do not understand topology and its importance for analytical as opposed to display functions. It is not uncommon for vendors to confuse topology with topography, a cartographic term that refers to a detailed map regardless of its data structure. For this reason, one should carefully inquire about the functionality of topological features claimed by vendors.

5.4.3 Digitization and Coordinate Systems

The most important GIS function is the conversion and transfer of data from each installation's engineering and chemical surety database (e.g., floor plans, utilities, other facilities) to the on-post EOC and its attendant microcomputer workstation. Some facilities information already exists in digital form, primarily through the efforts of architectural and engineering (A&E) contractors using CAD systems, but the vast majority exists only in the form of hard-copy maps and drawings. Digitization is a labor-intensive task, and it is absolutely essential in the preparation of the database that will be utilized during emergencies and routine operations of the EOC. It is important that the software employed for digitization be referenced to latitude/longitude so that geographic information can be integrated regardless of its source. For example, it may be necessary to integrate on-post maps and floor plans with U.S. Geological Survey (USGS) elevation data.

According to the *GIS World* survey, 57 of 63 systems support map digitization. A majority of systems (38) offer conversion from one map projection to another. However, given the common requirement in geographic analysis for map digitization, 38 is a smaller number than might be expected. In addition, most GIS systems are geographically referenced to latitude and longitude coordinates.

5.4.4 Computing Environment

Ideally, all of the systems employed for emergency DM in the CSDP would operate under a single computing environment (or operating system). This would reduce the training requirements for developers and operators and would improve speed whenever data and instructions were passed from one component of the system to another. Network telecommunications among on- and off-post systems would be an important requirement as developments proceeded. Telecommunications would be facilitated by adopting a single operating system for all facilities. The candidate software and hardware options include a variety of operating systems. No single system addresses all of the CSDP requirements. Thus, rapid deployment of currently available systems would necessarily involve different computing environments at different levels of the management structure.

In general, DOS (IBM and IBM compatibles) and Macintosh OS (Apple) have emerged as the leading operating systems for personal computers. VMS (DEC/VAX) remains strong at the minicomputer level. UNIX leads in the new category of graphics workstations and is promising because of its ability to function on all types of computers—personal computers (PCs), minicomputers, and main frames—as well.

Among GIS products, DOS has emerged as the clear leader among computing environments, with 37 of 63 GIS systems reporting DOS compatibility. This is due in large part to the growing application of personal computers. Some PC-level GIS vendors report OS-2 as a direction for new development, and two vendors list OS-2 as their current operating system. UNIX is the second most popular system (17 vendors), and VMS ranks third (15 vendors). The growth of UNIX is synonymous with the growing popularity of graphics workstations. Although Macintosh OS is growing as a direction for new development, only nine vendors list it as a current operating system. ARC/INFO and Moss still support Prime/PRIMOS.

5.4.5 Database-Management System (DBMS) Interfaces

Rapid DM in the CSDP will require a database-management system. Several options may suffice, but it is important that a single DBMS be selected. The criteria for selection should include the functional characteristics of the DBMS software, compatibility with a variety of different computers (PCs, graphics workstations, minicomputers, and main frames), and long-term viability of the vendor. A third of the vendors responding to the survey reported having no DBMS. The remaining vendors reported having a variety of 30 different DBMS interfaces. Oracle and Dbase (each with 13 vendors) are the most popular DBMS interfaces. No system is currently common enough to be considered an industry standard. Support is evenly divided between internal and external interfaces.

5.4.6 Data-Input Formats

The most striking feature of current data-input formats is variety. No industry standard appears to exist, although DXF (24 vendors) and DLG (23 vendors) are clear favorites. DXF is an exchange standard established by the vendors of AutoCAD, a commercial CAD system. AutoCAD has excellent features for capturing, processing, and displaying geometric data, but it does not capture topology or attribute data. DLG and DLG-3, which support geometry, topology, and attribute data, are formats developed and promulgated by the USGS. GBF/DIME (18 vendors) and TIGER (17 vendors) are essential for processing the U.S. Census data that now include detailed topographic databases (roads, street names, addresses, water bodies, power lines, etc., but not elevation) in addition to the traditional counts of population and housing characteristics.

Tiger will likely become the cartographic base for the entire United States during the 1990s. It provides a major step forward for emergency management. SIF (13 vendors) and ISIF (5 vendors) are formats developed by the Intergraph Corporation for its popular CAD system. Like AutoCAD, SIF and ISIF focus on geometry and may be important for specific facilities for which CAD data have already been developed by A&E contractors and for which the combined total of SIF (13 vendors) and ISIF (5 vendors) are close behind. DEM (10 vendors) is a format developed by the USGS specifically for its detailed elevation databases that can be used to calculate slope, aspect, and other terrain characteristics. ARC/INFO (a vector system that supports geometry, topology, and attribute data), ERDAS (a raster system for remote sensing analysis), and IGES (a graphics exchange standard) are supported by six vendors each. Finally, 39 systems are supported by no more that one vendor each.

5.4.7 Functional Characteristics

The analytical requirements of CSDP emergency DM are extensive. The emergency-planning phase, in particular, will require sophisticated data processing and modeling capabilities. Selecting an evacuation route, for example, involves measuring complex distances, integrating several databases (some of them for depicting points, some for depicting line features, and some for depicting polygons), and running simulation or optimization models. Even an action as simple as drawing a cordon around a building requires specific software that can draw a buffer around an irregular polygon.

In descending order of frequency, the functional characteristics considered in the *GIS World* survey are mensuration, mathematical operations, polygon geography, terrain analysis, network functions, and geometric operations. The earliest GIS systems were capable of measuring simple distances and areas. Today, almost all systems support simple measurements, and a majority support complex measurements. Only about a third are able to calculate a weighted buffer.

Mathematical operations, especially Boolean functions, are common among vendors. These operations are essential when comparing one map distribution with another. Even complex functions such as searching for the nearest neighbor, exponentiation maps, and differentiating map values are available in 30% to 50% of available systems.

Finally, most systems can perform fundamental polygon operations such as merge/dissolve, locating points or lines in a polygon, and overlay. Fewer than half can delete spurious polygons after overlay and only 10 systems can generate Thiessen Polygons.

5.5 GISs' GRAPHICS CHARACTERISTICS

The mouse and digitizing tablet are by far the preferred devices for inputting data, although a few systems support the trackball, thumbwheel, or light pen. Only six systems support a touchscreen. CSDP requirements will include the mouse and digitizing tablet, but all other devices are optional.

Virtually all commercial vendors offer color graphics. Most color graphics are offered on a single screen. However, dual screens that allow the user to monitor two separate sources of information at the same time are available from almost half of the systems. Some systems can operate in either single- or dual-screen mode. Color graphics are preferable for CSDP DM because they instantly clarify essential features of maps and menus. The choice between single vs dual screens, however, will depend on the software selected. Graphics workstations allow for multiple windows, with multiple tasks occurring simultaneously.

Menus are the preferred technique for user interface because they are easy to use. Two-thirds of all systems use function keys as a primary or secondary interface, and almost as many use a command language. Icons, pictogram-like features most closely identified with the Apple Macintosh system, have come into widespread use and have penetrated almost half of the market.

At APG and PBA, off-post emergency managers have expressed considerable interest in hard-copy technologies associated with ADSSs. Most available systems support almost all of the familiar hard-copy technologies already deployed, or anticipated for deployment, in off-post EOCs. These hard-copy technologies include relatively economical dot-matrix printers, ink-jet plotters, pen plotters, electrostatic plotters, and laser-jet printers. Likewise, almost all systems provide for user annotation and geographically referenced overlay grids. Only half of available systems can generate 3-dimensional plots, however. Vector map output is slightly more popular than raster map output. Regardless of how the hard copy is produced, facsimile machines can be used to transfer copies to other participating organizations such as those in protective-action and precautionary zones. Hard copies, of course, will not allow for interaction with the data.

Although the emergency-management community is concerned with standards for the future, it is ironic that state-of-the-art standards have not been heavily implemented in current systems. For example, fewer than half of the systems have adopted network standards, and 20% have adopted GKS (i.e., industry-wide) graphics standards.

5.6 AIR-DIFFUSION MODELING

As will be seen in Sect. 7, considerable effort has been expended at APG and PBA to develop ADSSs capable of modeling the dispersion of chemical-agent releases in the atmosphere. The most important meteorological features pertaining to a chemical-agent release at all CSDP sites are wind direction, wind speed, and atmospheric stability (Carnes et al. 1989). All air-dispersion model applications are constrained by acknowledged inaccuracies. Moreover, air-dispersion models must be fine tuned to specific source terms in the CSDP (such as GB, VX, and H/HD). Experiments with the HOTMAC air-dispersion model discussed below, for example, have been conducted with white smoke and simulant releases to create a comprehensive set of data that can be tested against meteorological simulations of ground-level and wind-field effects (Yamada, Williams, and Stone 1989). Similar fine tuning is necessary in other models.

It is relatively easy to enable Emergency Management Information System (EMIS) and GIS software to accept the results of several different atmospheric models. The selection of these systems, therefore, has little to do with the selection of the atmospheric model, and vice versa, except that hardware and operating systems of the EMIS and the atmospheric model must be compatible. Indeed, it may be advisable to select multiple atmospheric models for a variety of emergency situations and purposes. It may be wise to use a detailed, time-consuming model during emergency planning and recovery phases and an abbreviated, rapid model during routine and emergency operations.

The D2PC atmospheric-dispersion computer model developed by CRDEC, selected for estimating downwind doses of nerve and mustard agents resulting from accidental releases, does not account for topography, changes in wind direction through time, or any spatial changes in atmospheric conditions. Consequently, although useful as an analytical tool for estimating downwind distances for emergency-planning purposes (Carnes et al. 1989), the D2PC model may be inappropriate for use under real-time conditions such as those investigated in this report. As a result, it is necessary to weigh the advantages and features of several computerized air-diffusion models capable of modeling the dispersion of a chemical-agent release. Although many of these models are faster and more precise and can characterize ambient conditions in greater detail, the presence of all three characteristics in a single model is more problematic.

Fourteen computerized atmospheric-dispersion models were evaluated for this report. Of these 14, 8 were found to have satisfactory mapping capabilities associated with a chemical-agent-release plume. However, air-diffusion models, like other computerized models that simulate the movement of fluids in 3-dimensional space, have significant trade-offs among speed, precision, and detail.

For example, an increase in precision tends to increase the run time for a given air-diffusion model, thus affecting timely warning and effective response to an accidental agent release. Moreover, the addition of certain ambient conditions, such as the characteristics of surface land forms and terrain covered by the flow path, may increase computer run time and impede DM.

There are also trade-offs among levels of precision and computer system sizes—an important consideration from the standpoint of cost, user friendliness and, from a practical logistical standpoint as regards their deployment in an EOC, space. Air-dispersion models designed for long-range emergency planning and environmental analysis and models intended for use on large, very fast computers are very precise and provide abundant detail. On the other hand, models designed for rapid response and for use on smaller, personal computers must sacrifice precision and detail to achieve shorter run times.

The most commonly used models for rapid response are so called puff models that simulate the movement of air as a series of discrete puffs. The ALOHA model, developed by NOAA, and the Air Force Toxic Chemical Dispersion Model (also called AFTOX) both operate in this fashion. These and other air-diffusion models, including D2PC, can be incorporated into the final system deployed at CSDP sites.

Finally, the HOTMAC atmospheric-dispersion model, developed by Los Alamos National Laboratory, is an example of a prognostic, hydrodynamic model that may be valuable in CSDP emergency-planning operations. Even on a minicomputer, the model run time for a 2.5-h forecast is about 35 min (Yamada, Williams, and Stone 1989). Such a run time is unacceptable for real-time CSDP response that requires DM in 5–10 min. However, it would be acceptable for planning and recovery. HOTMAC developers recommend at least a substantial graphics workstation for practical application.

5.7 GRAPHICS SYSTEMS

Seven graphics systems were considered, but none was found to have pertinent features that would significantly enhance ADSSs beyond those features currently available in more general software systems. Of the seven systems investigated, Atlas Graphics was selected to be evaluated in further detail. Compatibility and user friendliness comprise a distinct advantage to using graphics software already integrated into a comprehensive emergency-management system or GIS.

6. CRITERIA FOR EVALUATING DM SYSTEMS

In this section we discuss the criteria by which a DM system should be assessed. These criteria are divided into institutional factors (Sect. 6.1) and ADSSs (Sect. 6.2). As noted in Sect. 1, these components of command, control, and DM are equally important for rapid mobilization of response capabilities and are mutually supportive.

6.1 CRITERIA FOR EVALUATING INSTITUTIONAL PERFORMANCE

A considerable body of literature on DM in emergencies suggests several criteria that can be used to evaluate the effectiveness of organizations' ERs to disasters. These include (1) disaster experience, (2) hierarchical control and flexibility, (3) role specificity and delegation of authority, (4) clear lines of communication and information, and (5) clear span of control or, clearly defined bounds of authority. Each of these factors has been addressed in some way by the current CAIRA manual, in DM guidance provided by contractor personnel, and by activities performed by on- and off-post emergency personnel at APG and PBA.

6.1.1 Disaster Experience

Disaster experience enhances the ability of an organization to participate in the warning process and to effectively respond to warnings (Mileti, Drabek, and Haas 1975; Barton 1970). Such experience provides information on organizational effectiveness and points out deficiencies, especially in communications (Neal and Sorensen 1986; Holland 1975).

Although no major chemical-stockpile accidents have occurred, the experiences that on-post officials at APG and PBA have had with minor chemical-stockpile incidents have partly shaped initial policies regarding warning. In addition, disaster experience in general has shaped the views of off-post officials in communities adjacent to APG and PBA regarding on- and off-post command and control for rapid-onset emergencies. The significance of disaster experience for emergency DM at APG and PBA is twofold. First, this experience has not included a sufficient range of events to adequately bound the types of problems that would be encountered in a CSDP emergency. Thus, drawing on emergency experience alone will not be sufficient to resolve institutional problems of rapid response. Second, prior disaster experience has shaped views of off-post responders as to the value of ADSSs and their needs for improvement.

6.1.2 Hierarchy and Flexibility

Hierarchical authority has been found to be the optimal pattern for organizational response (Dror 1988). For emergencies affecting multiple jurisdictions, hierarchical authority provides a means of clarifying who will have what responsibilities. Complex programs such as the CSDP have a need for flexibility among the various agencies involved in off-post ER. Flexibility ensures effective coordination of resources and quick response to unforeseen contingencies or unstructured problems (Pavlak 1988; Drabek et al. 1981).

Although there might appear to be some contradiction in reconciling hierarchical authority with organizational flexibility, they are actually quite compatible. The common goal of both criteria is to ensure that response organizations will not have to significantly alter their predisaster functions. The less organizations have to change, the more quickly they can respond to emergencies (Mileti and Sorensen 1987; Drabek et al. 1981). In some instances, this means placing certain functions under highly formal, standardized command and control procedures. In other instances, it may mean departing from standard operating procedures to maximize flexible response (Drabek et al. 1981). No single plan, element, standardization of procedure, or task should be taken so seriously that it precludes flexibility and adaptation to unforeseen emergencies or hinders ability to incorporate a change into ADSSs (Pavlak 1988). On- and off-post officials at APG and PBA have responded in varying ways to the twin issues of hierarchy and flexibility, as shall be seen in Sect. 7.

6.1.3 Role Specificity and the Delegation of Authority

Identifying responsible decision makers and clarifying their roles and responsibilities is essential for effective ER (Kreps 1978). Role specificity, also known as domain consensus, refers to the degree to which an ER organization understands its responsibilities and those of other organizations (Dynes 1978). In the CSDP, role specificity is supposed to be achieved by assigning points of contact and by designating certain individuals as responsible for off-post emergency notification and other salient tasks. The greater the degree of domain consensus among organizations, the greater the likelihood of timely response.

DM responsibilities should be allocated during the emergency-planning process. Program guidance for the CSDP has pointed to the central role Local Emergency-Planning Committees (LEPCs) can play in off-post DM. LEPCs are usually composed of local government officials and representatives of chemical facilities; police, fire, medical, and other organizations involved in chemical ER; and active community groups interested in environmental safety. LEPCs have been formed in direct response to Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA Title III) and, in most states, are based on county jurisdictions. Before LEPCs can take major responsibility for the off-post planning process in the CSDP, however, issues pertaining to their resources, professionalism, time-management constraints, and contending responsibilities at APG and PBA should be addressed (Feldman, 1989a; Feldman, 1989b). Section 7 will discuss the effectiveness of attempts to manage role specificity at APG and PBA.

6.1.4 Criteria for Evaluating Information and Communication Effectiveness

Clear lines of communication and information are central to rapid, effective ER (Leik et al. 1981). Information must be clear, unambiguous, and quickly communicated (Anderson 1969). Several elements of communication and information transfer are critical to CSDP emergency DM at APG and PBA. The following principal elements may be thought of as sequential components of an information framework:

- communication among on-post responders,
- communication among on- and off-post responders,
- communication among off-post responders, and

- communication among on- and off-post responders and the general public.

6.1.4.1 Communication among on-post responders

Immediate voice communication should be provided among on-post EOC and decontamination/detection personnel (the initial responders to a CSDP chemical-agent release) via secured radio and telephone systems to avert the public's monitoring of transmissions via police scanners or other devices. Telephone and radio communications networks should be secured to prevent rumors' being fueled by a few listeners incapable of accurately assessing the implications of this information.

Although considerable thought needs to be given to communications equipment, the relationship among that equipment and emergency personnel and institutions also requires attention. Rapid communication among on-post responders during a CSD emergency at APG and PBA requires that this equipment be allocated to designated personnel and that special operating frequencies be assigned to users (Irwin 1989). In addition, clear text, or plain language, should be used to facilitate communication with less-knowledgeable off-post responders and novice on-post personnel (U.S. FEMA 1987).

6.1.4.2 Communication among on- and off-post responders

Communication among on- and off-post responders during a CSDP emergency would be constrained by security considerations. The exact size of the chemical stockpile at APG, PBA, and all other CSDP sites is classified. Program security requirements established by the U.S. Army rank the safeguarding of classified information at a CSDP site a high priority during an emergency (U.S. Army 1989a). Moreover, initial on-post responders, as well as subsequent service-force responders who might later assist them, are instructed to protect munitions from sight and overhead surveillance in the event of an agent release (U.S. Army 1989a).

There may be some instances when local officials believe they either need to know additional information about the character of the APG or PBA stockpile to render proper and appropriate off-post response or need to enter the installation on request. It is conceivable that the confidence of off-post officials in the validity of on-post recommendations will be contingent partly on the release of certain classified information about the stockpile—perhaps something as simple as the location of a leaking igloo or container-handling building. In some CSDP states, such as Oregon, off-post responders are explicitly prohibited from entering the scene of a chemical accident unless SARA Title III Sects. 311 and 312 data are made available to state and local officials.

Programs established for coordinating state, local, and federal agencies' response to nuclear-weapons accidents reveal that compromise between standard, necessary military security practice and state risk-communication laws is possible (U.S. Congress General Accounting Office 1987).

6.1.4.3 Rapid warning and notification as a communications problem

A separate issue pertaining to communication among on- and off-post responders is rapid notification and warning. There are advantages and disadvantages of both specific and detailed emergency-notification classifications and general emergency classifications.

The basic question decision makers must resolve to their own satisfaction is "How many classifications are required to produce clear, easily understood terminology for identifying resource elements and facilities, delegating management authority, and ensuring uniform planning for different contingencies understandable by all jurisdictions and ER disciplines at a given CSDP site?" (U.S. FEMA 1987; Bragdon, Moreland, and Le Blanc 1988).

Differences in interpretation of classification terminology among agencies is likely to result in different patterns of operation and response. Thus, no matter how many classifications are employed, each on- and off-post ER official's understanding about what each warning category means and what response it requires must be absolutely clear. If officials do understand, a few, clear general categories may be adequate for rapid response. If this understanding is absent, however, the provision of many detailed categories for emergency warning could prove largely irrelevant in an emergency.

6.1.4.4 Communication among off-post responders

Many of the concerns pertaining to on-post communication apply with equal vigor to off-post responders. These concerns include the technical means of communication (dedicated phones, computers, and facsimile links, etc.) and domain consensus.

For some off-post communities, information flow among responders from different jurisdictions constitutes a problem during emergencies. Responders from one jurisdiction may be unclear about the tasks assigned to other agencies. Cross-training sessions, in which responders representing different emergency functions are given the opportunity to learn about each other's responsibilities, may offer a solution to this communication problem, as shall be seen in Sect. 7.

6.1.4.5 Communication among on- and off-post responders and the general public

In the event of a chemical release at a CSDP site, a JIC or Joint Information Body (JIB) is supposed to be established in a suitable facility outside the IRZ. This facility must be able to accommodate a large number of reporters and to facilitate a meaningful exchange of information with the public.

JICs (or JIBs) are supposed to be coordinated with on- and off-post EOCs to ensure clear, coordinated communication to the media and off-post officials. One issue that needs to be clarified beforehand is the nature of information that will be communicated to the public in the event of a CSDP release. It is important to ensure that the level of technical detail in preplanned messages designed for release to the public, as well as in preplanned graphics packages for computer display, be comprehensible. The causes of a CSDP release should be made clear. Preliminary assessments of risks to public health, safety, and the environment should be conveyed in a credible, believable manner. Although enhancements to communication among on- and off-post responders and the general public will not enhance rapid response, they may influence public acceptance of recommended protective actions.

Finally, many information programs designed to provide details about potentially high-consequence, low-probability events are sometimes viewed disparagingly as propaganda campaigns to quiet the public without giving them real information (Slovic, Fischoff, and Lichtenstein 1981).

Experience has shown that to alleviate such perceptions, a competent and credible program staff needs to be assembled in advance. Staff selection should be conducted in consultation with the people who are to receive information, such as local and state officials, representatives of the news media, and governmental public affairs officers. This is likely to enhance trust in communications pertaining to a CSDP emergency (Slovic, Fischoff, and Lichtenstein 1981). Local intergovernmental consultation and coordination boards (ICCBs) may facilitate this consultation process. The CAIRA manual suggests that CSDP installation commanders should periodically meet with members of the community to answer questions about chemical operations. Such meetings constitute one way to build confidence in the quality of off-post communications to the public in the event of a CSDP release.

This consultation process should include discussions about the type, character, and format of the information to be released to the press and the public to enhance trust in communications pertaining to a CSDP emergency (Slovic, Fischoff, and Lichtenstein 1981). Although consultation with local officials following a chemical release is important, experience suggests that wider consultation may be required to legitimate decisions. Consultation with many officials may entail special logistical problems.

Often, the governor of a state, or an on-scene coordinator designated by the governor, will demand to be kept apprised of the course of an emergency and to be consulted about possible response actions. As a general rule, governors merely want to know that efforts are being made to provide constantly updated and accurate information. In addition, governors sometimes have a need to be seen located as near as is practical to the scene of an accident. The accommodation of reasonable, prudent requests for this kind of service compose a vital mechanism for assuring the legitimacy of incident command and control.

6.1.5 Span of Control

Span of control is a central feature of good management practice in emergency organizations. The number of personnel controlled by and reporting to a particular unit commander should be large enough to carry out the tasks assigned to that particular unit in a timely manner but not so large that supervision and accountability become difficult. Each emergency responder should be able to concentrate on a primary assignment and without being distracted by other responsibilities or getting in the way of others performing the same task (U.S. FEMA 1987).

In assigning span of control, the goal is to balance managerial needs with safety considerations (Franklin 1989). Studies of span of control during emergencies (such as ICS-type response actions discussed in Sect. 4) have shown that any individual charged with emergency-management responsibility should have between three and seven people within his or her control. Five is believed to be the optimum (Franklin 1989). If a group exceeds seven people, its effectiveness deteriorates, because the individual in charge is more likely to be overwhelmed by attempting to organize, direct, and control subordinates (Franklin 1989).

It is, however, impossible to place an absolute number on optimal span of control. If the tasks are simple or routine, if the emergency is confined to a relatively small area, and if communications are good, one supervisor could optimally manage more than seven people. Conversely, very demanding tasks might dictate that a supervisor be made to manage no more than three people (Irwin 1989).

What is here termed span of control relates to emergency-classification levels and personnel assignments. Without a clear understanding of what level of alert should be initiated and what level of response is appropriate following a chemical-agent release, the delegation of span-of-control authority remains problematic. After span-of-control authority is clearly delegated, it is possible for ADSSs to track span of control within such alert systems.

6.2 CRITERIA FOR EVALUATING ADSSs

Studies of decision-support systems' effectiveness indicate several criteria by which digital-information technologies can be evaluated. These criteria include speed, accuracy, precision, comprehensiveness, ease of use, and cost. Although no single standard exists for any of these criteria because requirements vary from institution to institution, desired features can be generalized nevertheless. Trade-offs must be made among criteria because some of them are inversely or negatively related to one other. By relieving them of many computational and data-retrieval tasks, ADSSs allow decision makers to concentrate on exercising judgment. Computer systems employed for emergency DM should distinguish little between routine operations and critical emergency operations. Managers and operators should become accustomed to the hardware, software, and databases as an integral part of their daily work. Functional requirements should begin with current institutional practices at APG and PBA. What do emergency managers do now? How can current functions, such as retrieving and viewing maps and floor plans as well as accessing chemical-inventory data, estimating air-diffusion plumes, and conducting other surety functions, be automated to improve timely response if a chemical-agent release occurred?

The first priority in implementing ADSSs should be to accelerate the performance of routine, standard operating procedures involved in daily operations. Close collaboration among emergency personnel and computer scientists is necessary to ensure that the final design is functional and efficient. Thus, our first recommendation in this area is that both sets of personnel work together to research, develop, and deploy ADSSs.

6.2.1 Speed

At best, no more than 5–10 min should elapse between detection of an incident with potential off-post consequences and implementation of protective actions in the CSDP (Carnes et al. 1989). In the view of some off-post officials, such protective-action decisions may need to be implemented 2–5 min after a release is detected. This is because of population density, warning-system limitations, and other constraints. Rapid response depends on a combination of powerful hardware, efficient software, appropriate data structures, and well-trained personnel. If the EMIS is properly designed, DM will likely be more constrained by human activities than by the speed of data retrieval and display.

Information processing can be accelerated in two major ways. First, the computing equipment itself must be powerful in its ability to process numerical data and graphic images. Second, preprocessing databases, models, and scenarios could greatly reduce the real time for processing after an incident occurred. Software and databases can be designed for efficient processing. To develop an emergency-management system capable of responses faster than those of an analogue data-retrieval system, the range of likely incidents should be incorporated in system design to bound information requirements.

6.2.2 Accuracy

Quality assurance should be applied to the input data, calculations, models, graphics, and output data. Maintaining operator confidence in the results of information retrieval and generation depend on this assurance. Even trivial errors in seemingly unimportant data can undermine the confidence of operators and EOC decision makers and lead them to disregard or distrust data. The integrity of spatial information and spatial relationships among databases is just as important as the accuracy of numerical values attached to tabular data. This integrity can be maintained by ensuring the accuracy of spatial information and spatial relationships among databases.

6.2.3 Precision

Spatial information and other emergency-management data should be as precise as possible to ensure that they fill the needs of the emergency decision makers but do not overload them with nonessential information (Katz and Kahn 1974; Benbasat and Taylor 1982) (see Sect. 3.1.1). Air-diffusion models, for example, should be designed to accept measures of meteorological conditions and chemical releases that can be reasonably and quickly obtained by the personnel likely to be in the EOC at the time of an emergency. The level of precision of the resulting plume generated by the model should match the level of precision (base grid or other coordinates) used in recommending protective actions.

6.2.4 Comprehensiveness

The functional capabilities of an automated information-management system must satisfy a substantial, logical subset of requirements specified by emergency personnel that is essential to their specific institutional situation. Specialized programs, no matter how excellent they may be, would not likely be used at critical times if they are perceived as distractions from ER activities. By contrast, EOC decision makers are likely to employ a wide variety of specialized programs if those programs are an integral part of a system designed to meet general needs. This principal applies equally to software functions and to data content.

6.2.5 Ease of Use

Ease of use is an important factor in enticing EOC decision makers to incorporate computer technologies in their routine operations. Ease of use necessitates a user interface that is user friendly and can be run by decision makers with little or no previous computer experience. Most ADSSs available from vendors now employ some type of menu-driven interface that is augmented with commands driven by function keys. Included in the devices of choice are the on-screen cursor, mouse, digitizing tablet, and one- or two-keystroke functions. Employment of systems that include such features should be a high priority in procurement decisions.

6.2.6 Cost

Hardware costs for emergency-management systems are driven by the need for free-standing, dedicated systems located in the EOC. Any hardware solution that relies primarily on computers shared by emergency managers and other users is likely to entail conflicts over demand priorities. Moreover, a system whose memory and processing capabilities are located outside the EOC may be inaccessible in the event of a power failure, disruption of telecommunications lines, or even an act of sabotage. Finally, the system deployed by decision makers must be powerful enough to handle computationally complex operations such as air-diffusion models and GISs.

These requirements demonstrate the long-term need for the rapidly growing class of microcomputers known as graphics workstations. Although costs vary considerably (from $20,000 to $80,000, depending on the configuration of central processing units, memory, storage devices, and peripherals), graphics workstations are less expensive than minicomputer or main-frame systems with similar capabilities and will occupy less valuable space in EOCs. Moreover, they do not require special conditions to operate (large air-conditioning systems for cooling, for example—a logistical problem of importance in EOCs).

7. ASSESSMENT OF DM SYSTEMS AT APG AND PBA: APPLYING THE EVALUATION CRITERIA

On June 2, and July 26, 1989, respectively, site visits were conducted at CRDEC at Edgewood Area of APG, Maryland, and of PBA, Arkansas. During these visits, the authors of this report inspected the EOCs, participated in briefings on local CAIRA plans, and witnessed demonstrations of ADSSs. To assess the general adequacy of institutional processes and ADSSs, attention was directed to the criteria depicted in Sect. 6. A general comparison of the EOCs and ADSSs is depicted in Table 7.1.

7.1 APG's SURETY SITE AUTOMATION SYSTEM (SSAS) AND ITS INSTITUTIONAL CONTEXT

The goal of APG's SSAS, described as "an approach to faster and more reliable ER" (U.S. Army 1989b), is to cohere on-post information, including hazard prediction models, in a user-friendly manner to assist in rapid DM. When fully developed, the SSAS should be able to run several downwind meteorological models, automatically page emergency responders, depict the deployment of field command posts and other resources, and help recommend protective actions.

The current host computer is a Microvax II housed in an office belonging to the Site Automation group near the Edgewood EOC. Consideration is being given to the purchase of a future host, such as a Microvax 3400, that would be located adjacent to the EOC. The Microvax II is mated to an internally developed software package [version 1.0 of WATCH (Warning Against Toxic Chemical Hazards)].

The capabilities for downwind atmospheric hazards modeling now in place focus on the estimation of air-diffusion plumes with reference to the graphic display of key installation facilities and boundaries. The D2PC program, developed by CRDEC, has been adopted by APG. However, APG site automation staff are involved in research and development for MACH I (a more-advanced air-diffusion model), which is being developed at Lawrence Livermore National Laboratory as a potential substitute model. CRDEC is in the process of developing a report system to allow standardized depiction of accident source terms and amounts as well as meteorological conditions.

The plumes generated by the D2PC code are displayed as a series of polygons overlaid on a vector graphic representation of Edgewood area/APG. Hazard areas are shown as D2PC isopleth lines under three different categories: 1% fatalities, no-deaths distance, and no-effects distance. Facilities data include a general map of the site and vicinity, floor plans of key buildings, and data on building personnel present at different times of day. Meteorological data are acquired primarily from six towers located on the perimeter of the Edgewood area and one tower at the main APG site. When fully developed, the WATCH system and the SSAS should be able to:

- provide a full site information database depicting all buildings and facilities (by clicking on a building, for example, its entire floor plan may be depicted, as well as the number of people in that building at a given time).
- provide a real-time data link to local authorities (if they have display equipment capable of running WATCH).

Table 7.1. Comparison of Aberdeen Proving Ground and Pine Bluff Arsenal Emergency Operations Centers and Automated Decision Support Systems

Function	Aberdeen Proving Ground (APG)	Pine Bluff Arsenal (PBA)
On- and off-post direct communications?	No. CRDEC[a]/EOC[a] must report incident to main EOC at APG headquarters	Yes. Direct line from PBA EOC to Jefferson County EOC; voice only
Mobile EOC?	Not currently. Harford County intends to obtain a van	Yes. PBA mobile unit designed for on- and off-post officials' use
Staffing	8 persons per 8 activities as depicted in CAIRA[a] manual, 24 h/d	Variable staffing, 24 h/d
Automated Decision Support Graphics Capability?	Yes. Map displays provide site information data, structures, floor plans. Also, depicts D2PC isopleths as far as the 1% no-deaths distance	No, but desire for capability exists[b]
User access	E-mail connectivity to on-post users currently, off-post access in future. When fully developed, graphical/FAX[a] link to higher chain of command/off-post officials; paging system for emergency responders in planning. Connectivity and	On- and off-post access provided through modem. Off-post users who have modems and passwords have passive receiver access

Table 7.1. (continued)

Function	Aberdeen Proving Ground (APG)	Pine Bluff Arsenal (PBA)
User access (continued)	access depend on needs of off-post responders; can range from hazards prediction information to high-resolution graphics. Data access by off-post responders may be passive or interactive.	
Event logging?	No. None planned	Yes. Entries can be changed by authorized interactive users. May pose problems for record-keeping accuracy
Hardware/software	Hardware host: Microvax II in CREDC EOC/WATCH[a] v. 1.0 developed by CREDC; not commercially available	Hardware host: Microvax 15000 with 48 ports and a backup system/GENISYS v. 1.0, a commercially available menu-driven event/data logging system
Meteorological systems	Data fed from 6 Edgewood and 1 Aberdeen towers at 3 levels. Includes wind speed and direction plotted and fed into CHAWS[a], which is capable of manipulating data from a given tower + source term/type of release, etc. and	Data fed from 7 towers at 3 levels. Includes wind speed and direction fed to meteorological station adjacent to EOC. Additional data fed into display monitors on post include thunderstorm/ lightning data and others. Data fed to

Table 7.1. (continued)

Function	Aberdeen Proving Ground (APG)	Pine Bluff Arsenal (PBA)
Meteorological systems (continued)	plotting a no-deaths distance on display monitor. Future development: real-time meteorological sensor feed	CRT[a] displays, hourly log into GENISYS

[a]CRDEC = U.S. Army Chemical Research and Development Engineering Center; EOC = emergency operations center; CAIRA = Chemical Accident/Incident Response and Assistance; FAX = facsimile; CHAWS = Chemical Hazard Advanced Warning System; CRT = cathode ray tube.

[b]PBA's central criticism of APG's Surety Site Automation System is that dose exposure can be depicted only as far as the 1% no-deaths distance for a given source-term release as preprogrammed into the system. It does not depict actual dose exposure distances. However, PBA acknowledges that APG's geographic-information system (especially its depiction of mass-care centers and other off-post facilities) would be highly useful if it were joined to a better meteorological model.

[c]PBA has been designated as test site user for HOTMAC. Current plans are to run the program on a SUN work station (SPARC 4/370 GX-8-P8). Estimated cost = $800K.

Sources: Nick Marasco, Chief, Surety Site Automation Group, NBC Recon Division Detection Directorate, CRDEC, Edgewood Area, Aberdeen Proving Ground, Edgewood, Md., June 2, 1989; Mandy Kight, Chief Programmer, Emergency Operations Center, Pine Bluff Arsenal, July 26, 1989. Also, follow-up communications with Nick Marasco, APG, Sept. 12, 1989, and Ed Parham, PBA, Aug. 7, 1989.

- provide real-time access to meteorological/sensor data.
- depict real-time deployment of response forces.
- provide a graphical/facsimile (FAX) link to higher chain-of-command personnel, and
- provide an integrated paging system for responders that can be preformatted as a menu selection.

Since initial installation of SSAS in May 1988 and the installation of WATCH 1.0 in February 1989, considerable refinements have been made for readiness training and optimizing site response. The SSAS system was designed to be useful to off-post communities and to permit them to access the network. When hardware and software systems are close to being finalized, off-post personnel will be trained on SSAS use by CRDEC. Because Harford County intends to implement response plans around fireboxes (emergency call boxes on street corners) to coordinate alert, warning, notification, and evacuation plans, efforts are being made to ensure that the on-post data base used by the SSAS duplicate this format and display information in this form. However, considerably more refinement and progress will be required to make the system useful for rapid DM beneficial to off- and on-post response. Sects. 7.1.1–7.1.7 evaluate SSAS and its institutional context.

7.1.1 Graphics Display Structures and Inventory Database

A principle weakness of the current SSAS is that the polygon representing an atmospheric plume, and the vectors that represent installation facilities, is not linked through GIS data structures. This is a hindrance to timely response to a chemical-agent release. It is impossible to query both databases simultaneously to determine which facilities are located in the path of an approaching plume and which are not. To make this determination would require that all databases be fully represented in terms of geometry, topology, and appropriate attributes and be registered to a common geographic coordinate system, preferably latitude and longitude.

7.1.2 Database Development and Staffing

The Site Automation Staff (who are housed at the Edgewood Area of APG and are responsible for developing an on-post automated decision-support emergency-management system) currently includes one manager, two computer scientists, and two engineers. Although the automation concept adopted by this staff is sound, the size of this group may be too small to adequately develop the system to its full potential. By way of comparison, comparable agencies or firms developing similar types of EMIS or GIS maintain developmental staffs numbering in the tens or even hundreds of persons. These large staffs are necessitated by the size and complexity of the software and hardware systems and by the need for specialists in many fields, including systems integration, graphics, geography, and the social and physical sciences.

Maintenance of the SSAS inventory database alone will require the attention of a substantial component of the current staff. The current system contains an inventory database intended to be dynamic (i.e., changes in inventory and facilities can be entered into the database that is maintained by the line organization responsible for surety management). Frequent updates would be transferred to the WATCH inventory database.

If the APG Surety Site Information System effort is to attain its full potential, it will require a substantial expansion of technical staff. On the other hand, the size and expertise of the current Site Automation Staff appears ideal for an effort that would adapt available commercial or public-domain systems for application to the CSDP.

7.1.3 Off-Post Interface

Off-post ER officials in Harford County report that rapid, accurate assessment of an approaching hazard is the single most important piece of information necessary for initiating timely off-post response. However, although the SSAS under development at CRDEC is designed to provide this type of information, these same officials are skeptical of the current capabilities of this system, are somewhat confused by the failure to systematically compare its features with other available systems, and are concerned about the relationship between system costs and the ability to provide other emergency-preparedness enhancements.

The officials contend that the plume-plotting capabilities of the current SSAS may generate useful output too slowly and that promises made concerning its precision in tracking plume direction may be difficult to fulfill. It is important to Harford County that output concerning the character of an accident be transmitted as accurately as time permits. However, given a choice, it is more important that the information get to the off-post EOC as quickly as possible—within 1–2 min of a release—even if the precise direction of plume movement remains unknown.

7.1.4 Enhancements to the Off-Post ER Infrastructure

Enhancements to the off-post ER infrastructure to support and maintain the SSAS's capabilities require additional development. An ADSS's effectiveness is determined partly by this infrastructure. Although efforts have been made to identify a group of potential off-post users in Harford County and to encompass its concerns, greater effort needs to be expended on identifying the needs of Baltimore County and other off-post communities to exploit the advantages of SSAS-WATCH or, for that matter, the capabilities of another system.

For example, possible acquisition of an ADSS for the Baltimore County EOC to track HAZMATs and assist in DM is under discussion. Some type of responder paging system, such as that incorporated in SSAS-WATCH, is a highly desired feature. Improvements to the off-post infrastructure would require responding to these concerns and would also necessitate development of routine procedures for informing a particular institution of its location in or outside a plume if a chemical release with off-post consequences occurred.

7.1.5 Meteorology and DM

The EOC at Edgewood Area/APG is equipped with a computerized downwind meteorological-data display (a large-screen television). The display is transposed over a map of the installation. Data is fed from six meteorological towers around the post, and from a seventh tower located at the main area of APG. At several-min intervals, wind speed and direction data are plotted and fed to the EOC. A separate backup unit utilizes D2PC to model downwind hazard predictions. This information is not displayed in the map overlay, however. There are no electronic sniffers or other remote chemical detectors deployed around the chemical storage area. There are plans under consideration for the deployment of automatic continuous air monitoring systems to be placed around the perimeter of the chemical storage area. Such devices are capable of detecting small quantities of VX in less than 5 min and GB and toxic stack emissions (from a CSDP incinerator) in less than 3 min. Currently, initial detection of an agent release is provided by two military police who patrol periodically. Finally, there is no full-time on-post meteorologist assigned to the installation. In addition, meteorological towers surrounding Edgewood Area/APG are not regularly calibrated.

7.1.6 Emergency Experience

At APG, CRDEC's long experience in chemical research prompted its designation as the Army Materiel Command's lead agency for development of an ADSS for responding to chemical surety accidents. This research experience led CRDEC to contend that prepackaged software systems for ER were inadequate for rapid response and were not fully able to depict numerous features relevant for accident detection and warning (D. L. Feldman, APG Trip Report, June 2, 1989). Although this view is not necessarily shared by other CSDP sites (D. L. Feldman, PBA Trip Report, July 26, 1989), it has guided efforts to develop decision-support software at APG.

The organization of the EOC at Edgewood Area/APG reflects experience with chemical agents. At APG, the local (on-post) CAIRA plan has four components: alert, control, execution, and deactivation. To implement these components, the EOC is staffed at all times by personnel responsible for functions ranging from traffic control, security coordination, environmental quality, public affairs, medical liaison, and technical liaison to off-post decision makers. Unfortunately, the Edgewood area EOC cannot contact off-post officials directly but must go through Aberdeen area headquarters, an issue discussed in Sect. 7.3.4.

Emergency planners in communities adjacent to APG have had considerable disaster experience. The Harford County emergency-planning director has had emergency-operations experience at the state level, including coordinating statewide response to the Three Mile Island nuclear accident and managing local response to hurricanes. His assistant CSDP planner has served in the Army for 23 years in the emergency-operations area.

The experience of these two planners is reflected in two areas germane to CSDP emergency DM. First, for minor emergencies, defined as relatively routine incidents posing limited hazards, the off-post EOC in Harford County operates as a dispatch center to support field personnel. During more severe emergencies, the EOC serves as an incident-command center directed by the county sheriff, each of whom can direct various agencies and responders in the event of a CSDP accident, as shall be seen in Sect. 7.1.7. This is a pattern preferred by Harford County for off-post incident command in the event of a CSDP agent release with off-post consequences.

Second, Harford County's emergency planners harbor some skepticism regarding the capabilities of ADSSs such as that under development at CRDEC (SSAS). Their concerns involve questions about how expediently such systems are likely to perform in an emergency. Although some of these concerns are prompted by the status of the WATCH system under development at CRDEC, some are prompted by a simple lack of experience in the use of such systems in rapid-onset emergencies. Efforts to assuage these concerns should be undertaken during the further development of ADSSs at APG.

Off-post communities at APG and PBA have had some experience with low-probability, high-consequence emergencies relevant to DM planning in the CSDP. However, even with improvements in the local ER infrastructure as a result of implementation of SARA Title III, CAIRA plans are not completely integrated into chemical emergency-planning efforts at these sites (U.S. Army 1989a).

7.1.7 Hierarchy and Flexibility

At APG, the current structure of on-post hierarchical command and control may impede rapid off-post alert and notification in the event of a CSDP accident, because command and control for off-post alert and notification is provided through an indirect path of communication. CRDEC is a tenant at Edgewood Area/APG and must first notify the main EOC at APG, which, after assessing the magnitude of an incident, notifies off-post communities.

On the other hand, there is potential for flexibility in the event of a CSDP emergency, because county sheriffs in Maryland have considerable authority to command law-enforcement personnel from incorporated and unincorporated jurisdictions within a county. Based in English common-law tradition, this authority permits creation of a temporary ICS during an emergency, with the county sheriff at the top of a hierarchy. Thus empowered, the county sheriff can mobilize a centralized, coordinated response through the county EOC on behalf of all jurisdictions within a county.

7.2 PBA's GENISYS SYSTEM AND ITS INSTITUTIONAL CONTEXT

The emergency-management system at PBA is based primarily on analogue information. Computer systems are used only to process the event log and several types of meteorological data. Plans are being made to increase the involvement of computer systems, but the concept of an integrated EMIS is still new at PBA.

The host computer is a Microvax MV/15000 Eclipse system located in the PBA computer center in the same building that houses the on-post EOC. It is connected to an event log system that is based on a commercially available menu-driven software package. This software, Genisys, was chosen primarily because of its compatibility with the architecture of the host computer. The software vendor, DMS, Inc., provides three other utility packages to the PBA computer center. Other equipment maintained by the computer center are graphics software, spread sheets, office-automation equipment, and special software. This equipment is employed by various departments and offices of PBA but is not an integral part of the emergency-management function. Other functions performed by using this equipment include the routine logging of surety data, on-post law enforcement, and related matters. There is a backup system in case of failure or breakdown of the main computer.

There are 48 ports available for active (programming) users, who may input data or update previously entered information. As is the case at APG, stockpile inventory data is not yet available to the system. Efforts are being made to format such data to make it programmable. Passive (nonprogramming) off-post users can receive updated emergency information if they have been issued proper password commands. The entire system is used primarily as an incident report log. During an emergency, the system would provide status reports on the deployment of emergency forces, casualties, tasks assigned to various response forces, the status of the response actions, and the status of the emergency itself. Sections 7.2.1–7.2.6 evaluate Genisys and its institutional context.

7.2.1 Event Logging and Record-Keeping Security

The Genisys program is paradoxical. On the one hand, it expedites various emergency operations by helping decision makers keep track of events, decisions, and recommended actions. A major advantage of Genisys is the ease with which text can be recalled and edited. Therein, however, lies the paradox: the resulting database does not adequately serve as a verifiable record of decisions, because any individual with normal editing access to the system can easily change entries accidentally or intentionally. The system offers little protection to honest personnel. If personnel were involved in postemergency litigation, they would be unable to prove through the event log the veracity of their accounts of decisions.

Although it is possible to have good editing capabilities while maintaining the security of the database, Genisys lacks these features. The most sophisticated solution to this problem would be to enhance the software so that a record is retained of all revisions to text, permanent records are archived, and security features protect the archive through methods similar to those used by the intelligence community. A simpler, less-demanding (and somewhat less-secure) solution would be frequent recording of backup copies into the possession of a neutral party off-post.

7.2.2 User Friendliness and Off-Post Accessibility

One obstacle facing off-post accessibility of the Genisys system in Jefferson County and the Jefferson County EOC is uncertainty about Genisys's purpose and possible applications. For example, the head of the emergency-services department in Jefferson County reports that, although the terminal allows direct, interactive access to PBA, the equipment is rarely switched on unless PBA suggests there is an apparent need to do so. Greater effort will need to be made to ensure that off-post users understand the system's capabilities and are trained to use it in support of emergency-management functions.

7.2.3 Expansibility and Graphics Support

The potential for expanding emergency-information system and GIS capabilities on the PBA host computer is limited. A significant constraint is the computer center's reliance on Cobol, a computer language better suited for business data processing than for graphics. All graphically oriented systems depend on a body of commercial graphics software that is generally available in FORTRAN C or other languages. A second constraint is the hardware itself—the existing Microvax unit is more than 5 years old. This places the machine in an earlier generation of architecture that cannot adequately support graphics functions. Very little graphics software exists for the Microvax.

According to PBA, although a decision-support system with graphics support would be desirable, the current CRDEC ADSS is viewed as having more problems than advantages for PBA's purposes. It cannot depict dose exposures to actual accident distances but only to the 1% no-deaths distance assigned as a category by D2PC. However, it is contended by PBA that the CRDEC system's graphics support capabilities (especially as regards the depiction of mass care centers and other information) could be useful if it were tied to another system that depicted accurate meteorological information.

Thus, consensus exists that a GIS is needed, even though its particular features are subject to debate.

7.2.4 Meteorology and DM

The meteorological program at PBA is impressive both for the amount of information available and the automated mechanisms designed to integrate the information. PBA has an elaborate, well-equipped, technically sophisticated meteorological station. It is staffed by a meteorologist who can interpret and relay the data to points of contact in an emergency. The center's operator controls several systems housed in a room adjacent to the EOC. These systems involve:

- constant, direct feed from the National Weather Service (NWS) national headquarters, by both teletype and facsimile;
- constant, direct feed (including passive radar display allowing for the freezing and updating of radar images) from the NWS at Little Rock Airport;
- constant, direct feed from 7 meteorological towers located on the perimeter of PBA (5 of the towers monitor data at 3 levels every 15 min) that is displayed as a graphic image depicting site boundaries and met tower locations;
- an on-post lightning sensor that can depict strike frequency on a map of PBA and vicinity;
- an air-diffusion model (D2PC) that is run on an 80386 microcomputer; and
- severe-weather data (via Little Rock and Fort Smith airports).

The on-post meteorologist accesses Genisys for updating forecasts and communicating them via electronic mail to off-post officials in Jefferson County. Also, data is recorded into a permanent data archive file.

The biggest drawback to the system is that little data transmission occurs among the various meteorological functions and the Genisys event log. Each of the systems is operated independently of the others, with different command languages and operating procedures. There is a pressing need for an automated mechanism to integrate meteorological information with other emergency information. Aggregate meteorological data from the met station is currently fed to the system once each h by the base meteorologist and is displayed in a textual format. From the standpoint of rapid DM, the system cannot display a real-time depiction of a plume. This problem is exacerbated by the absence of a graphics-support capability, which reduces ability to utilize the very large amount of useful information displayed on various terminals within either on- or off-post EOCs. For example, despite the fact that the Genisys system has been installed off post at the Jefferson County EOC, during inclement weather conditions, the PBA meteorologist must phone information to the off-post emergency manager.

Finally, it is uncertain how HOTMAC would interface with present equipment. PBA has been tentatively selected to be the test user of HOTMAC. The on-post meteorologist is concerned that the Sun work station, which is a very large, expensive computer required to operate HOTMAC, would further restrict already-limited work space.

7.2.5 Emergency Experience

Attempts to integrate on- and off-post command, control, and communications and to promote enhancements to off-post ER were prompted in part by a BZ igloo fire in the 1960s. Moreover, after public concerns with off-post consequences of the CSDP began to be raised at Lexington–Blue Grass Army Depot in the early 1980s, PBA began a program to educate the greater Pine Bluff community on the potential risks of chemical demilitarization (D. L. Feldman, PBA Trip Report, July 26, 1989). Consultants were hired to perform hazards assessments, evaluate competing meteorological models for use in emergency DM, and to conduct engineering analyses of BZ agent disposal.

Attempts were made to ascertain the parameters of a maximum credible event. Independent estimates of accident scenarios under different meteorological stability conditions were also made. A briefing package on emergency preparedness was assembled for local communities. Finally, with the concurrence of state and local officials, a 50-km ER zone was selected for planning purposes, and an off-post emergency-training program was begun. The latter was prompted by concerns that off-post officials needed a greater understanding about CSDP accidents that could have off-post consequences and by fear that some on-post accidents could simply overwhelm PBA's internal response capabilities.

Although this experience has proven fruitful for promoting enhancements to emergency DM, there are gaps in the implementation of these enhancements. These gaps result from PBA's limited disaster experience and are exemplified by problems with PBA training programs for off-post HAZMAT responders. PBA training is offered to state and local responders and PBA participates in state and local HAZMATs training workshops. (Consideration is being given to ER training for local prison officials as well.) Although training has doubtless proven useful for enhanced emergency preparedness in the PBA area, it has not utilized established training programs offered by FEMA that could help set standards for certifying the quality of the course content and comprehensiveness of curriculum. In addition, no formal guidelines for retraining and refresher classes have been established.

The views of off-post officials on how DM for CSDP ER in the PBA area should be initiated have been shaped by disaster experience. A 1985 train derailment that caused a major chemical spill prompted Jefferson County to adopt (1) reliance on the organization in charge of the emergency for information, recommendations, and guidance on protective actions (the railroad, in the 1985 case) and (2) a preference for adjusting established ER procedures to the situation at hand rather than adopting entirely new procedures. These established procedures include gathering input from all communities and agencies affected by an emergency to encourage consensus DM.

One aspect of these off-post procedures that would appear to require greater attention from the standpoint of rapid DM, and for which past experience has provided little guidance, is that of domain consensus, which is discussed in Sect. 7.3.1 (Dynes 1978; Kreps 1978). Response to the 1985 train derailment was confined to a fairly small area. Not only did responders have considerable time to respond to the incident, but overlapping of functions did not pose a problem. This may not be true in a CSDP emergency.

7.2.6 Hierarchy and Flexibility

On-post officials have long been concerned with hierarchical command and control and organizational flexibility. A civilian engineer has been designated as assistant on-scene coordinator and is responsible for recommending protective actions to off-post communities in the event of a CSDP emergency. This is a departure from usual procedure at CSDP sites, which presumes that the commanding officer will be in charge of issuing warnings. The rationale for investing a civilian with this responsibility was the assumption that he or she would have greater rapport with civilian officials than would a military officer (D. L. Feldman, Trip Report, PBA, July 26, 1989).

It is not entirely clear, however, precisely what role this individual would play within the context of on-post chain of command. For example, would the assistant on-scene coordinator have authority to recommend protective actions to off-post officials or only to the on-post commander, who would then issue the warning? The effectiveness of this role for rapid response depends on clarifying such notification responsibilities (Dynes 1978; Dynes, Haas, and Quarantelli 1967).

7.3. INSTITUTIONAL ISSUES COMMON TO APG AND PBA

7.3.1 Role Specificity

At APG and PBA, cooperation among more than one LEPC is necessary for effective planning and allocation of responsibilities. In Maryland and Arkansas, LEPCs are organized on a county-wide basis. However, Emergency-Planning Zones (EPZs) adjacent to CSDP sites in both states encompass several counties. LEPCs in counties adjacent to both sites have already displayed an active interest in chemical-emergency planning. In Jefferson County, Arkansas, and Harford County, Maryland, positive efforts have been made to incorporate relevant PBA and APG personnel on LEPCs.* Chemically related munitions incidents at APG are now routinely relayed to LEPC members at APG; at PBA, installation representation on the LEPC as well as chemical response training offered to off-post agencies by PBA has helped build a base of trust.

Efforts to ensure domain consensus at APG and PBA have been far more problematic. Program guidance for ER in the CSDP, as well as the current CAIRA manual, suggest that on- and off-post law-enforcement procedures may need to be integrated for some emergency scenarios. Instances are contemplated in which off-post law-enforcement personnel may have to be recruited for on-post security in the event of a major CSDP accident. At PBA, this scenario has been an important motive for the training of off-post responders (D. L. Feldman, PBA Trip Report, July 26, 1989), as noted in Sect. 7.2.5. During a full-scale exercise at PBA held in June, 1989, information flow among off-post responders tended to be slow because of confusion over responsibilities (D. L. Feldman, PBA Trip Report, July 26, 1989).

Likewise, at APG, the interface between Edgewood area/APG and the off-post point of contact in Harford County is still under development. It is CRDEC's expectation that any and all emergency-related information would be shared with off-post officials in

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*Two of 12 LEPC members in Harford County, Maryland, represent APG, and 3 of 64 LEPC members in Jefferson County, Arkansas, are from PBA.

the event of a chemical-agent release with off-post consequences (D. L. Feldman, APG Trip Report, June 2, 1989). However, this expectation raises a number of questions concerning what jurisdictions would be responsible for which duties and to what degree security responsibilities can be shared among the installation and local communities.

Other authority and responsibility issues require further clarification. Will off-post personnel be permitted to monitor the health and environmental impacts of an emergency that is contained on post? Will police, fire, and other personnel in local communities adjacent to CSDP installations have to become familiarized with the layout of CSDP facilities and the properties of CSDP HAZMAT's to enter CSDP facilities? Although such arrangements exist in similar contexts in other programs (for example, the Oak Ridge, Tennessee, fire and police departments have access to information on hazardous-waste sites provided for Department of Energy facilities in that community), to what degree might this require compromising sensitive or confidential information in the case of the CSDP?

7.3.2 Routes for Rapid Off-Post Alert

After determination that a threat from a chemical-agent release at APG or PBA is significant, a decision must be made as to whom to notify and alert and what type of protective actions to recommend. As good as ADSSs may become, unless the pathway for DM among on- and off-post officials is clear, the information ADSSs provide will be limited (Mileti, Sorensen, and Bogard 1985).

Decisions pertaining to warning, notification, and protective action would be driven partly by information about an approaching plume—its speed, direction, and source term—and the quantity of agent released. After this information were derived, it would be necessary to decide whom to involve in the formulation of a decision to warn, what information to relay off post, and exactly whom to notify. There are two broad sets of uncertainties in these decisions that must be resolved: the character of the plume and the pathway for making decisions. APG typifies both sets of uncertainties.

The current emergency-notification procedure at Edgewood Area/APG represents an uncertainty involving the pathway for DM. Following detection of a CSDP incident at Edgewood Area, incident information such as source term data and meteorological conditions would be channeled into the EOC in CRDEC's headquarters. Emergency-status information would then be combined with other data regarding the disposition of response forces and the availability of resources. After processing this information, the Edgewood EOC is supposed to report the incident to a higher-level point of contact at APG headquarters.

It is the responsibility of APG to further assess and characterize the hazard, to formulate a response, and to notify the Harford and Baltimore county EOCs, which would in turn contact institutional populations, warn other off-post populations, and establish incident commanders to take charge of off-post response (D. L. Feldman, APG Trip Report, June 2, 1989). The requirement that emergency information at Edgewood be channeled through APG before reaching Harford County is a potential problem acknowledged by CRDEC, Harford County emergency planners, and by a community study of the CSDP (D. L. Feldman, APG Trip Report, June 2, 1989). One reason for this procedure is that CRDEC is a tenant at Edgewood and must itself request that the APG chain of command grant approval of decisions.

At PBA, on-post officials have long been concerned with reducing uncertainties pertaining to the character of a plume as well as the pathway or decision following an accident. After assessment and characterization of an emergency involving the CSDP, the PBA EOC would notify off-post local officials as well as the state of Arkansas' EOC in Conway (Schneider Engineering 1989a). Off-post command and control, as well as the details of on- and off-post relationships, however, are not as clearly specified. For example, the 1985 CAIRA plan for PBA contains only brief references to off-post activities, does not address the procedures for DM that must precede off-site notifications, and does not discuss off-post coordination of ER (Schneider Engineering 1989a). Moreover, although the Jefferson County Office of Emergency Services has been designated the lead agency for coordination of off-post response, it shares this responsibility with the state of Arkansas.

Grant and Jefferson counties have an agreement specifying that, in the event of a CSDP emergency, the former is automatically a part of the IRZ. Thus, response actions by both counties would be initiated simultaneously (D. L. Feldman, PBA Trip Report). For other counties in the 50-km EPZ, however, procedures for notification and alert are less clear. Although the Office of Emergency Services is charged with the responsibility of notifying adjacent counties in the 50-km EPZ, its understanding is that it should first contact the Arkansas EOC at Conway, which would then notify other counties as appropriate. Although acknowledging that the alert process could be accelerated as needed, requiring that the state be notified first could prevent timely warning of outlying counties.

Other on- and off-post procedures at APG contribute to decision-pathway uncertainty. After a period of trial and error, Harford County and APG have developed a memorandum of understanding (MOU) that permits a wide sharing of resources, information on special populations, facilities, and equipment. The MOU also designates incident commanders (one at APG and one in Harford County), who share responsibility for coordinating on- and off-post command and control. It is Harford County's understanding that in the event of a CSDP emergency, the on-post incident commander at APG would be in charge of alert and notification and would recommend protective actions. The off-post incident commander would then implement recommended protective actions and supervise the formulation of other response decisions.

The off-post incident commander is an elected official (the county executive). However, it is expected that during the immediate response stage, incident command would probably fall to the chief of the Joppatowne fire department or to a substitute. In all cases, the incident commander would have "full authority over ER operations at the scene" (Schneider Engineering 1989c) and would operate out of Harford County's EOC, which is located in Hickory, approximately 18 km north of the Edgewood area boundary and 18 km northwest of APG. Additional clarification of the relationship between the on-post incident commander and his or her off-post counterpart is needed.

7.3.3 Communication Among On-Post Responders

At APG, immediate voice communication is provided between the CRDEC/EOC and decontamination/detection personnel (the first responders to a CSDP chemical-agent release) by way of radio and telephone. At present, neither system provides secure communication. This means that members of the off-post public conceivably could monitor information on an unfolding emergency at APG, before an official bulletin is released to the public, by monitoring police scanners and similar equipment (D. L. Feldman, Trip Report, APG, June 2, 1989). Unsecured communications could result in rumors being fueled by a few listeners who could not accurately assess the implications of information they heard.

At PBA, secured communication is provided between first responders and the EOC through both fixed and mobile systems. A mobile command center, recently purchased by PBA to provide communication and working space for staff support from the arsenal as well as from Jefferson County, can connect with commercial and radio telephone systems while in the field (D. L. Feldman, Trip Report, PBA, July 26, 1989).

Although considerable thought has been given to rapid communication among on-post responders during a CSDP emergency at APG and PBA through the integration of communications equipment, greater thought needs to be given to the kind of information broadcast via communications equipment, the allocation of communications equipment to designated personnel, and the assignment of special operating frequencies (Irwin 1989). Clear text, or plain language, should be used whenever possible for rapid interface with less-knowledgeable off-post responders and novice on-post personnel (U.S. FEMA 1987).

7.3.4 Communication Among Off-Post Responders

At APG, off-post officials have stated a need to communicate directly with on-post EOC officials through dedicated phones, computers, and facsimile links, and with each other through an interactive network among county EOCs (D. L. Feldman, APG Trip Report). At PBA, off-post communications problems have been singled out for special attention by off-post officials. These problems are attributed to lack of understanding among agencies as to what each of their respective responsibilities would be in an emergency.

Although the responsibilities of off-post responders at PBA are clearly defined in the CAIRA plan for Jefferson County, an emergency exercise in June 1989 revealed that information flow among off-post responders tended to be too slow for timely response in the event of a CSDP chemical-agent release with off-post consequences. A principal cause of this slowness was that many responders were unclear about the tasks assigned to other agencies and often assumed that tasks they were supposed to manage were being managed by someone else. Conducting cross-training sessions, in which responders representing different emergency functions are given the opportunity to learn about each other's responsibilities, has been suggested as one solution to this communication problem.

7.3.5 Communication Among On- and Off-Post Responders

As noted in Sect. 6.1.4.2, communication among on- and off-post responders during a CSDP emergency would be constrained by considerations of security surrounding the chemical stockpile's size at APG, PBA, and all other CSDP sites. These constraints may affect the confidence off-post officials have in on-post instructions following a CSDP agent release. At APG and PBA, on-post officials have acknowledged the importance of these issues for emergency command and control. CRDEC officials have suggested that, in an emergency, nothing will remain classified (D. L. Feldman, CRDEC, APG Trip Report, June 2, 1989). At PBA, a more modest approach has been suggested. A figurative "tearing down of the installation fence" would take place to ensure that on- and off-post responses are parallel (D. L. Feldman, PBA Trip Report, July 26, 1989). This would be accomplished by ensuring that PBA public-affairs officials would be available to advise off-post officials.

There are potential inconsistencies between these installation policies and official U.S. Department of Defense (DOD) policy. Under DOD's voluntary compliance with SARA Title III, the Army has agreed to report to LEPCs and State Emergency Response Commissions chemical incidents that have the potential for off-post consequences. At the same time, however, DOD has stated that it cannot comply with SARA Title III Sects. 311 or 312, which require reporting the types and quantities of chemicals stored, handled, trans-shipped, or destroyed on site *before* an emergency (Schafer 1987). The conflicting responses of DOD to parts of SARA Title III presents an important quandary because, as seen in Sect. 6.1.4.2, some CSDP states prohibit off-post responders from entering the scene of a chemical accident unless SARA Title III Sects. 311 and 312 data are made available to state and local officials. Some compromise between standard Army security practices and state risk-communication laws on the other may be necessary to facilitate timely off-post response.

7.3.6 Communication Among On- and Off-Post Responders and the General Public

Plans are underway for development and site selection of JICs or JIBs at APG and PBA. These JICs and JIBs must be located outside the IRZ and must be able to accommodate a large number of reporters.

Most of these issues hinge on inconsistencies at APG and PBA in the handling of emergency information designed to be released to off-post officials and the mass media. Because the inconsistencies pertain to rapid warning and notification, they are discussed in detail in Sect. 7.3.7. Two problems of inconsistency are (1) the assumption at PBA that those counties outside the IRZ (e. g., Jefferson and Grant) need only be notified of a CSDP agent release after it has been determined that the release is likely to extend beyond the IRZ, despite questions pertaining to the adequacy of time for taking preparatory actions in the PAZ and (2) provision in the APG schema for notification of the news media during the early stages of a release, even though procedures for notifying PAZ officials are less explicit.

The nature of information that would be communicated to the public in the event of a CSDP release also remains to be made explicit in warning notification systems at APG and PBA. Finally, as noted in Sect. 6.1.4.5, the consultation process should include discussions about the type, character, and format of the information to be released to the press and the public. This is likely to enhance trust in communications pertaining to a CSDP emergency (Slovic, Fischoff, and Lichtenstein 1981). At APG and PBA, on- and off-post officials are actively seeking to utilize local ICCBs as fora for exchanging information about the CSDP. In addition, the CAIRA manual suggests that CSDP installation commanders should meet periodically with members of the community to answer questions about chemical operations. Such meetings may also provide a means of addressing the need to consult state officials, noted in Sect. 6.1.4.5. Consultation with state officials through ICCBs may obviate the need for accommodation of requests to be seen at the site of a CSDP accident since complications entailed by such requests will be better understood.

7.3.7 Rapid Warning and Notification

Another problem common to APG and PBA pertains to rapid notification and warning. APG and PBA have taken the notification classification schema recommended by the current CAIRA manual, designed for use at all CSDP and other Army HAZMATs sites, and employed it as a point of departure for developing their own systems. At APG, a fourfold emergency-classification system is in use. At PBA, the emergency-classification system contains six levels of alert (Schneider 1989d). At both sites alert levels vary with the severity of the release and meteorological conditions. There are distinct advantages and disadvantages in the APG, PBA, and CAIRA incident level schemata, but all three have potential problems (see Table 3.1).

Specific pathways for alert and notification remain unclear, the character of recommended protective actions is unspecified under all three systems, and there are inconsistencies regarding which off-post officials should be alerted and when (see Table 3.1). On this last issue, while all three schemata provide for relatively early notification of officials within the IRZ, there are differences in provisions for contacting PAZ officials. The CAIRA manual recommends "widespread notification" of PAZ officials from the time it is determined that a chemical release may extend beyond the storage area but is thought to be confined on site. This is to allow PAZ officials adequate time to prepare to establish processing or decontamination posts, set up a JIC, or receive evacuees from the IRZ. It is also designed to allow for early, effective rumor control within the PAZ.

PBA's scheme, however, presumes that adjacent counties (areas outside the IRZ counties of Jefferson and Grant) would need to be notified of a CSDP agent release only if it were determined that the release would likely extend beyond the IRZ. This may not give PAZ officials adequate time to take the kinds of preparatory actions discussed above, particularly because PBA's CAIRA plan provides for an elaborate system of evacuee processing and decontamination at the boundary between the IRZ and PAZ. In addition, PAZ officials are likely to discover that an event has occurred through monitoring police communications.

The APG schema implies that a PAZ alert should be geared to the severity of a chemical-agent release, much like that of PBA. However, while APG's schema explicitly allows for notification of the news media during the early stages of a release, procedures for notifying PAZ officials are less explicit. This is a potential inconsistency in policy, because after the media were alerted, even on a precautionary basis, widespread dissemination of information about the incident would likely reach the PAZ anyway.

Classification of accidents also varies widely among the three schemata. Although the CAIRA manual's classification schema provides general guidance, APG's schema is imprecise regarding off-post responsibilities following a release. Finally, PBA's schema appears to presume a greater level of precision concerning accident characterization than current ADSSs can provide (see Table 3.1).

8. RECOMMENDATIONS FOR IMPROVING DM AT APG AND PBA AND APPLICATIONS TO OTHER CSDP SITES

In this section, we outline the components of a total DM system design by summarizing major concerns from site visits, recommending changes in institutional procedures to enhance timely warning and response, and suggesting guidelines for the development and acquisition of ADSSs.

8.1 SUMMARY OF CONCERNS FROM SITE VISITS

At APG, enhancement of rapid DM capabilities will need to focus on (1) improving graphics display structures, (2) improving inventory database development and augmenting staff size, (3) improving off-post interface and enhancements to off-post infrastructure, and (4) more fully integrating meteorological capabilities into the DM system. The latter will require hiring a full-time on-post meteorologist and ensuring regular calibration of meteorological towers.

At PBA, enhancement of rapid DM capabilities should focus on (1) promoting event logging and record-keeping security, (2) creating a direct interface for meteorological data within the ADSS, (3) resolving uncertainty about the purpose and possible applications of the ADSS for off-post officials, and (4) improving the potential for emergency information and geographic information display capabilities on the PBA host computer.

Finally, at APG and PBA, efforts should be made to improve the pathway of DM from on-post decision makers to off-post points of contact. The requirement that emergency information at Edgewood be channeled through APG before reaching Harford County can be rectified. Likewise, the alert process at PBA could be accelerated considerably by eliminating the required middle link, the Arkansas EOC at Conway, in off-post communication among PBA and outlying counties.

8.2 RECOMMENDED INSTITUTIONAL ENHANCEMENTS

The principal obstacle to improved command and control for ER is the enormous potential complexity of the affected environment after an accident. To improve command and control at APG, PBA, and other CSDP sites, it is best to begin by enhancing procedures that already work effectively and by discarding or significantly modifying those procedures that are not effective. In this synergistic fashion, CSDP sites may learn from past deficiencies (Comfort 1988). In summary, we recommend the following institutional enhancements.

8.2.1 Provide Off-Post EPR Training to Hasten Response

- Design training programs to ensure standardized, integrated emergency response by on- and off-post responders.
- Certify that responders have met certain standards of quality and comprehensiveness of curriculum as appropriate to their functions.
- Establish formal guidelines for retraining and refresher classes.

- Make available cross-training sessions in which on- and off-post responders representing different emergency functions are thoroughly exposed to one another's tasks to better ensure domain consensus.

8.2.2 Simplify the Pathway for Alert and Notification Among On- and Off-Post Officials

- Allow direct on- and off-post communication among the Edgewood Area EOC and Harford and Baltimore counties for alert and notification in the event of a CSDP emergency. At other CSDP sites, ensure that the EOCs in charge of monitoring the chemical stockpile have direct communication links with off-post officials and have the authority to warn.
- Urge a clarification of off-post community notification procedures at PBA by eliminating the requirement that warnings go through the state EOC at Conway. If appropriate, implement a similar procedure at other CSDP sites.
- Establish procedures for prompt notification of Local Emergency-Planning Committees and State Emergency-Response Commissions throughout PAZ counties.

8.2.3 Continue to Integrate On- and Off-Post Communications Systems

- Assign communication systems to designated personnel and ensure their operation on pre-assigned frequencies. Avoid communications systems for emergency use that are radically different from those intended for everyday, routine use.
- Use clear, uncoded text or plain language for emergency communications among on-post personnel and among on- and off-post emergency responders to hasten understanding of the magnitude and character of the emergency. Use this clear text every day.
- Use dedicated, secure means of communication to discourage public monitoring of transmissions and the fueling of rumors.
- Resolve potential inconsistencies among APG, PBA, and DOD policies on the sharing of information with off-post communities during an emergency. In particular, consider ways that CSDP states can quickly obtain SARA Title III Sects. 311 and 312 data to allow off-post responders to enter installations, if needed.

8.2.4 Refine Emergency-Notification Schemata to Ensure Clarity Concerning Recommended Protective Actions and to Identify Whom Should Be Warned

- Use clear terminology easily understood by all jurisdictions and ER disciplines for identifying resource elements and facilities, delegating management authority, and ensuring uniform planning for different contingencies.
- Avoid terminological differences among agencies that are likely to result in different patterns of operation and response. Ensure absolute clarity of understanding among on- and off-post officials as to what each warning category means and what it requires officials to do.
- Avoid alert classifications that assume greater precision in accident characterization than is possible through the use of ADSSs.

8.2.5 Develop Public Information Programs that Enhance Trust and Confidence in Army Command and Control

- Develop a consultation process with communities and the mass media about the type, character, and format for information to be released to the press and the public through JIBs and JICs.
- Explore the possibility of periodic meetings between CSDP installation commanders and communities to answer questions about chemical operations and to ensure confidence in warning and alert systems.
- Consider needs for a wider network of consultation with state officials following a chemical-agent release to ensure the legitimacy and acceptability of Army command and control in off-post areas.

8.2.6 Recognize the Roles of Hot and Cold Reasoning, Judgment, and Intuition in Emergency DM

- Recognize that linear reasoning is logical and digests facts in an orderly manner, whereas hot reasoning is more effective at bringing to bear important values that are essential for evaluating the consequences of rapid-onset emergencies.
- Recognize that information generated by ADSSs may overwhelm decision makers unless it can be quickly prioritized and placed into perspective relative to the immediate needs at hand.
- Avoid reliance on a formal, fixed set of procedures dictating how to respond under certain accident scenarios.
- Because persons who have good judgment and intuition tend to make good decisions in an emergency, select experienced personnel who have developed these qualities for high-level DM roles.

8.2.7 Manage the Problem of Bounded Rationality Within the EOC by Encouraging Different Specialists to Work Together

- Provide EOC staff with means to convert general, abstract, intractable problems such as saving lives or minimizing property loss into specific, tractable ones that can be analyzed and segmented further for exercise and readiness-assessment purposes.
- Define ER goals in tangible and, if possible, quantifiable ways, such as by moving a certain number of responders into an area, evacuating people from the IRZ within a specified period of time, and so on.
- Encourage the input of diverse points of view and ranges of experience within the EOC while at the same time minimizing the number of people participating in DM during the emergency.
- Pair different specialists to work on selected pre-emergency tasks such as communications, logistics, or planning to help ensure domain consensus within the EOC.
- Avoid personnel complacency and maintain high levels of personnel readiness for rapid-onset emergencies by establishing mechanisms for administrative feedback. Require lower-level personnel to keep a log of activities to identify and correct problems or grade deficiencies.

8.2.8 Anticipate The Possible Effect of Stress on Accident Containment, Rapid Response, and Mitigation

- Monitor work loads of CSDF personnel and EOC personnel, especially during periods when accidents caused by errors in human judgment are more likely to occur (when the facility is started up or shut down, for example).
- Provide detailed procedures to enhance operator performance and DM in the presence of conflicting information. Ensure that emergency information is depicted in a clear, useable format.
- Promote stress-compensating measures such as special training and drills to establish a proper mental set, effective displays of critical information in the EOC, and special procedures compatible with restricted cognitive and problem-solving capabilities. Provide training in stress and its effects.
- Train EOC supervisors and other incident-command personnel to be aware of personality factors likely to cause stress.

8.2.9 Using the ICS Model to Develop an Effective Protocol For Integrating On- and Off-Post DM

- Build on established ER protocols and methods of interjurisdictional assistance in developing an ICS. In the case of APG, use the authority of county sheriffs as a point of departure for integrating off-post command and control. In the case of PBA, urge Jefferson and Grant counties to take the lead in developing an ICS-type system by building on protocols used in other emergencies.
- Adopt an optimal span-of-control system (3–7 people per responsible individual) to allow each emergency responder to concentrate on a primary assignment and not be distracted by other responsibilities. This recommendation can be adopted even without subsequent adoption of a complete ICS.
- Consider strategies for communities to make in-kind contributions to an integrated ER system.
- If a full-blown ICS-type system proves too difficult to establish, explore ways to identify potential off-post organizational problems likely to slow coordinated response. Also, encourage the assignment of specific responsibilities to minimize overlap and confusion, and encourage rapid mobilization of emergency resources.

8.3 RECOMMENDED ENHANCEMENTS TO ADSSs

8.3.1 Working Toward a Common Solution

We recommend that a single hardware and software solution be adopted as a common base for the emergency-management system at all eight CONUS CSDP installations. Arguments favoring a common solution are compelling. The overriding factors are cost, compatibility, and perceived equity across sites. The most likely candidates for immediate deployment are a combination of currently available commercial and public-domain systems. Future developments are likely to be more cost effective if efforts are directed toward a single software package and a single hardware architecture. Specific recommendations follow in Sect. 8.3.4.

Even for the near-term purchase of commercial hardware and software, however, there may be a cost advantage in negotiating bulk procurement of numerous systems from a single vendor. Also, there are cost advantages in training all on- and off-post operators for a common system, and there are also advantages in achieving training objectives.

Compatibility is important from the standpoints of cost and of functional utility. By sharing software and data among common systems, costs are less than they would be if software and data were being combined from different systems. Advancements from one system to another also result in cost advantages. As for functional utility, data and software can be shared rapidly without conversion.

8.3.2 Phased Development

It would be advantageous to adopt ADSSs that draw on the lessons, experiences, and applications of models developed for the U.S. armed forces in other contexts because (1) such models have had time to be proof tested and debugged, if necessary, and (2) U.S. armed forces' experiences provide a standard for comparing advantages and disadvantages of newer systems.

The ideal EMIS does not exist in commercial or public-domain offerings. However, some available systems are designed to handle a large portion of the ER requirements of the CSDP. We therefore recommend a phased approach to systems development and implementation to meet long and short term program needs:

- Adopt an EMIS for immediate deployment at CSDP sites—a Phase I effort.
- Enhance particular aspects of this Phase I system that could be improved with minimal effort and expense.
- Simultaneously undertake design, development, and testing to improve long-term capabilities of the system deployed—a Phase II effort. This Phase II effort should avail itself of the features offered by the Phase I system. However, it may be substantially different in concept.
- As consensus on needs and capabilities develops and as resources become available, a transition from the Phase I system to Phase II should be made.

8.3.3 Off-Post Linkages

We recommend telecommunications linkages and automated systems to support the rapid coordination of on- and off-post response. In general, these systems should mirror the institutional linkages and information exchanges presently in place between APG and PBA (and, respectively, Harford and Baltimore counties, the state of Maryland, Jefferson County, and the state of Arkansas). This will require rugged remote workstations in off-post locations with dual (voice/data) communication capabilities. Telecommunications would vary from site-to-site depending on distances of communities to installation, current telecommunications infrastructure, type of data-processing systems already deployed, and other factors.

Distributed information systems will require careful consideration and development of protocols regarding control over systems and databases. A database should be agreed on by on- and off-post emergency managers. Key on-post officials, as well as off-post officials in the IRZ, should be authorized to process, analyze, and alter this database. Actual users in the PAZ and beyond should be permitted to analyze but not alter this database unless compelling reasons dictate otherwise. Other nonuser agency officials in the PAZ and beyond may be authorized to passively view the results of analyses but should not be permitted to run the software without authorization from officials who are permitted to do so. A set of protocols implemented through control procedures in the hardware and software should permit sharing selected information immediately with organizations that need to have access to it for timely response. This protocol should be predetermined, and variance for unique community situations needs to be taken into account.

8.3.4 Evaluation and Recommendations

The first priority at CSDP sites should be to install a working system as quickly as possible. Waiting for the perfect ADSS is not viable. This would extend the period of vulnerability for on- and off-post populations and reduce the likelihood of a timely warning and response in the event of a chemical-agent release posing potential off-post consequences. Although commercial and public-domain systems available today are imperfectly suited to the needs of the CSDP, they represent a significant improvement over the current automation support available at APG and PBA. Current systems, employed correctly, would facilitate response 5–10 min after accident detection.

We recommend (1) rapid deployment of the best available technology and (2) simultaneous development of advanced systems oriented toward specific CSDP needs. These systems should be developed and deployed in a phased program based on manageable increments of best available technology to make optimal use of limited resources; to ensure adequate time for training, proof testing, and equipment debugging; and to address urgent DM needs.

We recommend the following steps:

- Development of an On-post EMIS

  –Select and install the best available EMIS system at the eight CONUS CSDP sites as soon as possible. It is imperative that procurement of hardware and software systems be coordinated and linked to ensure compatibility.

  –Hardware specifications for the near-term computer platform should include the following:

    Total cost of central processing unit (CPU) and peripherals should be $20,000 or less.
    Processing speed should be 25 MHz or greater.
    Operating system should be compatible with one or more of the applicable EMIS software packages.
    Memory should be 4 MB (or greater) of 32-bit random-access memory (RAM).
    Fixed disk storage should exceed 100 MB, with an average access time less than 25 MB.
    Local area networks (LANs) and telecommunications should be supported, but each workstation must be capable of working primarily as a stand-alone system without dependence on host machines or telecommunications links.

–EMIS software specifications for the near-term system should include the following:

Map and floor plan digitization support must be available through software, contractual arrangements, or both.
The software must support an inventory database and rapid retrieval system for chemical stores, including materials in transit.
The database must include RDS-type data for all chemical agents, and the software must support rapid retrieval, editing, and updating of such data.
Graphics capabilities must support rapid display of maps and floor plans.
Software must support rapid access to air-diffusion models and rapid display of air-diffusion plumes.
Software must support a viable geographic coordinate system referenced to latitude/longitude.
Software must support a variety of data screens that may include such items as emergency contacts, special emergency needs, and emergency resources.

Based on the above specifications we, recommend adoption of EIS/C or CAMEO for the Phase I system, beginning with immediate deployment at APG and PBA. Of 40 systems evaluated (see Appendix C), these 2 were found to meet these specifications and to have the most comprehensive list of features, including HAZMATs data storage and retrieval, emergency management, and display functions essential for timely warning, notification, and DM (see Tables 5.1 and 5.2). The principal shortcoming of EIS/C and CAMEO is in the area of geographic information processing. This deficiency will need to be rectified if they are to meet long-range needs at CSDP sites.

A summary of the reasons for selecting EIS/C and CAMEO is as follows:

–Of the systems evaluated in Table 5.1, EIS/C and CAMEO provide the most complete list of features that are compatible with personal computer systems in the hardware cost range specified above.
–EIS/C and CAMEO contain reasonably complete databases of RDS records that serve as a foundation for inclusion of CSDP source terms.
–EIS/C and CAMEO are compatible with microcomputer hardware systems currently in use and are readily available through existing procurement networks such as Comprehensive Coordinated Agreements negotiated by FEMA, NOAA, and state and local governments.
–EIS/C and CAMEO are menu-driven systems, designed for ease of use by nonprogrammers, such as off-post emergency managers, who are less likely that on-post users to be experienced with computer systems.
–EIS/C and CAMEO accept the output of atmospheric-dispersion models and can be modified to accept others.
–EIS/C and CAMEO include inventory DBMSs.

• Selecting and Installing EMIS for Emergency Coordination, Planning, and Recovery

We recommend selecting and installing an EMIS for key agencies involved in emergency coordination, planning, and recovery activities. It is imperative that the purchase of hardware and software systems be coordinated and linked to ensure compatibility with on- and off-post rapid-response systems.

–Hardware specifications for the computer platform should include the following:

Total cost of CPU and peripherals should be $80,000 or less.
Processing speed, memory, and fixed disk storage should exceed those specified for the on-site EMIS.
Operating system should be compatible with one or more of the applicable EMIS coordination, planning, and recovery systems.
LANs and telecommunications should be supported.

–Coordination, planning, and recovery system software specifications should include the following:

Map and floor plan digitization support must be available through software and through contractual arrangements.
Graphics capabilities must be able to support rapid display of maps and floor plans.
Software must be able to support access to air-diffusion models and display of air-diffusion plumes.
Software must be able to support rapid access to transportation and evacuation models.
GIS software must be able to support a viable geographic coordinate system referenced to latitude/longitude.

FEMA's IEMIS is suggested as a candidate system for coordination among federal and state agencies. IEMIS is a public-domain system designed to facilitate coordination among federal agencies, states, and regional emergency-management organizations. Its principal strength is in the large number of spatial databases that can be accessed at the federal level. Its strongest analytical components are the atmospheric dispersion and transportation evacuation model.

Current capabilities include text processing, electronic mail, database development and management, file management, business graphics, and access to meteorological data. The system supports interactive color display and editing of an extensive map database that forms the background images for model 63output. Current models are primarily oriented toward radiation incidents. However, its graphics functions and many of its databases would be of generic interest to the CSDP (U.S. FEMA 1986).

The system and hardware configuration (VAX minicomputers) are not well suited to the on-post, real-time response needs of the CSDP but may serve the CSDP's operational requirements for interagency coordination, planning, and recovery in the event of a CSDP accident.

- Development of an Advanced EMIS

Initiate a program to advance the state of the art in EMISs to meet the specific needs of CSDP. In working with the CSDP, Oak Ridge National Laboratory will develop a list of recommendations for future development. These recommendations may include, but are not limited to, the following:

–improved GIS software and data structures capable of representing geometry, topology, and attributes in a unified system;

–improved methods of digitizing maps and floor plans including advanced scanning technologies;
–improved methods for continuous, automated input of meteorological data;
–improved systems for monitoring materials in transit and in chemical demilitarization processing;
–improved telecommunications and more-rugged equipment for mobile and off-site workstation access and linkage to other agencies;
–advanced hardware systems, including computer platforms based on parallel processing, and advanced storage systems;
–an expert system, based on artificial intelligence, for identifying hazards and remedial actions;
–improved modeling capabilities;
–interface to robotic systems for observation and response;
–a priority list of chemicals that is based on hazard potential; and
–inclusion of satellite data and aerial photographs.

9. CONCLUSIONS: ISSUES FOR SITE-SPECIFIC EVALUATION AND IMPLEMENTATION

There are a number of site-specific factors that will require ongoing monitoring, assessment, and evaluation as command, control, and decision-making systems and procedures are put into place. The principal factors are

- Authority to warn. The need for an on-post EOC issuance of alert in the event of a chemical-agent release involving the CSDP is predicated on the assumption that, although the consequences of a release might not be as severe as some members of the public might believe, consequences of a chemical-agent release could pose a greater risk than some on-post officials are willing to acknowledge. To ensure that off-post officials would be adequately warned, even if on-post personnel did not perceive an incident to be serious, is a more difficult task than has been acknowledged. Continued effort will have to be made in this area. Under what conditions might an on-post incident commander be given authority to make some off-post decisions? Moreover, under what conditions should the on-post commander be able to order protective actions?
- Coordinated response between the IRZ and the PAZ. The PAZ is characterized as essential for evacuee support. How can coordinated DM be conducted during planning and following an accident to ensure that PAZ officials are firmly integrated into off-post command and control? What kinds of exercises might be most effective to test this preparedness? Could an ICS coordinate agencies well outside the IRZ? How can alert level classification schemata improve the interface between IRZ and PAZ responsibilities?
- Intra-organizational problems: varying styles of on-post command, control, and DM. At many CSDP sites, CAIRA plans contain inconsistencies, and lines of DM and notification authority are unclear. This is true despite the fact that on-post command and control is supposed to be defined in such plans for each installation (U.S. Army 1988). What are the differences in DM authority among tenant agencies at CSDP installations? What kinds of personnel staff EOCs at these installations, and is this staffing adequate for DM tasks? Are multiple layers of approval required for making decisions? Are there varying procurement practices at CSDP sites that may affect acquisition of emergency-management systems?
- Off-post command and control through EOCs and their interfaces with ADSSs. In some off-post communities, a particularly troublesome problem is the role and status of EOCs intended to provide centralized management for emergency DM. It has been recommended that in those areas adjacent to CSDP installations where more than one political jurisdiction is affected by the possibility of an off-site chemical release, the next higher jurisdiction should be invested with the authority to centralize off-site notification and ER. Two problems are apparent and will require continued monitoring. First, although some county governments around installations have EOCs adequate to these tasks, others do not. Second, it is not always clear what constitutes the next higher political jurisdiction.

What specific enhancements to EOCs are needed to improve their DM, communication, warning, and alert functions? What drawbacks to a unified command and control system continue to prevail at some communities adjacent to CSDP sites? How can county emergency-management staff, already overworked, be better integrated into a comprehensive emergency-management system designed for rapid response in the event of a chemical-agent release?

We conclude by suggesting that the technological features needed to support command and control on post and at remote locations on and off post at all CSDP sites will include the following features:

- telecommunications via hardware or other appropriate medium,
- network software,
- established protocols, and
- ruggedized computers and peripherals for field operations.

For stationary locations, the medium of choice is fiber-optic cables with redundant lines. This would provide the highest level of reliability, speed, and data-transmission quality. Coaxial cable is only slightly less suitable because it would be vulnerable to electromagnetic pulses in the event of a nuclear attack. However, for the CSDP, both media are well suited for the transmission of voice, text, and graphic information. Conventional telephone lines, however, are not reliable at the speeds of transmission required for graphic images.

Cellular phones and pocket radios are adequate for voice and text communication with mobile workstations. They are too slow and unreliable for satisfactory transmission of graphic images. If the transmission of graphic information is deemed essential, the options are:

- Transmit commands that regenerate an identical image at the mobile workstation without transmitting the original image. This requires similar hardware, software, and expertise at both ends.
- Transmit via satellite communications, microwave, or other high quality/high cost link.
- Generate hard-copy images and transmit likenesses via facsimile. This is an inexpensive solution, but the image would lack the data structure and information content that could be transmitted by other media.

Network telecommunications become increasingly complex as the number and diversity of users increases. The simplest form of network telecommunications would be for the EOC to generate all information and transmit directly to one or more passive workstations. This could be accomplished with minimal effort via telecommunications software such as that available for EIS/C and CAMEO.

At the opposite end of the spectrum, a large number (at least one for each EOC within an affected jurisdiction) of workstations could be linked together. Some information would be authorized for all to receive, and other information would be restricted to authorized notes of the network. The problem would be more complex if the network contained a variety of hardware architectures, operating systems, languages, data formats, and DBMS types. Table 9.1 depicts a likely configuration and protocol for implementation at APG, PBA, and other CSDP sites. Sophisticated network software and hardware systems would be required.

Table 9.1. Network configuration and protocol for a typical CSDP[a] site

Authorized protocol capability	Organizational component
Proprietor of database	On-post EOC[a]
Ability to change database	On-post EOC, other on-post components when specifically authorized
Send all types of data	On-post EOC
Receive all types of data on demand	On-post EOC, on-post mobile units, restricted federal agency components
Send selected data	On-post mobile units, off-post communities in IRZ[a], state and federal coordinators
Receive selected data on demand	Off-post mobile units, off-post communities in IRZ, state and federal coordinators
Passive receiver for all types of data	Restricted federal components
Passive receiver for all types of data	News media, off-post communities in PAZ and beyond

[a]CSDP = Chemical Stockpile Disposal Program; EOC = Emergency Operations Center; IRZ = Immediate-Response Zone

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APPENDIX A

FUNCTIONAL CHARACTERISTICS OF EMERGENCY MANAGEMENT INFORMATION SYSTEMS (EMISs)

APPENDIX A

FUNCTIONAL CHARACTERISTICS OF EMERGENCY MANAGEMENT INFORMATION SYSTEMS (EMISs)

The following checklist of functions and characteristics is suggested for evaluation of EMIS systems under consideration for satisfying current and future decision making needs of the Chemical Stockpile Disposal Program:

- Emergency Plans
  - –Preparation
  - –Retrieval
  - –Revision

- Selected Geographical Information System Functions (see Appendix B)

- Spatial Databases
  - –Maps and Engineering Graphics
    - Floor plans
    - Transportation Networks
    - Topographic Maps
    - Regional and Vicinity Maps
  - –Utility Systems
    - Electrical
      - Water and Process Liquids
      - Steam and Process Gases
      - Communications
    - Sewer
      - Drainage
      - Petroleum
        - Liquid
        - Gas
  - –Other Spatial Databases
    - Population
      - Resident
      - Institutional
      - Transient
    - Elevation
    - Terrain
    - Land Cover
    - Land Use
      - Water bodies
      - Geology and Soils
      - Seismology

- Inventories
  –Chemical Stockpiles
  –Hazardous Material Stores
  –Other Materials

- Hazard Assessment and Response Guidance
  –Material Safety Data Sheets
  –Response Data Sheets
  –Hazardous Materials Information System Database

- Contacts
  –Public Officials
    Local and State Emergency Managers
    Federal Emergency Management Agency
    Local Emergency Planning Committees
  –Media
    Utility and Transportation Supervisors

- Resources
  –Personnel
  –Materiel
  –Contractor Support

- Special Needs
  –Hospitals
  –Schools
  –Day Care Centers
  –Nursing Homes
  –Resort/Recreational Facilities

- Regulatory Requirements

- Event Log

- Meteorology
  –Data
  –Models
  –Source Terms
  –Accident Scenarios

- Transportation
  –Evacuation Management
  –Routing
  –Monitoring
  –Logistics and Scheduling

- After Action Report

- Remote Workstations

- Telecommunications Networks
  –Voice
  –Data
  –Facsimile
  –Local Area Networks
  –Electronic Mail

APPENDIX B

FUNCTIONAL CHARACTERISTICS OF GEOGRAPHIC INFORMATION SYSTEMS (GISs)

APPENDIX B

FUNCTIONAL CHARACTERISTICS OF GEOGRAPHIC INFORMATION SYSTEMS (GISs)

The following checklist of functions and characteristics is suggested for evaluation of GISs appropriate for current and future development of EMISs:

- User-Friendly Human/Machine Interface
  - –Menu Lists
  - –Pop-Up Menus
  - –Function Keys
  - –Command Language
  - –Icons

- System Supervisor

- Data Structure
  - –Vector
    - Raster/Vector
  - –Raster
    - Quadtree
    - TIN

- Data Acquisition and Conversion
  - –Reformat External Files
  - –Convert Map Projections
  - –Reference to Lat/Lon
  - –Scale
    - Resolution
    - Filtering
    - Digitizing
      - Manual Grid Overlay
      - X. Y Tablet
      - Raster Scanning
      - Add Identifiers
      - Topology Assignment
      - Area
      - Network
      - Attribute Assignment
  - –Editing
    - Chain Editing
    - Addition
    - Replacement
    - Modification
      - Topological Error Detection
      - Repositioning

Image Processing
  - Geometric Rectification
  - Radiometric Rectification
  - Classification

Zoom
Pan
Blotch
Statistics

- Data Transformation and Integration
  - –Raster to Vector
    - Grid to Polygon
    - Grid to Line
    - Grid to Point
  - –Vector to Raster
    - Polygon to Grid
    - Line to Grid
    - Point to Grid
    - Polygon Intersection
  - –Grid to Grid
    - Interpolation
    - Extrapolation
  - –Dime Vector to Chain to Polygon

- Database Management
  - –Structure
  - –File
    - Relational
    - Hierarchical
    - Network
  - –SQL
    - Hypertext/Hypermedia
  - –Spatial Data Processing
  - –Attribute Data Processing
  - –File Editing and Updating
  - –File Concatenation and Merging
  - –Append
  - –Storage
  - –Retrieval
    - Via Keyboard
    - Via Cursor
  - –Record or Key Searching
    - Sorting
    - Data Loading
    - Q Query
    - Record Insertion
    - Backup
    - Copy

Rename
Listings and Report Generation
Record and File Summaries
Catalogs
Directories

–Protection and Security
Activity Logs
Utilities and Maintenance
Linkability to External Systems and Models

- Data Analysis, Statistics, and Modeling

–Mensuration
Straight Linear Distance
Area
Perimeter
Buffers Around Points
Buffers Along Straight Lines
Buffers Around Polygons
Buffers Along Curved Lines
Proximity Distance
Curved Distance
Weighted Buffer

–Mathematical Operations
Boolean Operations/Multiple Maps
Boolean Operations/Multiple Themes
Analysis Within Corridor
Add/Subtract Maps
Multiply/Divide Maps
Nearest Neighbor Search
Exponentiate Maps
Differentiate Map Values

–Polygon Geometry
Polygon Merge/Dissolve
Point-in-Polygon
Line-in-Polygon
Polygon Overlay
Delete Spurious Polygons
Generate Thiessen Polygons

–Terrain Analysis
Compute Slope
Interpolate Elevation
Compute Compass Aspect
Generate Elevation Contours
Generate Cross-sections
Line-of-Sight Viewshield
Cut and Fill
Model Drainage

–Geometric Operations
    Coordinate Geometry (Compute Shortest Path)
–Trigonometry
–Modeling
    Spatial Index Computation
    Screening Models
    Terrain Models
        Slope
        Aspect
        Drainage Patterns
        Viewshield
    Pattern Recognition
    Network Analysis
        Network Tracing
        Network Flow
    Routing
    Linear Programming
    Gravity Models
    Diffusion Models
–Centroid
    Direction
–Proximity Calculations
    Categorization
–Class Intervals
    Ranking
    Statistics
        Mean
        Mode
        Median
        Standard Deviation
        Correlation
        Spatial Autocorrelation
        Regression
        Minimum Aggregate Travel
        Chi-square Analysis
        Cluster Analysis
        Factor Analysis
        Frequency Distribution
    Temporal Analysis
    Artificial Intelligence
    Expert Systems
    Rule-based Logic
    Knowledge Engineering
    Cognitive

- Graphic Output and Display
  –Contouring
  –3-D Perspective and Isometric

–3-D Imaging
–Polygon/Segmental Mapping
–Grid Cell Mapping
    Cartesian
    Raster
    Polar Coordinates
–Graduated Circles
–Pie Charts
–Flow Charts
–Line Symbolism
–Graphic Overlay
    2-D Overlay
    3-D Overlay Perspective
–Mapping Vertical Data Samples and Strata
–Legends
–Labels
–Titles
–Annotation and Text
–Georeferenced Overlay Grid
    Scaling
    Windowing
    Zoom
–Magnify
    Pan
    Rotate
    Polygon Shading
    Hashing
    Gray Level
    Color
    Histograms
    Bar Charts
    Spline Interpolation
–Graphics Output
    Vector Map
    Raster Map
–Standards
    Network Standards
    GKS Graphics Standards
    Cartographic Data Exchange Standards
–Computing Environment
    DOS
    UNIX
    VMS
        Macintosh
    VS
    OS2
    PRIMOS
–Data Input Formats

DXF
DLG
GBF/DIME
TIGER
SIF
DEM
ARC/INFO
ERDAS
IGES
DLG-3
ISIF
–Landsat
ETAK
SPOT
GIRAS
MOSS
DIF
–Pict 1
IBM
–Atlas
DGN
TIFF
HPGL
ELAS
MAP
AVHRR
ASIF
–Calma
CLDG III
CTG
DTED
DTM
–Easydata
EPSF
FGIS
GNIS
GPG
–Gradis 2000/3000 GRD
IDIMS
IGDS
–Informap
LISP
LMIC
–Micropips
ODYSSEY
–Ordinance Survey
OSDMC
OSIF

OXF
–Pallette
PCI
PCIPS
–Pict 2
SISIF
SLF
SYLK
TARGA
TERRAMAR
TIPS
TIROS
UKNTF
URBAN
WDB II
–Database-Management Systems (DBMSs)
Internal DBMS
External DBMS
Oracle
Dbase
Ingres
Informix
SQL
INFO
DB-2
Lotus
RDB
IMS
Rbase
Adept
Britton Lee
Condor
DBF
DIF
Double Helix
Empress
Fasport
Hypercard
QMNIS
Quattro
Request
SAS
SPSS
Sybase
Unify
UserBase
ZIM
4th Dimension

- Graphics System Characteristics
  - Mouse
    - Digitizing Tablet
    - Trackball
    - Thumbwheel
    - Light Pen
    - Touchscreen
  - Screen Graphics
    - Color
      - Single Screen
      - Dual Screen
      - Multiple Windows
      - X-Windows
    - Hard-Copy Output Device
      - Dot-Matrix Printer
      - Ink-Jet Plotter
      - Pen Plotter
      - Electrostatic Plotter
      - Laser Printer

APPENDIX C

REVIEW OF THE EIS/C EMERGENCY MANAGEMENT SYSTEM

APPENDIX C

REVIEW OF THE EIS/C EMERGENCY MANAGEMENT SYSTEM

The purpose of this document is to review the EIS/C Emergency Management System. This software review is based on (1) approximately one year of experience with EIS/C and EIS/DRAW source code and object code, (2) published documentation and demonstration software provided to Oak Ridge National Laboratory (ORNL) by the vendor, and (3) a demonstration presented to U.S. Air Force and ORNL personnel at Tyndall AFB on Apr. 19, 1988. The demonstration was presented by Dr. James Morentz, President of Research Alternatives, Inc. (RA), the company which developed the software and markets the EIS/C system. The EIS software system is in place at approximately 300 locations, including Scott Air Force Base, Kings Bay Submarine Base, and Los Alamos National Laboratory. One user in California operates the system on 11 portable microcomputers. RA's experience with mobile units has employed the IBM PC/AT or compatible (Intel 80286 processor), operating at 10 MHz. These are portable microcomputers, but they have not been ruggedized to military standards.

The suffix /C indicates a special-purpose version for use at chemical facilities. This should not be confused with the fact that EIS/C also happens to be programmed in the *C* language. The system currently runs on the PC DOS operating system. Future directions may include IBM's new OS/2 operating system. RA has been approved as a beta test site for Microsoft OS/2.

In a typical working environment, the microcomputer is free for use in other applications when not required for emergency operations. If an emergency occurred, an alarm would sound, overriding any nonemergency applications, and the operator could switch quickly to the emergency-management mode.

User Interface and Training. The system employs user-friendly menus and single keystroke commands that are indicated by a keyboard overlay. The initial training requirement amounts to approximately 1.5 h and is offered as a tutorial by the vendor. Help files are accessed quickly in a similar manner. RA offers more extensive training programs, but fewer than a dozen of its current customers have requested this service. Presumably, they have found the 1.5-h tutorial to be sufficient for training.

Database Management. EIS/C provides a database-management structure and numerous functions for producing graphics and reports. It is not designed as a database-building tool. The operating assumption is that databases in the EIS/C format will be available from external sources. RA offers to prepare digital maps and other databases as a service to the customer. Identical databases can also be prepared at ORNL using the EIS/DRAW software previously purchased from RA.

The database-management system (DBMS) is a relational structure specific to emergency-management applications. No commercial software packages are used in the DBMS; the software is RA's proprietary design. Object code licenses for deployment to all AFB fire departments have been offered for a fixed price.

EIS/C contains material safety data sheets (MSDSs) for approximately 2700 materials, but RA should not be characterized as a hazardous-materials-database supplier. Numerous private companies and government agencies—e.g., the National Oceanic and Atmospheric Administration (NOAA)—provide database services. RA should be viewed as a gateway to hazards information.

The map database is maintained as a series of preprocessed images. The RA digitizing process allows for conversion of latitude/longitude coordinates to EIS/C internal raster coordinates, but the geographic processing software within EIS/C recognizes only the internal raster coordinates. This approach improves efficiency but sacrifices generality of the software. Each image is a bit map stored on hard disk. Current experience includes 20, 40, 70, and 140 MB disks.

Also included in the database is a series of icons representing, for example, fire hydrants, emergency-management teams, and various types of heavy equipment. The icons are stored in digital form. Definitions are published in the manual but are not listed in the digital icon record.

Air-Diffusion Modeling. The air-diffusion model in EIS/C is the ALOHA model developed by NOAA. The same air-diffusion model is used in NOAA's CAMEO emergency-management system. The Radian Corporation's air-diffusion model, CHARM, can also be run from EIS/C. During an emergency involving airborne pollutants, the operator could call up a pre-calculated polygon or generate a new polygon. In either case, the polygon would represent the likely plume or pattern of dispersion estimated for a specific set of meteorological conditions. The pre-calculated plume(s) would be based on one or more scenarios, while the plume generated during the incident would be based on current, monitored meteorological data. ORNL has modified the EIS/C source code to provide direct access to the AFTOX air-diffusion model and to facilitate display of AFTOX plumes on EIS/C maps.

The model is designed to be interactive in that the location of the incident and the name of the hazardous material can be passed from EIS/C to the air-diffusion model, and meteorological data (wind direction and speed, etc.) can be entered (manually or automatically) from weather-station monitors. The map display distinguishes among as many as three isopleths of pollutant concentrations as an overlay to other facilities and background maps.

Capabilities. The locator function allows input of spatial information via a screen cursor. For example, the database can be prepared so that colored polygons indicate rooms with different levels and types of risk. For example, one color might indicate that the room is unsafe due to toxic risk and another color might indicate radiation risk. Emergency-management resources can be included in the database and displayed on the maps and floorplans. For example, fire hydrants can be shown, and the fire hydrant database can contain attributes such as the last date of inspection. The location of heavy equipment can be shown with attributes indicating, for example, the names of individuals and organizations to contact in order to obtain authorization for their use.

The location of emergency-management teams can be displayed, and attribute information about the teams can be recorded. A log of incidents and actions can be maintained as an archive for post-incident analysis. This log might indicate, for example, that the fire department was informed and at what time. At the conclusion of the incident, EIS/C can structure itemized paragraphs and titles into an emergency-management plan consistent with Federal Emergency Management Agency guidelines.

The system allows for onscreen notes in a graphics window. For example, weather information might be continuously displayed.

Limitations. The event log does not contain security procedures that would ensure its integrity as a database, and the EIS/C commercial product does not include software to convert graphic and geographic data from other sources (such as the base civil engineer) into the emergency-management system. As a step in this direction, ORNL has developed conversion software to convert AutoCAD DXF files into EIS/C format. This covers a large range of GIS and CAD sources because DXF has become a common exchange format for both types of systems, including Intergraph, which is employed by civil engineers at many military bases. Unfortunately, conversion is only part of the problem. It would also be necessary to substantially edit the content of the GIS and CAD databases. Unedited maps and floorplans will contain too much spatial and textual information for effective communication in the EIS/C screens.

At present, the system does not include a model for evacuating personnel along the transportation networks. Evacuation routes may be indicated as preselected links in the transportation network. These links can be displayed, but the system does not recognize the structure of the network (connectivity, attributes, etc.) in the manner that would be needed for transportation modeling.

APPENDIX D

INFORMATION ON THE SURVEY OF GISs AND RELATED SYSTEMS

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The following histograms depict a profile of the GIS industry derived from a survey of 63 GISs and related systems administered by *GIS World* (*GIS Technology* 1989) and discussed in the text (see page 22). The analysis is derived from an article in preparation by H. D. Parker and J. E. Dobson (Parker and Dobson, to be published).

The number of systems claiming each specific feature is represented by a bar of proportional length. A bar of length 63 would mean that all systems claim that particular feature. However, in actuality, no feature is common to all systems, and many features are claimed by only 30% to 50% of the systems.

The reader should bear in mind that all answers were submitted by the vendors, and were not independently verified.

Table D.1. System characteristics

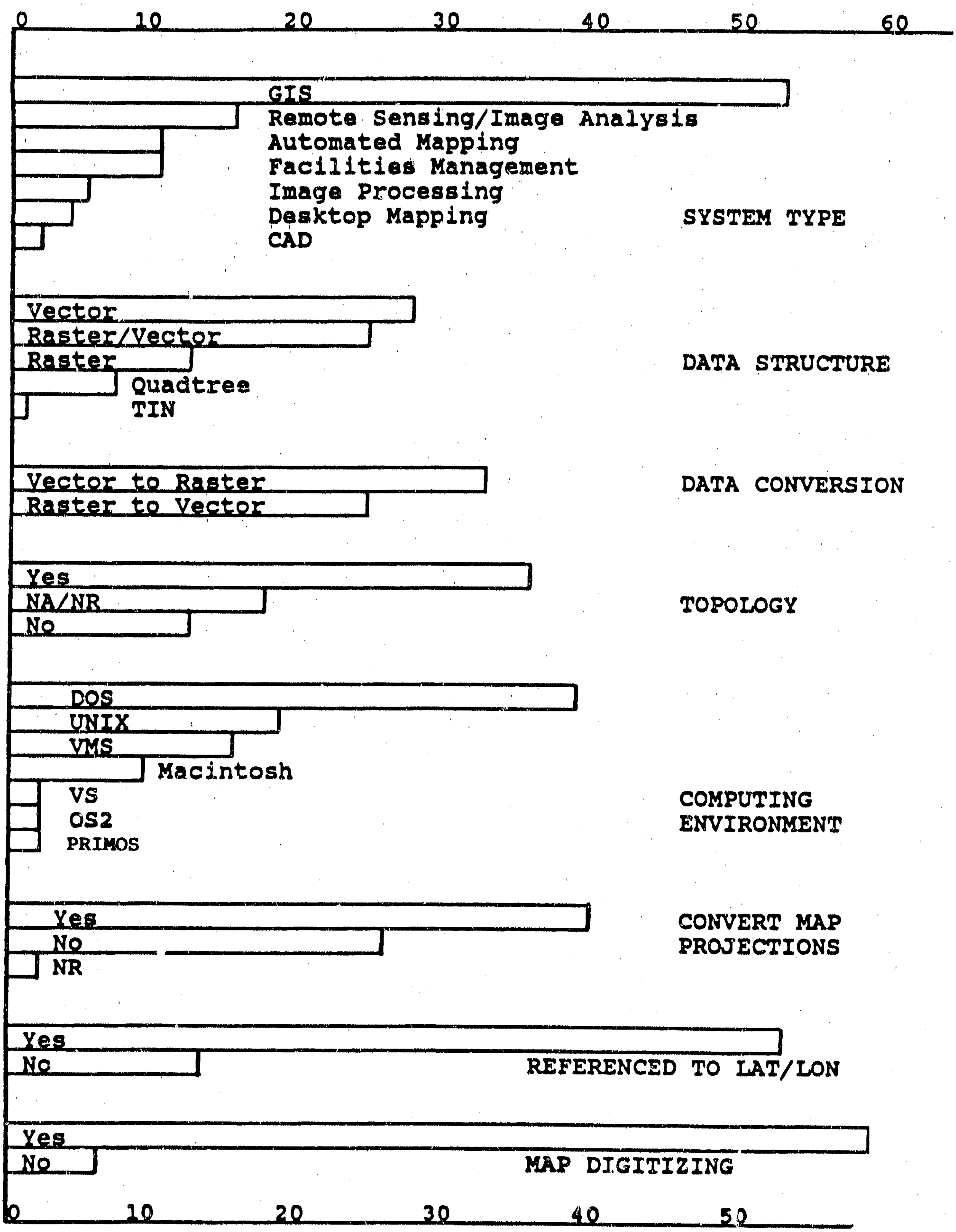


Table D.2. Data Interfaces

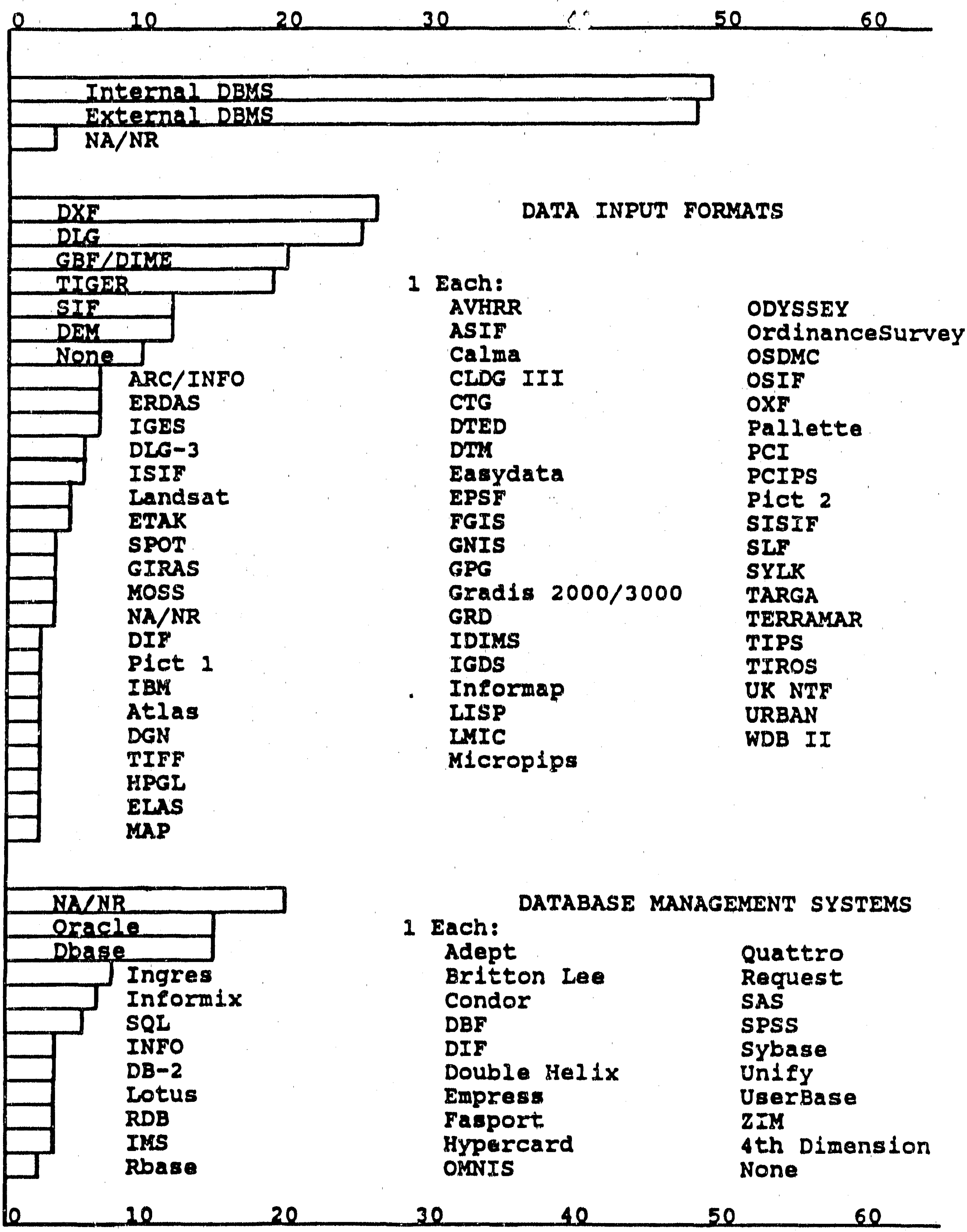


Table D.3. Graphics system characteristics

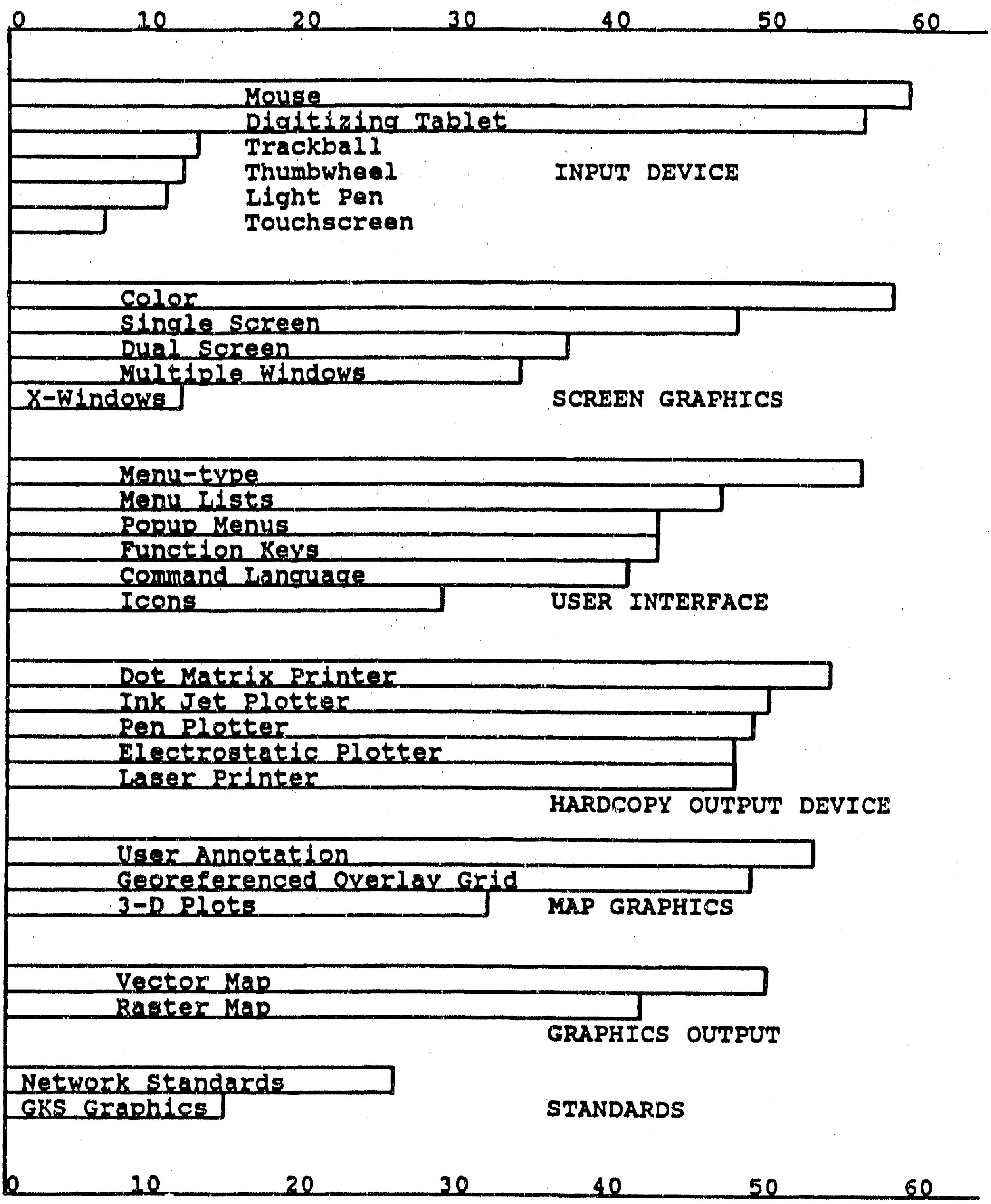
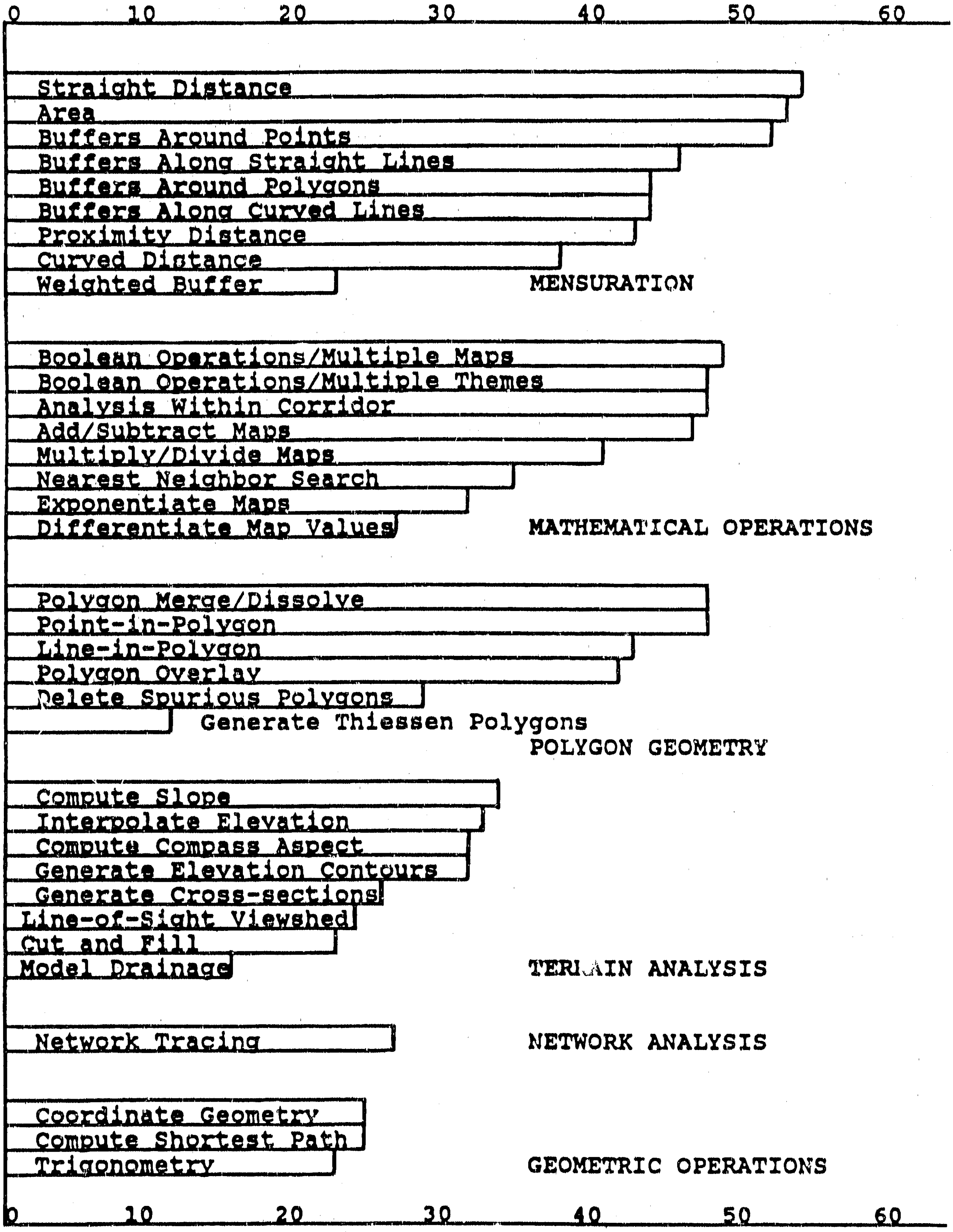


Table D.4. Functional characteristics



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