Self-Organization in Complex Systems

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THE PROBLEM: SELF-ORGANIZATION IN DYNAMIC ENVIRONMENTS

Self-organization represents the spontaneous emergence of order in natural and physical systems (Kauffman 1993). This process also has been observed in networks of community organizations that emerge after natural or technological disasters (Drabek 1981; Comfort 1990). Recognizing the urgent needs created in stricken communities by a destructive earthquake, hurricane, flood, fire, or release of hazardous materials, people respond voluntarily with their time, material goods, skills, and knowledge to restore order to their communities.

Seeking to use available resources efficiently and to integrate new resources into existing structures for effective action, organizations responding to disasters often change operating procedures and practices in fundamental ways. That change occurs in part through voluntary selection among alternatives for action and in part through mutual adjustment in performance among the participating organizations. Order returns to the community through a creative process of reciprocal exchange, learning, adaptation, and choice among multiple participants operating at multiple levels of responsibility, experience, and knowledge.[1]

The process of self-organization in the context of disaster environments, which generate interactions among organizations and their operating environments in newly evolving complex systems, offers important insights into the general problem of initiating change. The extent, form, and rate of self-organization varies significantly, however, from disaster to disaster, community to community. Self-organization is potentially important in explaining the processes of change and resistance in large, interdependent systems, which often precipitate disaster by their inability to adapt their performance appropriately or in time to avert known risks.

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[1] This statement is based on direct professional observation of a series of eight major earthquakes from 1985 to 1992: Mexico City, 1985; San Salvador, 1986; Ecuador, 1987; Whittier Narrows, 1987; Armenia, 1988; Loma Prieta, 1989; Costa Rica, 1991; Erzincan, Turkey, 1992.

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I undertake five tasks in this paper. First, I distinguish the process of self-organization in dynamic social systems from regulatory or chaotic efforts to institute change. Second, I identify the components and characteristics of the process of self-organization in a specific type of dynamic environment, disaster operations. Third, I develop a preliminary assessment of the conditions that facilitate or inhibit the emergence of self-organization in rapidly changing, dynamic conditions, illustrating these conditions with selected examples from an actual case of disaster operations. Fourth, I present selected screens from a prototype interactive, intelligent, spatial information system for hazardous materials management that illustrates the capacity of information technology to support the emergence of self-organization in dynamic conditions. Finally, I offer a set of recommendations for incorporating the process of self-organization into policies of risk reduction for vulnerable communities.

THE CONCEPT OF SELF-ORGANIZATION

Self-organization represents a fundamental reallocation of energy and action within a system in order to achieve a larger goal. The phenomenon of self-organization first was recognized as an important aspect of the wider process of change in operating systems in the physical and biological sciences (Ruelle 1989; Prigogine and Stengers 1982; Prigogine and Nikolis 1989; Bak and Chen 1991; Kauffman 1993). In the physical sciences, researchers sought to explain unexpected aberrations in the operation of mechanical systems, in which minor fluctuations in performance would cumulate at certain points, eventually leading to large disruptions in the operation of the system. These points of energy attraction within the operation of the system were termed "strange attractors" (Ruelle 1989), indicating that the unplanned clustering of energy at specific points in the system was outside the prescribed plan of operations and occurred without external design. The strange attractors shifted the pattern of energy flow within the system, eventually altering the operation of the entire system.

Bak and Chen (1991) noted the recurrence of this phenomenon in natural environments, presenting their explanation in the form of the "sandpile" analogy. In this analogy, adding another grain of sand to the pile at some indeterminate point causes the entire sandpile to rearrange itself without outside intervention.

Observations of change in living systems led biologists to describe these processes as occurring on "fitness" landscapes (Kauffman, p. 205), in which the energy driving the system appears to flow on a continuum from order to chaos. In orderly transitions, energy in the form of system units—for example, proteins—was distributed relatively evenly through the process, creating a "smooth" landscape for performance. In chaotic transitions, energy would cluster at certain points in the system's operation, creating "peaks," which in turn would form "valleys" or "basins" of attraction, resulting in "rugged" landscapes (Kauffman 1993, 176). These peaks and valleys would cumulate energy over repeated operation to affect seriously the performance of the system and, at a certain threshold, would throw it into turbulent, nonpredictable behavior, or chaos. This pattern is similar to that observed in dynamical systems in the physical sciences.

Locating an operating system on the continuum from order to chaos depends on the fit of its procedures to the landscape, or conditions, of its environment. This analogy recognizes that an organization's operating procedures and its environment form a distinct, interdependent system in practice. The evolving new system more successfully incorporates changing requirements from its environment and reflects the adaptive capacity of its component units.

Understanding when, how, and where change may occur in dynamic environments is a primary challenge for disaster managers charged with the legal responsibility for reducing risk to their communities. Creative change is not likely to occur at either end of a continuum of system performance that stretches from order to chaos (Kauffman 1993). On the order end of the continuum, systems designed for control tend to become paralyzed or self-destruct in rapidly changing environments. Lacking flexibility, their precise rules for operation may no longer apply or, worse, may punish innovative efforts to find more effective means of functioning in altered conditions. On the chaos end of the continuum, systems without sufficient structure to hold and exchange information tend to disintegrate into unpredictable performance under swiftly changing conditions. Small changes in operating conditions may lead to large disruptions in performance, or avalanches of disorder (Prigogine and Stengers 1984; Kauffman 1993; Waldrop 1993).

In Kauffman's (1993, 174, 208-27) terms, creative change is most likely to occur in a narrow region, the 'edge of chaos,' that has sufficient structure to allow participants to hold and exchange information, but sufficient flexibility to allow mutual adaptation among the participants to substantive changes in their operating environments. This region allows the development of "complex systems" (Kauffman 1993, 174) in environments characterized by rapid change. In complex systems, small changes in operating performance are frequent, and large scale disruptions are few. Complex systems are distinguished by a capacity for self-organization, that is, the ability to rearrange and reform their patterns of operation in mutual adaptation to changing needs and capacities of their components as well as changing demands and opportunities from the environment. The distinguishing characteristic of this process is that it occurs as a result of communication, selection, and adaptation processes within the system itself and between the evolving system and its environment. It is not imposed externally. The result is a new and more constructive order in dynamic response to a changing environment.

THE COMPONENTS AND CHARACTERISTICS OF SELF-ORGANIZATION

The concept of self-organization needs to be redefined and reinterpreted in order to assess its presence and functions in the performance of social systems in rapidly changing environments. First, self-organization is a continuous process that occurs in social contexts through "communicative acts" (Luhmann 1986). These acts are most often forms of verbal, written, or electronic communication transmitted directly between two or more actors within the system or between the system and its environment. These acts also may include symbolic and nonverbal forms of communication (Feldman and March 1988), which transmit indirectly powerful messages through example and action. Communicative acts, both direct and indirect, are the "building blocks" (Luhmann 1986) of the process of self-organization.

The internal motivation that drives this process of communication is the desire for creative self-expression, or "autopoesis" (Luhmann 1986). This intrinsic desire for self-expression leads individuals to seek broader realization of their capacity through organized social activity (Luhmann 1986). This desire serves as the "homing device" in individual activity that returns each member to the larger goal of the system. Individuals communicate with one another and exchange information in reference to specific problems. This exchange of information allows them to consider alternatives for action at the next opportunity for choice. Individuals exercise choice in selecting action alternatives based at least in part on the goal of the larger system and the extent to which it facilitates their particular searches for self-expression.

Second, self-organization, coupled with selection, creates the system's capacity for adaptation to environmental conditions

(Kauffman 1993, 173). Self-organization recognizes that individual choices, communicated across organizational frameworks, affect the operation of the wider system. In this respect, voluntary selection allows individuals operating within organizational systems to cluster around points of energy that they find more attractive, creating a "peak" of energy distribution over repeated interactions and aligning other members to that point, in a "basin" of attraction.

Third, self-organization recognizes the influence or control that some units exert over other units in an interdependent system. When tasks are interconnected, one unit may not be able to function properly without the willing cooperation or support of another unit or units within the system. Interestingly, when the number of actors and the number of interactions among those actors increases within the system, the system is able to achieve only ever-poorer resolutions to shared problems (Kauffman 1993, 51). At that point, the system may slide toward chaos or retreat toward order.

Fourth, self-organizing systems are massively parallel-processing systems (Kauffman 1993, 237), where different components perform different functions simultaneously in order to achieve the desired goal of the system. Different components may operate at different rates of speed in processing information, require different types of information and resources for action, and respond to different needs and clientele. The system is integrated through a shared commitment to a common goal, which in turn sets the boundaries of the system.

In summary, the process of self-organization represents an important learning capacity among the members and subunits of a social system (Churchman 1971). This learning capacity depends on open communication channels and clear feedback patterns within the system (Argyris 1982 and 1990; Schon 1987; Benveniste 1987) and between the system and its environment (Luhmann 1986; Kauffman 1993). Social systems are open systems (Scott 1992), where there is a continuous flow of information, action, energy, and challenging events from the environment. Self-organization is responsible action in recognition of continuing entropy in organizational systems, distinct from external regulation (at the order end of the continuum of efforts to bring about change) or anarchy (at the chaotic end of the continuum).

If we understand self-organization to be essentially a collective process of communication, choice, and mutual adjustment in behavior based on a shared goal among members of a given system, we can begin to specify the components and characteristics of that system. This specification allows us to develop measures of self-organization and to monitor the process in response to different challenges from the environment occurring at different times under different conditions and locations.

Four measures appear to characterize the process of self-organization in any setting. These are based on Kauffman's (1993, 175-209) description of self-organizing systems as 'N-K systems,' where N equals the number of actors in the system, K equals the number of interactions among these actors, and P equals the 'bias for choice' among the actors, or the goal of the actors that drives action. These three measures—number of actors, frequency of interactions among the actors, and goal of the action—allow us to identify a fourth measure—the boundaries of the system—operating in response to specific events, times, conditions, and locations in the wider environment.

Adding four characteristics from the environment—event, time, location, and operating conditions—that precipitate action from the system, we identify eight measures that provide critical information for understanding the process of self-organization. In the context of disaster operations, disaster managers may use these eight measures to assess an emerging system of response organizations. This information then facilitates the process of creating a new order out of the disaster-altered conditions and returning the community to normal operations.

Applying these measures to a given case of disaster operations is essentially a set of classification and induction tasks (Holland et al. 1986). Once completed, however, this analysis creates a shared knowledge base for participating disaster managers that informs the process of self-organization. This potential for increasing self-organization can be illustrated most effectively in reference to an actual case of disaster operations, the Pittsburgh oil spill of January 2, 1988. This case is selected because it represents an event that brought the Pittsburgh community just to the edge of chaos, not catastrophic devastation. This moderate emergency allows us to consider more carefully the properties of self-organization, in concept and process, in disaster management.

The Pittsburgh Oil Spill, January 2, 1988[2]

It is possible to characterize the event, the participating actors, the frequency of interaction among actors, the goal of the operations, and the principal operating conditions of the

[2] This section draws heavily on a previous article by L. Comfort, J. Abrams, J. Camillus, and E. Ricci. 1989. "From Crisis to Community: The Pittsburgh Oil Spill." *Industrial Crisis Quarterly* 3:1: 17-39.

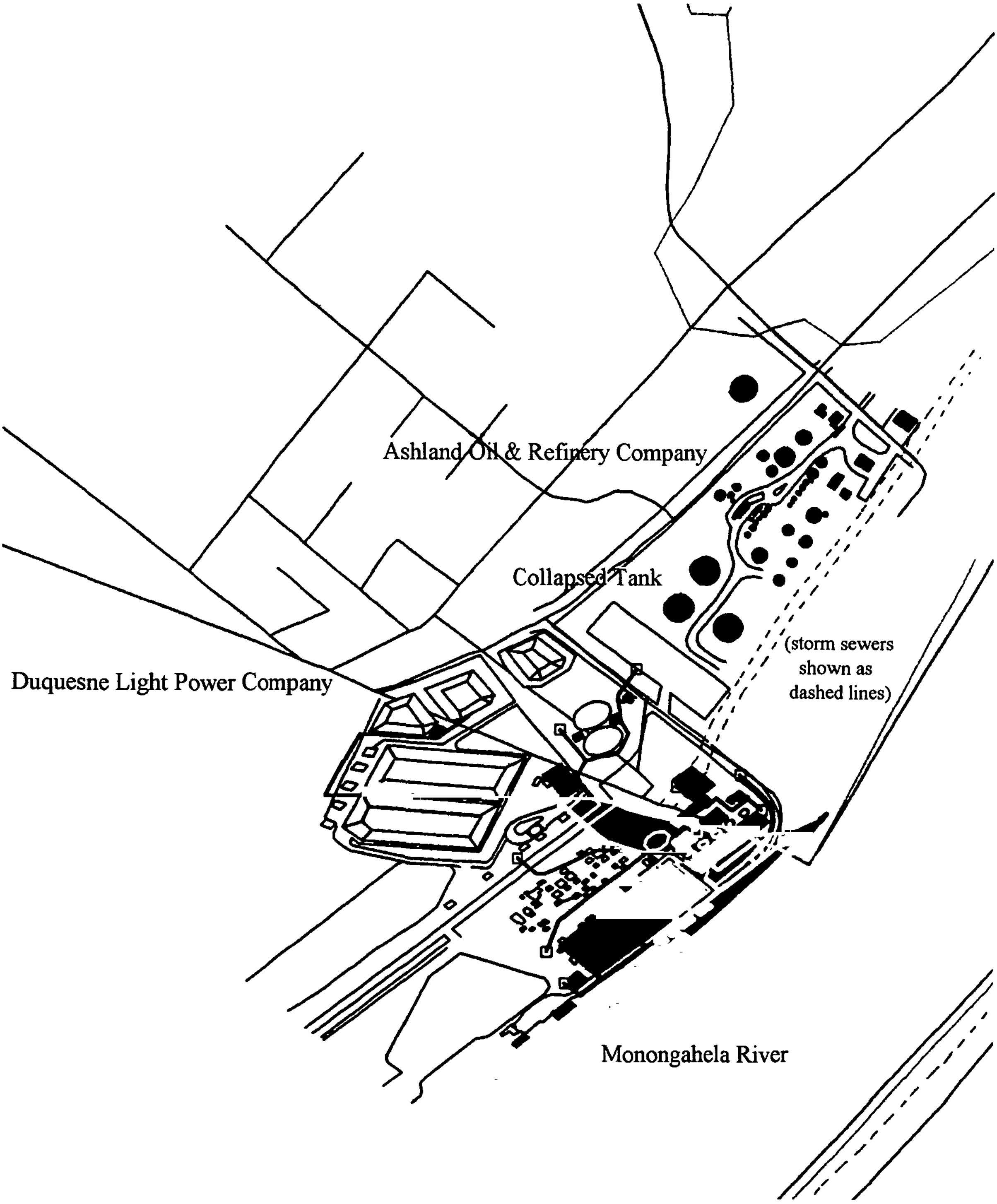
Pittsburgh oil spill in terms of the eight measures that define a potentially self-organizing system. Space does not permit a detailed analysis in this article. Rather, the case will be described briefly to illustrate the applicability of this method to an emerging complex system of disaster operations.

The crisis began on January 2, 1988. at 5:10 P.M. when a four-million-gallon tank of diesel fuel collapsed at the Ashland Oil Company's tank storage site on the Monongahela River, twenty-seven miles south of Pittsburgh (Exhibit 1). Approximately 3.8 million gallons of diesel fuel no. 2 were in the tank, and the force of the collapse caused the fuel to splash out of its containment area into the containment area of the neighboring Duquesne Light plant. In subfreezing temperatures, diesel fuel no. 2, with a flashpoint of fifty degrees, presented little danger of fire. With cautious relief, emergency operations personnel began to organize the massive clean-up operations, expecting to contain the spill at the Ashland site and adjacent properties.

At approximately 10:00 P.M., emergency response personnel, making a routine check of the spill site, discovered gasoline leaking from a nearby tank. The first tank's collapse had damaged a second tank, filled with gasoline, and caused at least four leaks in its piping structure. Leaking gasoline, with a much lower flashpoint than diesel fuel no. 2, created a more urgent danger. Emergency response personnel focused their attention and resources on identifying and plugging the leaks in the gasoline lines, fearing an explosion that would threaten the seven hundred residents of the town of Floreffe, just across the highway from the Ashland Oil Company facility. Virtually all work on clean-up operations stopped as local officials ordered the evacuation of twelve hundred residents of Floreffe and adjacent areas as a precautionary measure. Working through the night, emergency response personnel found and plugged the last gasoline leak at dawn, and evacuated residents were allowed to return to their homes, weary but out of danger.

At first light, emergency personnel discovered a third and potentially more serious danger. Throughout the night, the spilled diesel fuel had flowed into the Monongahela River through an undiscovered storm drain located on the Duquesne Light property next door. The spill, which emergency personnel had expected to contain on land, had now created an oil slick on the Monongahela River that extended bank to bank, seventeen miles long. The Monongahela River serves as the main source of water for some 850,000 residents in the Pittsburgh metropolitan region. Ordinarily, diesel fuel would float on top of the water, not endangering

Exhibit 1
GIS Map Showing Detailed Representation of Spill Site



the water intakes located some seventeen feet below the surface of the river. The fast-running Mon, however, had carried the slick over two locks and dams, and the tumbling action of the river had emulsified the oil through the water to the depth of the water intakes. Emergency personnel confronted the threat of either contaminating the water supply of area residents or shutting down the water intakes, limiting severely the supply of water available to residences, businesses, hospitals, schools, and other facilities in the area. Given the added risk of permanently damaging the water filtration systems on the river, the water authorities closed the water intakes, cutting off the water supply to several large municipalities in the area. Lack of water created a new threat to public safety, as the fire departments in the region were dependent on water for fire suppression.

The crisis continued for two weeks, with multiple local, county, state, and federal jurisdictions responding to the successive needs of the area residents. Private and nonprofit organizations, affected directly and indirectly, also responded in innovative ways to assist area residents in coping with the water shortage and in warning the communities downstream of the approaching oil slick. Fortunately, no lives were lost due to this spill, and the innovative capacity of the many participating organizations contributed substantially to reducing the threat to area residents and returning the community quickly to normal operations.

Did the organizations involved in the oil spill and related emergencies engage in self-organization? If so, to what extent? Could this process be increased? By what means and at what times? By drawing on data from a previous analysis it is possible to characterize the organizations responding to this event as an N-K system.

Briefly, at least twenty-five different types of organizations—public, private, and nonprofit—responded to calls for assistance. These organizations included public agencies ranging from municipal volunteer fire companies to county hazardous materials response teams to state environmental agencies to the U.S. Coast Guard and the Environmental Protection Agency. Private businesses also responded, ranging from the Ashland Oil Company and the USX Corporation to local car washes and bottled water distributors. Nonprofit organizations, from the University of Pittsburgh to the Pittsburgh Zoo to convalescent homes, contributed expertise, personnel time, and use of facilities in the community effort to reduce the damaging consequences from the spill.[3] This set of organizations, many of them

[3] A selected list of major agencies involved in emergency operations includes:
Private Sector: Ashland Oil Co.; O.H. Materials Co.; USX Corporation; Anheuser Busch Co.
Public Sector: Floreffe VFD; other municipal volunteer fire companies; Jefferson Borough Council; other municipal councils; Pittsburgh Department of Public Safety; Allegheny County Emergency Management Agency; Beaver County Emergency Management Agency; other county emergency management agencies; Allegheny County Health Department; Allegheny County Maintenance Department; Allegheny County Board of Commissioners; Pennsylvania Department of Transportation; Pennsylvania Fish Commission; Pennsylvania Game Commission; Pennsylvania Department of Environmental Resources; Pennsylvania Emergency Management Agency; Pennsylvania National Guard; Pennsylvania Emergency Management Agency; U.S. Coast Guard; U.S. Environmental Protection Agency; U.S. Army Corps of Engineers.
Nonprofit Sector: Floreffe Fire Dept. Wives; University of Pittsburgh; Pittsburgh Zoo; ORSANCO; Allegheny County Red Cross; Salvation Army.
This list is not complete, but it indicates the types of organizations that were involved in the emergency response and recovery operations.

interacting with one another for the first time during the response operations, had different responsibilities, contributed different resources, represented different interests and groups within the community. Yet each was engaged in response operations to serve the larger goal of the community's welfare and could be identified as a member of the emerging community response system.

These organizations communicated not only with one another but also with the Allegheny County Emergency Operations Center (EOC), located at 1520 Penn Avenue in Pittsburgh, twenty-seven miles north of the spill site. The Allegheny County EOC's Dispatch Center logged an estimated thirty-seven thousand incoming and outgoing messages during the first ten days of emergency operations.[4] Broken down roughly, approximately 3,700 messages per day, 154 messages per hour on a 24 hour basis, 2.6 messages per minute were directed to or from the emergency coordinator and EOC staff. These figures give only a rough approximation of the number of messages transmitted during the emergency, and this number includes only those directed to or from the EOC. Other communications were directed among public, private, and nonprofit organizations at the municipal, county, state, and federal levels of jurisdiction, between jurisdictional levels, and among networks of organizations that crossed jurisdictional levels.

While it is possible to identify the frequency, types, targets, and sources of communication among organizations participating in the emerging network of response organizations, it is virtually impossible for a single manager to acknowledge, much less comprehend, the volume of information unless there is some form of classification, integration, synthesis, and induction system (Holland et al. 1986). The danger is that critical information may be lost in the sheer volume, and this information, such as that regarding the existence of a storm drain on the property of the Duquesne Light facility adjacent to the Ashland site, may be precisely that which escalates a relatively low level emergency into a major crisis that affects hundreds of thousands of people's lives, business operations, and health for a two-week period.

In the case of the Pittsburgh oil spill, the goal of emergency operations was clear—to protect the health and safety of the residents of the affected area, and secondarily, to protect their property. This goal served as the basis for decision making as the focus of the crisis shifted from the collapsed tank to the gasoline leak and evacuation of Floreffe residents to the water contamination and shortage problems of metropolitan Pittsburgh. The goal

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[4] Dispatch Communications Log, Allegheny County Emergency Management Agency, January 2-January 11, 1988. This high rate of communications during disaster operations was corroborated by Cmdr. Eugene A. Miklaucic, Coordinating Officer of the Marine Safety Office, Pittsburgh, U.S. Coast Guard, who estimated approximately two hundred messages per hour coming through his command post during the most urgent hours of disaster operations. Interview, Pittsburgh, July 16, 1988.

also set the boundaries for the response system. Organizations with other purposes in mind, such as dumping effluent into the river while the water intakes were closed, were excluded from the evolving network of community support and exchange.

The four environmental characteristics—event, time, conditions, and location—are easily identified from the sequence of events, recorded in the situation reports filed by participating public and private agencies with legal responsibility for managing the spill.

Building on Kauffman's conception of an N-K system, we are able to identify the critical components and characteristics of an evolving network of organizations that respond to emergency events. Carefully developed and documented, this network allows us to monitor the extent, rate, and type of change that occurs in the performance of organizations responding to emergency events. It provides us with the needed measurement instruments to assess the process of self-organization in this complex system.

CONDITIONS THAT FACILITATE OR INHIBIT SELF-ORGANIZATION

Returning to Kauffman's concept of self-organization and the conditions that support or inhibit this process, we find evidence of a degree of self-organization among the agencies responding to the Pittsburgh oil spill and instances where the process may have been inhibited. When one reviews the events of the Pittsburgh oil spill, the following five conditions critical to the process of self-organization, or the spontaneous emergence of new order in dynamic, rapidly changing contexts, appear to be validated.

Sufficient Structure to Hold and Exchange Information

Self-organization requires the capacity of multiple actors to focus their attention on the same problem at the same time. During the Pittsburgh oil spill operations, three major problems demanded the time, attention, resources, and energy of the responding organizations. Some organizations took primary responsibility for one problem, others focused on other problems. Not always did all organizations know what was occurring at other sites of emergency operations, and actions taken at one site constrained the possibilities for constructive resolution of problems at other sites.

The problems were interorganizational, interjurisdictional, and interdisciplinary. Detailed knowledge of engineering plans for the oil facilities, water purification standards of the county health department, location and depth of the water intakes, rate of the current and access points to the Monongahela River, location, storage capacity, and rate of consumption for municipal water tanks were needed to make timely, informed decisions to bring the spill under control. More important, this information was needed to prevent secondary and tertiary consequences that proved threatening to the community. The information was available in the community, but it was located at different sites and was accessible to separate organizations. Drawing together the relevant information for this particular emergency required a more sophisticated capacity to access and disseminate information in a timely way and to represent technical information to managers from different disciplinary backgrounds in ways that they could readily understand. Given the information facilities available, it was difficult for managers to develop a perspective of the operations that was at once sufficiently comprehensive of the whole event and sufficiently detailed at specific sites to make timely, informed, efficient decisions.

Sufficient Flexibility to Adjust Behavior to Dynamic Changes in Behavior of Other Participants

Without adequate information facilities, it was difficult for managers of different organizations, especially managers at different levels of jurisdictional responsibility, to understand the conditions under which their colleagues were operating. Under these conditions, elements of distrust and disagreement developed among managers, which consumed energy and caused distraction from the primary goal of the operations. When informed cooperation, trust, and commitment to the shared community goal are intermittent or lacking among participating managers, authorities resort to legal remedies, which often is not the most effective means of resolving the problem. During the Pittsburgh oil spill, there was extraordinary cooperation among agencies where the managers knew and trusted one another. Conversely, there was serious disagreement and inability to adjust behavior to the requirements of unfamiliar operating conditions, for example, the dispute over oil clean-up technologies on the rapidly flowing Monongahela River. Under dynamic conditions, timely, accurate feedback of information from parties affected by actions taken in response operations is essential to maintaining the flexibility characteristic of self-organization.

Shared Goal Among Participants that Serves as a Basis for Choice

The goal of emergency operations—protection of the lives, health, safety, and property of residents of the community—was clear in the Pittsburgh oil spill. As the sequence of events unfolded, this goal needed interpretation in terms of specific conditions and specific costs. What degree of health was critical in terms of water purification? What degree of risk was manageable in terms of fire hazards? What degree of cost was reasonable for reimbursement from the spill? While general agreement existed on the overall goal, different applications of this goal generated controversy. Decisions on the appropriate interpretation of the goal could be made more confidently with access to a wider range of information and expertise.

Recurring Opportunities for Interaction

Participating organizations with recurring opportunities for interaction during the spill were more likely to adjust their behavior mutually to achieve the shared goal of bringing the spill under control and returning the community to normal operations. Organizations that worked alone showed less willingness to adjust their behavior. Recognition of long-term association and continuing interaction by participating organizations (Axelrod 1984) and ready access to communication facilities are critical elements in this process. Opportunities for recurring interaction would have been facilitated by a stronger communication capacity.

Capacity for Integrating Information in a Dynamically Evolving Knowledge Base that Serves as a Basis for Informed Action

During the Pittsburgh oil spill emergency operations, incoming information was recorded through computer-aided dispatch centers and standard emergency procedures for filing situation reports on situation boards and paper records. The respective emergency managers exhibited remarkable capacity to integrate dynamic information from an evolving set of events. Yet information technology now presents the possibility of providing greater capacity to hold, store, exchange, integrate, and synthesize information in timely ways that will support the managers' ability to address even more complex problems. Using this capacity will likely increase the managers' capacity to take informed, timely action under evolving emergency conditions.

LINKING INFORMATION TECHNOLOGY TO PROCESSES OF SELF-ORGANIZATION

Current research illustrates the applicability of information technology to facilitate and accelerate the process of self-organization among multiple organizations in emergency response networks. At the University of Pittsburgh, we are building a prototype interactive, intelligent, spatial information system (IISIS) for hazardous materials management[5] that will support decision processes for emergency managers in a broad, multiorganizational, multijurisdictional network. An IISIS includes three components in a computerized information system that combines information search, processing, representation, storage and retrieval functions with electronic communication, graphic mapping, and logical inference capabilities. These components working together will support the five conditions identified above to facilitate the process of self-organization in dynamic environments. The components are

- an interactive field status board that creates an emergency-specific database to support decision making in emergency operations;
- a graphic mapping capability that allows the spatial representation of information from the field status board to multiple organizations and jurisdictional users; and
- a capacity for logical inference by the computer from information reported on the field status board to relevant knowledge bases included in the system.[6]

These components, operating interdependently, can improve the utility of information available to emergency managers engaged in separate but related functions vital to emergency operations. The field status board uses the concept of an electronic blackboard to enable emergency managers to report changing conditions from multiple field sites to an emergency coordinating center. This information is integrated by computers in a continuously evolving record of emergency events, conditions, actions, outcomes, resources, and problems that can be accessed directly by authorized emergency managers from remote sites.

Using a geographic information system, information from the field status board can be displayed graphically at remote sites, enabling managers at distant locations to visualize operating conditions in the emergency environment. Adding the capability of computerized logical inference routines, emergency personnel can enter data from multiple sources into the computer to produce a calculated set of alternatives for response under specified conditions. Such routines can be used by emergency managers to explore alternative actions or to confirm possible choices against existing data from the knowledge base. The operations of these three components produce information that is stored in a layered, multijurisdictional database by function, discipline, and time phase in disaster operations.[7]

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[5] This research is supported by a grant from the Allegheny County Emergency Management Agency, Pittsburgh, Pennsylvania. I acknowledge, with thanks and appreciation, the committed work and contributions of the IISIS staff: Theresa Woods, Anthony Harris, Ron Gdovic, Carrie Smarto, Theresa Williams, all graduate students at the University of Pittsburgh.

[6] These components of an IISIS have been discussed in detail in L. Comfort, T. Woods, and J. Nesbitt. 1990. "Designing an Emergency Information System: The Pittsburgh Experience." In Tom Housel, ed. *Advances in Telecommunications Management*, vol. 3. New York: JAI Press, pp. 13-31.

[7] For a fuller explanation of the hardware and software components of an IISIS, please see L. Comfort. 1992. "An Interactive, Intelligent, Spatial Information System for Hazardous Materials Management." Pittsburgh: University of Pittsburgh Mss.

While this project is still under development and space prevents presentation of the entire project, two selected screens illustrate the capacity of the IISIS to assist practicing managers working in the dynamic environment of disaster operations (Exhibits 2 and 3). The IISIS provides structure for storing and exchanging information among the participating managers in an emergency response organization, and it promotes flexibility in adapting their organization's behavior to the requirements of the situation. The computerized knowledge base facilitates prompt feedback on actions taken and enables interactive communication among the participating managers through ease of access and timely reporting. The system as a whole operates to maintain the focus of the participating managers and organizations on the community goal of reducing risk from hazardous materials. In practice, we expect the IISIS to support the evolution of a network of public, private, and nonprofit organizations oriented toward solving their shared problem of responsible management of hazardous materials (Churchman 1971).

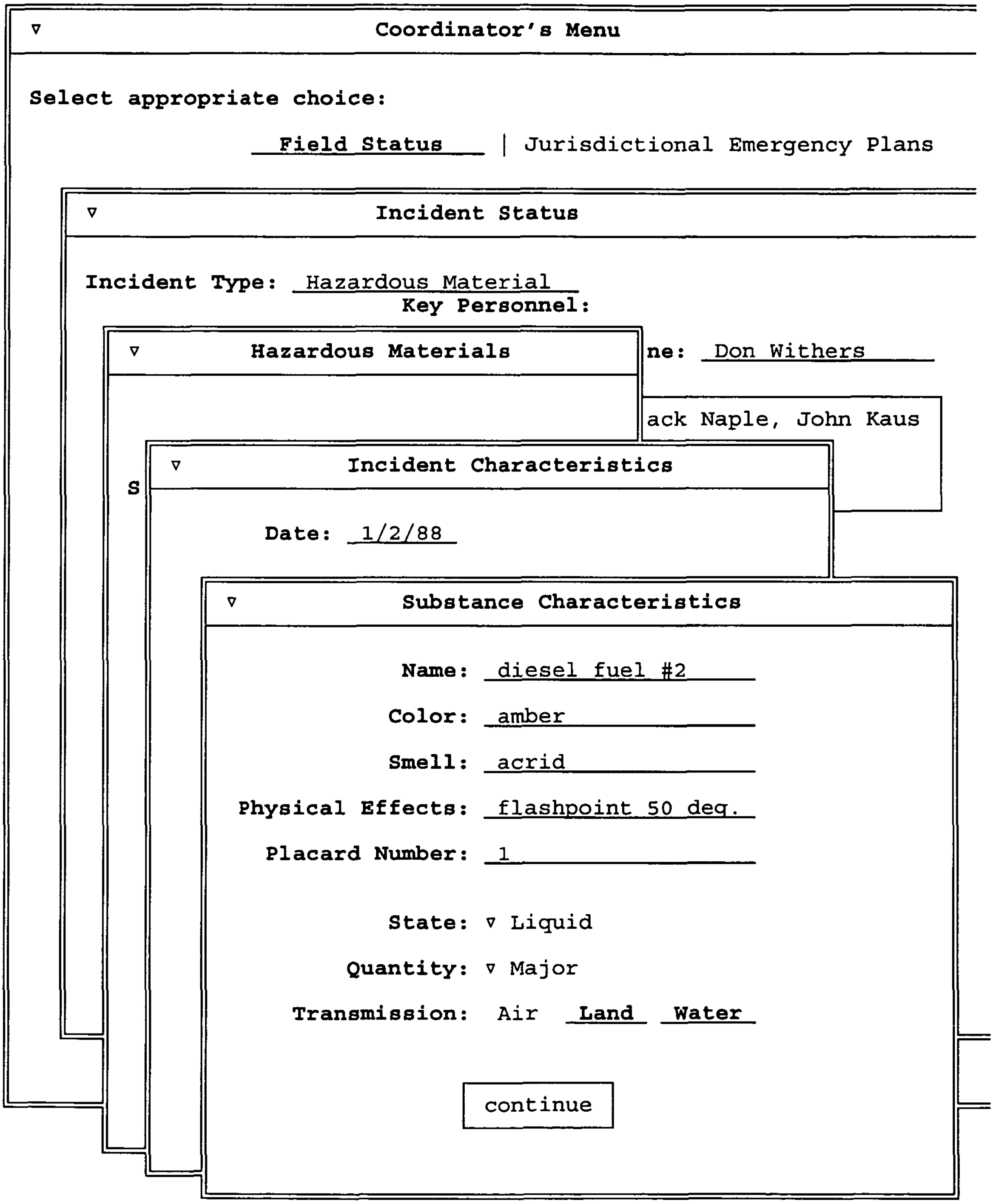
CONCLUSIONS AND RECOMMENDATIONS

In summary, linking information technology to organizational design and practice offers substantial potential for enhancing the process of self-organization among organizations participating in an evolving network of emergency response organizations. The primary effect of an IISIS is to maintain the balance between order and chaos that allows innovative response to changing conditions. That is, an IISIS serves to maintain sufficient structure to enable organizations to hold and exchange information as well as sufficient flexibility to enable them to adapt their behavior to rapidly changing conditions. The speed of information processing and the organization, selection, and representation functions of a well-designed information system, operated with trained practicing managers, support the functions of a complex system and facilitate informed choice and adaptive learning in reference to a shared goal.

Based on this understanding of the processes of self-organization in complex systems, four recommendations offer potential for increasing self-organization in the community management of hazardous materials.

- Develop a community-wide process of search, exchange, and maintenance of information relevant to hazardous materials, potential releases, vulnerabilities, and resources for action.

Exhibit 2
Layered Screens from the IISIS Field Status Board



Select appropriate choice:

Field Status | Jurisdictional Emergency Plans

Incident Type: Hazardous Material

Key Personnel:

ne: Don Withers

ack Naple, John Kaus

S

Date: 1/2/88

Name: diesel fuel #2

Color: amber

Smell: acrid

Physical Effects: flashpoint 50 deg.

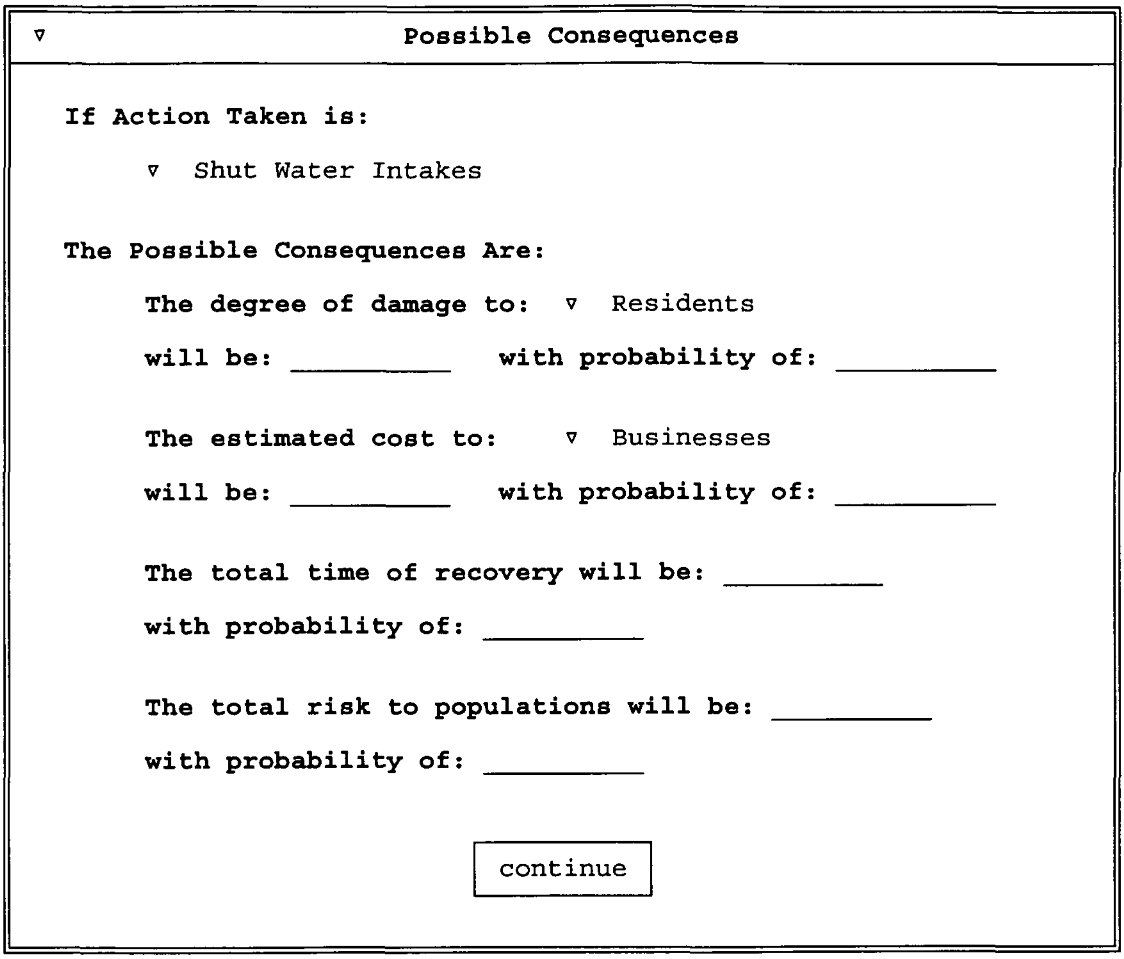
Placard Number: 1

State: ▿ Liquid

Quantity: ▿ Major

Transmission: Air Land Water

Exhibit 3
"Likely Events" Screen from Intelligent Reasoning Component, IISIS



▽ Possible Consequences

If Action Taken is:

▽ Shut Water Intakes

The Possible Consequences Are:

The degree of damage to: ▽ Residents

will be: __________ with probability of: __________

The estimated cost to: ▽ Businesses

will be: __________ with probability of: __________

The total time of recovery will be: __________

with probability of: __________

The total risk to populations will be: __________

with probability of: __________

- Engage responsible organizations in a regular process of communication, dialogue, and action to assess existing risks and to develop the skills to reduce that risk.
- Clarify the goal of responsible hazardous materials management for different types of organizations with different levels of responsibility and resources for action.
- Invest in the information technology and infrastructure that will allow community organizations—public, private, and nonprofit—to operate as a 'complex system.'

The vital but elusive characteristic of self-organization is its spontaneity. While influenced by the actions of other organizations or groups, it cannot be imposed by external regulation nor can it be suppressed by perpetual chaos. From either order or chaos, a system will move toward the creative balance of order and flexibility that distinguishes an effective complex system. The task for emergency managers is to maintain that balance under dynamic conditions.