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Essays on Leadership in Organizations

Learning under Uncertainty: Networks in Crisis Management

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This article examines learning in networks dealing with conditions of high uncertainty. The author examines the case of a crisis response network dealing with an exotic animal disease outbreak. The article identifies the basic difficulties of learning under crisis conditions. The network had to learn most of the elements taken for granted in more mature structural forms—the nature of the structural framework in which it was working, how to adapt that framework, the role and actions appropriate for each individual, and how to deal with unanticipated problems. The network pursued this learning in a variety of ways, including virtual learning, learning forums, learning from the past, using information systems and learning from other network members. Most critically, the network used standard operating procedures to provide a form of network memory and a command and control structure to reduce the institutional and strategic uncertainty inherent in networks.

All organizations and networks face some measure of uncertainty. Learning helps to manage uncertainty. The idea of network learning to meet asymmetric problems combines what Kettl (2005) has identified as the three major drivers of action in building a government for the 21st century: the imperative for knowledge-driven organizations, the increase in nonroutine problems, and the growing need for nonhierarchical solutions. The primary research goal of this article is to understand how networks learn under conditions of uncertainty by studying a crisis response network. In particular, I focus on mechanisms that foster learning during crises—intracrisis learning. A secondary research objective is to understand the role of network structure in reducing uncertainty.

Why do crisis response networks need to learn? Crisis management theorists have answered this question in different ways. A basic objective of crisis management is to accumulate wisdom by "learning together from the event in order to prevent, lessen the severity of, or improve upon responses to future crises" (Hillyard 2000, 9). Learning is one way of measuring the success of crisis response, with an effective response informing new policies and procedures that are applied to future incidents (Pearson and Clair 1998). According to Comfort, the crisis response network is "necessarily a learning system" because it "depends upon the ability of its participants to generate valid information, facilitate informed choice, and foster timely commitment to action. Further, the network is strengthened when the participants reflect upon actions taken, retain the procedures that proved effective, and discard those that were not" (1988, 5). The ability to learn during crises gives responders the capability, flexibility, and confidence to deal with unexpected events (Roberts and Lajtha 2002).

The topic of learning during crises also needs special attention because it is different from learning in routine situations. The scope of learning required during crises is inherently greater, demanding new understanding of the most basic aspects of the causes, consequences, and solutions. Even in routine situations, learning is incomplete because of bounded rationality (Simon 1991). Too much information is met with limited human cognition that restricts search and evaluation processes. However, routine environments will, through trial and error learning, facilitate the cumulative understanding of cause and effect factors. Rationality is even more bounded in nonroutine situations, in which the range of what is certain is diminished, relevant experience is lacking, heuristics are not

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available or provide faulty guidance, and search processes are even more incomplete. Administrative man may still be intendedly rational when facing a crisis; he has a general goal of returning to normalcy, but the obstacles limiting his knowledge of *how* to return to normalcy are more extreme.

This article begins by reviewing the crisis management literature to assess the possibility of crisis learning. I then describe the challenge faced by a network that was responsible for eliminating an exotic animal disease in California. The subsequent section applies Koppenjan and Klijn's (2004) model of network uncertainty to the case, examining the nature of substantive, strategic, and institutional uncertainty. Finally, the particular ways in which the network was able to learn are described in detail.

The Possibility of Crisis Learning

In this article, learning refers to the identification and the embedding of practices and behaviors by the network to improve crisis response. This is consistent with instrumental definitions of learning occurring in organizations (see Argyris and Schön 1996, 16; Levitt and March 1990; Mahler 1997, 519; Moynihan 2005; Senge 1990) or networks (Koppenjan and Klijn 2004, 124). Despite this instrumental approach, the organizational learning literature "offers relatively few treatments of the problem of how to build learning organizations" (Lipshitz, Popper, and Oz 1996, 301), an oversight that is even more pronounced in network settings and crises.

To supplement the extensive literature on organizational learning, I focus specifically on the possibility of crisis learning. Crises are characterized by high consequentiality, limited time, high political salience, uncertainty, and ambiguity. Large-scale crises overwhelm individual organizations and demand a network of responders (Boin and 't Hart 2003). According to Boin et al., crisis learning contains a paradox: "When the need to learn is at its peak, the institutional capacity of public leaders and their organizations may be disappointingly low" (2005, 120). There are multiple reasons why crisis learning is difficult, summarized in the list in the next column. These barriers to learning are examined in greater detail in the remainder of this section.

The consequentiality of crises makes learning more difficult. We learn best from experience, observing our failures and remedying them in the future (Senge 1990, 23), but high-consequence events make incremental experiential learning prohibitively costly (La Porte and Consolini 1991). In such cases, it will be cheaper to look for alternatives to trial and error learning.

Barriers to Effective Learning During Crises

- The high consequentiality of crises makes trial and error learning prohibitive.
- Crises require interorganizational rather than organizational learning.
- There is a lack of relevant experience, heuristics, SOPs, or technologies to draw on.
- The scope of learning required is greater than for routine situations.
- The ambiguity of previous experience gives rise to faulty lesson drawing.
- Crises narrow focus and limit information processing.
- There is a rigidity of response: actors recycle old solutions to new problems.
- Political dynamics give rise to bargaining and suboptimal decisions.
- Crises provoke defensive postures and denial of the problem, responsibility, or error.
- Crises provoke opportunism as actors focus on their positive role.

The potential to learn depends greatly on the availability of applicable lessons. Some situations will clearly be more applicable than others, depending on variables such as time, geography, the nature and scope of the crisis, relevant technologies, the actors involved, and so on. However, crises, by their very nature, occur in unexpected and unique ways. Despite attempts to apply lessons from one crisis to another, the ambiguity of cause and effect relationships allows multiple, contradictory, and mistaken lessons to emerge from crises (Auf der Heide 1989, 7; Boin et al. 2005, 116). Even clear warnings of impending crises can be overlooked, misinterpreted, or ignored (Boin and 't Hart 2003, 547). Turner (1976) found that preventable disasters frequently could be connected to rigid institutional beliefs, ignoring outside complaints, difficulties handling multiple sources of information, and the tendency to minimize danger.

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Even as crises make learning difficult, they demand that decisions be made. Urgency can lead to ill-considered lessons (Boin et al. 2005, 122). The wish to avoid past mistakes blinkers decision makers and limits information processing. Threat rigidity may occur, whereby people respond to new threats in a rigid and inflexible manner, recycling previous responses and known routines for new problems (Staw, Sandelands, and Dutton 1981; Stern 1997).

Crises can also limit learning by fostering defensive reactions and opportunism. The politics of accountability tends to seek guilty individuals, overlooking system failures (Drabek 1994, 32) and fostering defensiveness. As a result, actors disassociate themselves from perceived negative outcomes and deny that a problem exists, or deny that they made an error or that they are responsible for a solution (Argyris and Schön 1996). Information is suppressed or used as ammunition to rationalize behavior and deflect blame rather than to identify useful lessons (Boin and 't Hart 2003, 548; Boin et al. 2005, 120). Opportunism limits learning because actors misframe crises to exaggerate the positive role that they have played (Stern 1997, 78).

Up to this point, we have discussed some of the basic difficulties of learning from crises, but crises can also create learning opportunities. In areas in which actors perceive themselves as being closely accountable, crises prompt them to process information effectively (Tetlock 1992). Lagadec (1990) sees the potential for crisis learning if certain principles are followed: identifying the major hazards, including those that are taboo; involving partners; making strategic decisions to reduce risk; and making leaders responsible for these issues.

Distinguishing between the puzzling ("the capacity to learn: what went wrong, why and what needs to be changed so that it will not happen again?") and powering ("the capacity to reform: can policy makers instigate substantive changes in the wake of leadership") components of crisis learning gives rise to the insight that crises may make puzzling more difficult but make powering easier (Boin et al. 2005, 116). Powering becomes easier because crises have a catalytic effect, focusing political attention, widening the interest of involved publics, incorporating new ideas, and breaking down resistance to change (Birkland 1997).

The powering aspects of crises should not be exaggerated. Jasanoff's (1990) study of the aftermath of the Bhopal disaster identifies how preexisting policy ideas found new political support, but she concludes that this type of learning was more akin to an incremental muddling through rather than a major paradigm shift that may be beyond contemporary policy institutions. The political dynamic of learning in high-profile incidents can mean that learning is shaped by the distribution of power and the negotiation of bargains. Such bargains may be compromises that weaken optimal solutions (Lovell 1984). Schwartz and Sulitzeanu-Kenan (2004, 97) warn that although crises draw political attention, policy change requires certain conditions: a perception of a problem in need of a solution, a perception that increased legal and hierarchical accountability is a feasible solution, and a political climate that is conducive to policy change.

Experience from previous events can be usefully applied to similar crises and represents a form of learning from the past. Comfort (1989, 1994) points out that earthquake responders in San Salvador and California benefited from the accumulation of experience from previous earthquakes because the actors involved had a better understanding of role expectations and appropriate processes, as well as a more complete base on which to develop strategies in response to their environment. Such useful experience can be converted into standard operating procedures (SOPs) that can be applied to other crises and adjusted as appropriate.

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To further parse the relationship between crisis and learning, it is useful to recognize the distinction between intercrisis learning (learning from one crisis and making changes to prepare for another) and intracrisis learning (learning that seeks to improve response during a single crisis episode). Both types of learning are relevant in any crisis because response leaders will seek lessons from past experience but also make ongoing assessments about the effectiveness of the current response. There is less research in intracrisis learning, which this article focuses on, because such learning is typically a retrospective exercise (Jasanoff 1990).

Additionally, the dynamic nature of a crisis makes intracrisis learning more difficult than intercrisis learning (Lagadec 1990, 21). In postcrisis phases, the meaning of the event has been defined, making it easier to identify suitable policy changes. During a crisis, actors must engage in sensemaking under limited time and intense pressure, evaluating the nature and scope of a crisis and searching for an appropriate response (Boin et al. 2005). Responders do not have the luxury of carefully calculated decisions but instead must engage in "fuzzy gambling" (Dror 1989), making decisions in the face of uncertainty with little sense of basic probabilities.

Actual crisis experience helps, giving responders an ability to deal with pressure, to engage in sensemaking, and to recognize when constraints such as rules are helpful or not (Comfort 1989, 334). Virtual experience, in the form of simulations, can offer some of the same benefits, as participants undergo the psychological experience of a crisis (Lagadec 1990).[1] Simulations also help to foster relationships with potential network members (Dror 1989; Hillyard 2000).

Intracrisis learning is facilitated by the ability of responders to establish equilibrium between action and an unsteady environment—what Hedberg, Nystrom, and Starbuck (1976) refer to as a "self-designing organization." Such attributes include a culture that "cherishes impermanence" and accepts the need to constantly monitor the environment and amend procedures (43). This ability is distinct from planning, which relies on the past as a guide to the future and therefore is prone to error. Instead, Hedberg, Nystrom, and Starbuck warn that "an organization should plan on its future but not rely on its plans" (59).

In routine crises, standard procedures that work well in one setting can usually be applied to another, as the fighting of forest fires has shown (Bigley and Roberts 2001). In such a setting, successful intercrisis learning reduces the need for intracrisis learning. Forest fire fighting operations are also an example of high-reliability organizations. While the literature of high-reliability organizations has largely focused on crisis prevention rather than crisis response, some of the properties of such organizations—adequate resources, processes that reward error discovery, a commitment to continually search for system improvement, and a strong sense of mission valence—also appear to be consistent with intracrisis learning (La Porte 1996).

Less familiar crises with nonroutine tasks are more difficult to manage (Dynes 1970). The potential for a disjuncture between processes and the environment is more likely when responders are relying on a set of embedded procedures from a different environment (Hedberg, Nystrom, and Starbuck 1976). In such a situation, intercrisis learning can restrict intracrisis learning, as historical analogies create blind spots or cognitive prisons (Brändström, Bynander, and 't Hart 2004). The SOPs that are appropriate to one crisis can become inappropriate constraints in another setting, requiring responders to unlearn previous processes before new ones can be created (Comfort 1988).

Comfort's research on how responders code and distribute information also offers insights into intracrisis learning. Comfort (1989) argues that human processes are incapable of matching the information demands of a crisis and that the use of information systems extends the decision capacity of responders. Information systems foster network coordination by providing timely and accurate information and can act as error-detection systems, identifying discrepancies between plans, actions, and outcomes (Comfort 1988). Another example of an intracrisis learning practice is the reliance on daily meetings among responders. In such meetings, previous events are analyzed and the day's action items are established and communicated. Such meetings facilitate a "common knowledge base" about the nature of the task, fostering mutual coordination and adjustment (Comfort 1994). Through such interactions, the participants learn each others' capacities and preferences.

A Network under Stress: The Exotic Newcastle Disease Taskforce

To illustrate the possibility of learning under conditions of uncertainty and urgency, I present case evidence on the outbreak and eventual containment of exotic Newcastle disease (END) in the state of California. The disease is highly contagious and generally fatal among poultry. It affects the respiratory, nervous, and digestive systems of poultry and other birds. END can completely wipe out an unvaccinated flock, and even vaccinated birds are susceptible. END spreads relatively quickly, making it difficult to track and contain. The virus survives for long periods in ambient temperatures, which increases the difficulty of limiting the spread of and eradicating the disease. The virus can travel in the excrement of infected birds, and bird saliva can transfer the virus via contaminated water, implements, cages, boots, and human clothing. The commercial poultry industry, by keeping chickens in close proximity, allows such diseases to have a huge impact. END has the potential to cripple a poultry industry, and the discovery of END in California prompted trade bans by major export markets.

An outbreak of END in California was confirmed on October 1, 2002, and subsequently spread to Arizona, Nevada, and Texas. Quarantines were also placed in Colorado and New Mexico. A taskforce was created to eradicate the disease, involving a network of 10 state and federal agencies, including veterinarians, forest service officials, health and human service officials, highway patrol officers, lab technicians, and short-term employees. Appendix 1 details the network participants and their respective roles. More than 7,000 workers rotated in and out of the network, although the maximum size at any one time was approximately 2,500.

Once quarantines were established, network teams visited private residences and commercial bird premises to diagnose whether an infection existed or was nearby. If there was a suspected case of END, the value of the birds was appraised, the birds were euthanized, and the premises were cleaned and disinfected. The network found 932 premises that were infected. By September 16, 2003, final quarantine restrictions related to END were removed. The network was successful relative to the nearest parallel, the 1971 outbreak of END in California, because it took less time and resources to eradicate the disease.

In understanding the value of the END case, it is helpful to bear in mind some basic contingencies. The case offers insights into the possibility of intracrisis learning under two specific conditions. First, there was very limited previous experience that could be drawn on. This made intracrisis learning more pressing and more challenging. Second, the crisis evolved over the course of several months, giving responders the chance to adapt responses and reducing the risk of problems such as panic or cognitive overload among decision makers. Learning was badly needed, and responders had time to learn, providing positive conditions for intracrisis learning. In this respect, the END case provides what George and Bennett (2004) refer to as a crucial case test—failure to learn under such circumstances would challenge whether theories of intracrisis learning are plausible. However, these conditions should also inform any effort to generalize from the case. Some crises are so extreme and occur so rapidly that by the time a reasoned evaluation can be made, the response phase has passed and only recovery remains. Other crises, such as the END case, allow longer response periods, even as they retain the crisis characteristic of urgency (Lagadec 1990; Rosenthal et al. 1988, 436).

It is worth characterizing the case in relation to other forms of networks. Following Hall and O'Toole and most studies of networks, I treat networks as multiple organizations dependent on one another to achieve a common goal (Hall and O'Toole 2000, 677). As will be described in subsequent sections, the taskforce employed a hierarchical structure of authority in the form of an incident command system. Though networks are sometimes presented as an ideal-type with decentralized structural forms and voluntary coordination (Powell 1990), research has shown that networks employ varying levels of centralization (Provan and Kenis forthcoming). While centralization is distinct from hierarchy, it raises the possibility of alternate network governance structures, of which command and control is one example, albeit an unusual one.

The END taskforce showed aspects of both network and hierarchy. The key management challenge was a network challenge: how to coordinate actors from different organizations in working toward a common goal under crisis conditions of decisional urgency, high uncertainty, and threat (Rosenthal et al. 1989). But the network used a governance approach that resembled a hierarchy, with formalized rules and authority flowing through a command and control structure. The applicability of the case findings to other types of networks and crises is examined in the conclusion.

Case evidence comes from three major sources that provide detailed accounts of the outbreak. First, the Policy and Program Development Unit of the Animal and Plant Health Inspection Service (APHIS, part of the U.S. Department of Agriculture) developed a 289-page after-action review that drew on 75 individual interviews, six focus groups, and a survey of 2,400 network participants (Werge 2004). Second, APHIS also commissioned an outside review of the outbreak, leading to a four-volume, 343-page series of reports by the CNA Corporation (Howell 2004; Howell et al. 2004; Speers and Webb 2004; Speers et al. 2004). The text of both sets of reports was transferred into a qualitative software package for content analysis. Finally, I undertook interviews with 13 senior managers from the most influential organizations involved in the network—APHIS, the Animal Health and Food Safety Services (AHFSS, part of the California Department of Food and Agriculture), and state and federal forest service officials. Interviews were taped, transcribed, and content analyzed. The qualitative software facilitated a mixture of deductive and inductive coding of factors associated with the operation of the network. A number of interviewees and other END participants also provided comments on earlier drafts of my analysis.

The Nature of Network Uncertainty

Crises are defined by their relationship with uncertainty (Brändström, Bynander, and 't Hart 2004, 191), which Steinbruner defines as "an imperfect correspondence between information and the environment" (2002, 16). Crises are also extreme examples of the wicked societal problems that cut across traditional public boundaries and require a network response (Koppenjan and Klijn 2004). The idea of a network response to crises is not new. Although he noted that it was overlooked it the disaster literature, Dynes was discussing the role of interorganizational relationships as far back as 1970. He argued that new and nonregular crisis tasks would require an ad hoc network of responders. Three decades later, Hillyard (2000) detailed different types of crisis response networks in the areas of wildfire management, emergency management, and public safety.

Koppenjan and Klijn (2004) categorize three types of network uncertainty. Substantive uncertainty is the lack of knowledge about the problem or overload of nondefinitive information. Strategic uncertainty arises because networks contain multiple actors who retain some measure of strategic autonomy, creating uncertainty about what choices they will make. Institutional uncertainty arises from trying to coordinate actors who have their own perceptions, norms, and objectives and who come from different institutional backgrounds, administrative levels, or organizations. The value of this threefold categorization is that it underlines not only that networks face uncertainty related to the task but also that the network form itself increases uncertainty about coordination. The process of overcoming these uncertainties is a process of learning, according to Koppenjan and Klijn: "[C]ooperation presupposes learning between the actors, crossing the boundaries of organizations, networks and coalitions" (2004, 10). The remainder of this section examines substantive, strategic, and institutional uncertainty in the END case.

Substantive Uncertainty

There was little substantive uncertainty about the nature of the disease or about the goal of eliminating it. The main area of substantive uncertainty was how to achieve this goal. The mobility of END was one factor that made its elimination difficult. Most emergencies are centered in a particular geographic area, moving slowly and observably, if they move at all. One network member compared his experience of battling wildfires to END:

> On this kind of disease outbreak situation there is a much higher degree of uncertainty. In a fire situation, there may be an uncertainty such as the direction in which the fire is going to go, but it's a fire. But in the case of Exotic Newcastle Disease, is it Newcastle Disease? Is it not? Is it mutating somehow? Is it increasing its virulence? Is it decreasing its virulence? Is it being confused with other diseases? Do we really know what's out there? Is it really in this particular flock? Is it not in this particular flock? Is it in this community? Is it not? There's a much higher degree of not knowing what is actually going on.

Responders were never able to resolve the basic question of how the disease had entered California.

Identifying and eliminating carriers was made more difficult by the outbreak of END among backyard flocks. Preplanning had assumed that any major avian disease would occur among commercial poultry. According to the Agriculture Department area veterinarian in charge, Dr. Paul Ugstad, "I don't think any of us in our planning had any idea of how difficult it is dealing with an outbreak in an urban neighborhood. I don't think any of us understood the magnitude of the backyard poultry population. We are very comfortable with, and become accustomed to, working with traditional agricultural production facilities." The search for infected backyard fowl dominated network activities, accounting for 96 percent of premises investigated (Speers et al. 2004, 68).

If the outbreak had occurred only among commercial producers, managing the outbreak would have been simpler to deal with in many respects. Commercial firms are smaller in number, easily identifiable, and easier to coordinate. They have a staff on hand that can help dispose of the birds. Because commercial operations are similar, standard methods of appraising birds and cleaning and disinfecting premises work well. The backyard population was more challenging to deal with. Most obviously, there was a lower effort-to-payoff ratio. The average number of birds depopulated in backyard premises was 59, whereas the equivalent number for commercial premises was more than 120,000 (Speers et al. 2004, 75). Each backyard premises was slightly different, making it more difficult to write standard procedures that would satisfy all situations. The type of birds might differ from one owner to another, making appraisal slower and more complicated. The disease spread more quickly and in more unpredictable ways because of the ability of birds to move around in neighborhoods and because of their interaction with humans.

Detection was also more difficult in backyard populations. The network did not know who infected bird owners were, and the probability of self-reporting was low. Many backyard owners have limited discretionary income, reducing the likelihood that they will contact a veterinarian if their birds become sick. In addition, the disease was prevalent among the estimated 1 million game fowl in California (Speers et al. 2004, 16). Although owning game fowl is not illegal, cockfighting is, leading to suspicion of public officials among owners. Game fowl interacted regularly in the unsanitary conditions of cockfight meetings, providing ideal conditions for the spread of the disease. The cockfighting season runs from Thanksgiving to the end of December, just as the network was trying to quarantine the movement of fowl. The backyard dimension also added a cultural complexity to the work of the network, as a high proportion of the backyard owners were Hispanic. Network members had to go into poor Hispanic neighborhoods and seek cooperation with the locals. This was a daunting task for many who did not speak Spanish, had little knowledge of local geography, were unfamiliar with the culture, and were from parts of the country with a much lower percentage of Hispanics.

Substantive uncertainty translated into role uncertainty for individual network workers. Many found themselves in an unfamiliar environment, working with individuals they had not met before, and being assigned to tasks with which they had little or no experience. Given the absence of a readily available set of management principles and tactics for END, basic tasks and procedures had to developed and disseminated to network members as the disease spread (see Howell 2004, 24–25, for a list of these tasks).

The case shows how the urgency of crises exacerbates problems of uncertainty. Developing substantive knowledge about uncertain conditions and constructing a network both take time. However, a crisis setting does not allow time. The network has to be constructed quickly. Decisions have to be made at a rate consistent with the pace of events rather than negotiated by consensus. The END outbreak required a rapid response, and failure to implement tasks quickly meant that the problem would become exponentially worse. As the network grew rapidly in size from 100 to more than 2,000 people, the administrative resources of the agencies involved were increasingly taxed. The urgent nature of the task, combined with the dramatic growth of the network, stretched the ability of the network to focus on anything other than day-to-day operations, demoting the development of policy or management systems to secondary concerns.

Strategic and Institutional Uncertainty

Whereas substantive uncertainty is driven by the nature of the problem, both strategic and institutional uncertainty are inherent to the network form. Actors came from different levels of government and very different types of organizations (see appendix 1). APHIS and its state counterpart, AHFSS, provided a high number of vets and filled most senior positions. These vets were familiar with dealing with animal diseases. The U.S. Forest Service and the California Department of Forestry and Fire Prevention were less influential in the network but, unlike most of the vets, had a great deal of experience in organizing emergency response.

Much of the strategic uncertainty that networks face arises from their relatively loose structural form. Membership tends to be voluntary, members can leave when they want to, and collective decisions depend on consensus rather than the giving and receiving of orders (Powell 1990). Strategic uncertainty is likely to be particularly high in new networks, as the various actors seek to maximize their position in the network but know little about the intentions of other actors. As network actors develop relationships and interdependencies with one another through repeated interactions, trust increases, as does knowledge of the strategic calculus of other members. Familiarity is also likely to reduce institutional uncertainty, as the different backgrounds of actors become known and as the ways in which these differences can acceptably shape behavior become defined. Networks that grow old are therefore in a better position to resolve strategic and institutional uncertainty.

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The urgency of crises limits the opportunity for responders to develop and rely on trust-based relationships during a crisis. Consistent with the findings of Hillyard (2000), strong prior working relationships and preplanning helped to reduce strategic uncertainty and institutional uncertainty. Prior to the outbreak, California's mobilization plan for exotic diseases affecting livestock (CDFA 2002, 9) had identified that such diseases were the joint responsibility of the state veterinarian from AHFSS and the area veterinarian in charge, a federal employee of APHIS permanently based in California. In California, state and federal officials had strong working relationships and daily interactions prior to the END outbreak. Once the outbreak occurred, they formed a partnership to deal with it and maintained this partnership throughout the outbreak, even though federal money and human resources were increasingly used as the network grew larger. This partnership formed the hub of the network, reducing the potential for possible power struggles.

Formal structure was also key in fostering coordination in the form of an incident command system (ICS). Versions of ICS have been around for decades, but this approach has become more important since the U.S. Department of Homeland Security published a new national policy on crisis management. The National Incident Management System pushes all federal, state, and local crisis responders to use ICS (DHS 2004). ICS gives an incident commander responsibility for organizing the basic managerial functions required for most crises: operations, logistics, planning, and finance and administration. When an incident becomes too large or too geographically diffuse, additional incident commands are established under the control of a single area commander. The ICS essentially overlays a hierarchical structure on a network, using a central command to manage conflict, coordinate action, and reduce classic network characteristics, such as a reliance on consensus. Consistent with the partnership that AHFSS and APHIS had developed, they formed a joint command to run the ICS headed by one commander from each organization. This appeared to work well, and network members saw the ability of the key agencies involved to work together as a major success factor (Werge 2004).

The adoption of the ICS helped to curb strategic uncertainty by reducing the autonomy of member agencies. It reduced institutional uncertainty by establishing a common management framework. One participant noted that the ICS "gives us that common terminology, common organizations so we immediately can start working closely with each other . . . when we are all trained on the same organizational model, it comes together seamlessly."

The ICS created learning challenges of its own. Most network members had not worked with an ICS framework before, and so many network members had to learn what the ICS was and how it was supposed to operate. As Human and Provan (2000) point out, the perceived legitimacy of the network in the eyes of its members is critical for its evolution and success. Ultimately, members accepted the combination of the network and ICS approach as appropriate to achieve their shared goals. Even so, the vague nature of the ICS left much to be decided, including how to staff the ICS and how to adapt it to the peculiarities of the crisis. Most of the key staffing decisions were dictated by the AHFSS and APHIS, but members of the network did not consistently agree on how to adapt the ICS to the needs of the crisis. As Koppenjan and Klijn (2004) suggest, institutional background shaped interpretation. The vets involved, who had little experience with ICS, were more likely to argue that the ICS model needed to be changed and adapted to the needs of the outbreak, in terms of both structure and the level of discretion given to teams executing tasks. The forest service officials had used ICS many times and thus did not see the need to adjust a model they perceived as working well.

One factor that exacerbated uncertainty was turnover in the network. The network was tasked primarily by temporary workers. While many frontline workers came from temp agencies and could be employed for the duration of the outbreak, most supervisors and managers were borrowed staff. They rotated in and out of the network, typically serving for three weeks or less because of the continued needs of home agencies, as well as the burnout factor arising from performing a difficult and stressful task for long hours and usually away from family. Organizational learning begins with the individual, and the lack of continuity limited the ability to build up experience among personnel.[2] Employees starting a new position had to learn their roles, just as the old occupant had finally mastered his. Even those serving a second or third term in the network might find themselves working in a different role than they had before, adapting to unfamiliar supervisors, with different preferences and ways of operating.

Methods of Learning

The END network learned in a number of ways, summarized in the list in the next column and examined in turn.

Virtual Experience

Virtual experience provides an understanding of crisis task demands by simulating these demands through preplanning, role-plays, training, and simulations.

Learning in Emergency Networks

- Virtual experience: Identify which categories of lessons are suitable for pretraining and on-the-job training.
- Other network members: Bring together appropriate complementary skills, identify skills that are capable of being learned and those which are better left to specialists.
- Information systems: Create timely information systems that monitor allocation and achievement of tasks.
- Learning forums: Ensure that information is examined and discussed on a regular basis and that it shapes operational decisions.
- SOPs: Build and disseminate formal routines where none exist.
- The past: Draw lessons from the past cautiously and sparingly, remaining aware of differences with present. Generic management systems and skills are easier to transfer.

Such virtual experience avoids the risk of costly error inherent in trial and error learning. Three types of virtual experience were relevant for the END network: pretraining that occurred as part of the home organization's regular training, preplanning, and on-the-job training during the emergency.

There was some pretraining in the concepts of ICS among both federal and state actors, although it was rarely complemented with practical experience. One vet noted his limited familiarity with ICS: "I think I had taken an online, very introductory course several years ago but I had no specific training at all for that position that I was in." This is not to suggest that pretraining is not useful—indeed, it forms the basis for the expertise of the various network members and therefore the rationale for their inclusion in the network. But pretraining that is unrelated to practice is less likely to be perceived as relevant until a situation arises in which those skills are actually required.

Preplanning suffers similar risks. There was preplanning for the general threat of exotic animal diseases but little specific attention paid to END. In any case, the backyard nature of the outbreak ran counter to expectations about how END would occur, and detailed preplanning based on this faulty assumption would have offered limited help in developing specific response techniques. The main benefit of preplanning meetings was that it brought together the relevant actors, fostering working relationships before the crisis occurred (see also Boin et al. 2005, 147).

To complement the limited pretraining and preplanning, there was a good deal of highly specific on-the-job training. The after-action review of the outbreak notes, "The 2003 END outbreak represents the largest on-the-job training experience in animal health incidents in the last thirty years" (Werge 2004, 9). Network employees were given training for the particular tasks they were to implement, that is, cleaning and disinfecting, euthanizing, or disposing. This training was particularly critical for frontline employees who had no relevant experience. As part of their training process, employees had to read the parts of the SOP manual relevant to their job and sign a statement confirming that they understood these SOPs. This was true even of employees who were returning to the network for a second or third rotation. On-the-job training had a clear relevance to network members. It was not a set of intangible skills that might serve at some uncertain point in the future. Instead, training provided skills that were needed to deal with an immediate and vital task. The major disadvantage of on-the-job training was that it delayed the point at which responders were ready to enter the field.

Learning from Others

Organizations learn from one another (Levitt and March 1988), and one of the expected benefits of networks is to facilitate this learning. Networks speed up the diffusion of information and provide more detailed and credible sources of information (Kraatz 1998). Network members tend to imitate the practices of one another and are particularly likely to look to other members with expertise in an area that is rife with uncertainty (Brass et al. 2004, 805). By pooling knowledge, interorganizational learning reduces substantive uncertainty and fosters partnership skills among participants (Brass et al. 2004).

The logic of learning from the experience of others is similar to that of virtual learning. It allows learning from failure without incurring the cost of failure. The most prominent example of learning from others within the END network was the reliance on state and federal forest service officials to provide advice and leadership on how to use ICS and to transfer this knowledge to others. One network member noted, "The use of ICS for END represented a steep learning curve for animal health agencies and for others involved in the incident." Another recalled, "I was lucky enough to have a Forest Service mentor. . . . It was really the organizational structure, the ICS structure that they were mentoring us on and specific functions because a lot of us were going into positions we had never ever done before."

In some cases, the organizations in the network might not actually try to learn from others but instead expect that other members become responsible for tasks relevant to their specialization. This is a logical response when the expertise involved is complex enough that the costs of learning it are higher than the costs of having another do it, and the cost of learning will not be offset by future use of that knowledge. For instance, firefighters did not need to learn about epidemiology as long as vets were on hand. It did not make sense for the entire network to learn Spanish if they could contract out to workers with those skills. The network supported teams in the field by hiring guides who had knowledge of the local geography, culture, and language. By hiring this expertise, the backyard aspect of the outbreak became less formidable.

Learning from Information Systems

A well-established management technology is predictable, reducing the need for constant monitoring. By contrast, the technology of eliminating END was developed as the outbreak occurred, and its effectiveness had to be constantly assessed relative to the goals. In addition, a system was needed to task actions to multiple teams because they covered different geographic areas. The Emergency Management Response System (EMRS), a tasking system for incident response, provided such a mechanism. A manager looking at EMRS could tell whether premises had been visited and what actions had taken place or needed to occur. EMRS kept track of the location of personnel and other resources and reduced the potential for error, such as personnel visiting the same premises twice or reporting inconsistent information.

Comfort (1989) argues that information systems such as the EMRS are critical in facilitating crisis network response, but some systems are better than others. Information systems that fail to collect and deliver timely information through the hierarchy limit the potential for learning (Lagadec 1990). The EMRS avoided this problem by having an information flow that was consistent with the structural design of the ICS. Another potential problem is that information systems reflect the assumptions of their designers about which information is relevant and therefore may not be fully attuned to new challenges (Hedberg, Nystrom, and Starbuck 1976, 51). The emergent properties of the EMRS reduced this risk because it was flexible enough to be adapted to the particular conditions of END and the evolving needs of the network. For example, a tool to centrally track financial costs was added, as was an administrative component to track equipment, vehicles, and details about personnel including their contact information, completed training, and assignments. A task management component was added to allow the inclusion of information related to meetings and tasks. A mapping module was also added to the EMRS that allowed responders to see where the disease was occurring and nearby locations where the disease was likely to spread. This helped to prioritize where to send survey teams. Each field worker had a global positioning system receiver and a map that showed the grid for which the survey or surveillance team was responsible. Once premises in that zone were visited, the information was entered into the EMRS and future maps showed that these premises had been completed.

Learning Forums

Learning forums are "routines that encourage actors to closely examine information, consider its significance, and decide how it will affect future action" (Moynihan 2005, 205). Learning forums are consistent with what Argyris and Schön (1996) refer to as "dialectical learning"—a form of debate that reveals assumptions, biases, and facts and evaluates different alternatives. Such debate increases cognitive differentiation and integration (Stern 1997, 72). Established organizations or networks may be able to survive without a discursive analysis of processes and performance, but the demands and uncertainty of crisis response make learning forums essential.

During the most critical stages of the END outbreak, each incident command had a mandatory meeting that occurred early each morning. At the meeting, network members received updates on the status of the incident, new changes to practices, weather briefings, and operation plans for the day, including what and where tasks were to be achieved. The incident command meetings were accompanied by an incident action plan that summarized much of the information being exchanged, such as the number of birds depopulated, the number of premises quarantined, the number of infected premises, and the number of premises yet to be depopulated. Area commanders also held daily conference calls with the incident commanders.

Early in the outbreak, when there was a single incident command and a relatively small number of people working on the network, meetings were the dominant process by which information was shared and tasks were allocated. As the network grew, it increasingly relied on formal rules. One network participant noted, "Initially the group was small enough that we could use informal communications, but as the group got bigger it had to be formalized because, as you bring in that number of people, you have to have a working chain of command . . . You have to have procedures in place so that people coming in can understand what they need to do and what they shouldn't do." However, even with the increased importance of SOPs to guide employees, senior managers continued to use regular meetings to identify process and performance issues.

Creating Network Memory through Standard Operating Procedures

The increasing formalization of the network made SOPs the critical method by which lessons were stored and disseminated. SOPs encode inferences from history that guide organizational behavior, institutionalizing learning by recording, conserving, and retrieving experience through routines (Crossan, Lane, and White 1999; Levitt and March 1988). SOPs become, in effect, the organizational memory—or in this case, the network memory.

This model of learning reflects a cybernetic approach (Steinbruner 2002). The cybernetic approach assumes the need for a system that simplifies the decision burden in highly uncertain and complex environments. SOPs perform this task by providing a set of feedback loops that tell responders what action is appropriate in a given situation. In the cybernetic model, SOP responses represent a form of automated learning. Higher-level learning occurs when the SOPs themselves are changed, with new processes gradually replacing older ones if they reduce error or offer superior responses to critical variables (Steinbruner 2002, 78–79).

In the END case, SOPs had to be written, and sometimes rewritten, as the outbreak was occurring. The SOPs were developed based on the insights of network members as they learned more about the disease, as the following comment from a network participant illustrates:

> Operationally, we knew what to do. We had to make certain adjustments. For example, cleaning and disinfectant, we know basically how to clean and disinfect something. We know how disinfectants work, how to use them. But we did not know how much you had to do to disinfect these backyards. How do you know these yards are clean? So we had to do some trials and studies during the course of the outbreak to come up with some SOPs.

Feedback from the public also led to SOPs:

> There were literally thousands of SOPs that were created, and I think that, in fact, that standardization is something that is needed in those kinds of situations because you have this tremendous pressure of rotation all the time. You know, people coming on not knowing how to approach things. The lack of standardization when we went out and talked to people in communities was one of the things that drove the community people crazy because the way you treated this person was different from the way you treated that person and the way this other person got treated.

While the initiation of SOPs was mostly a bottom-up process, they were subject to review at area command and, in some cases, were also initiated by area command staff. The process operated in a way consistent with the cybernetic model just described. The SOPs were developed and then modified to seek improvement and eliminate operational errors. Members of the public and network members themselves were encouraged to offer feedback to the network. In doing so, they provided forms of error detection. The SOP manual created during the taskforce ultimately exceeded 400 pages and provided procedures for every aspect of operations.[3]

Learning from the Past

Previous crises are an obvious source of lessons (Comfort 1989). However, learning from the past is risky and may provide faulty guidance. The ability to transfer lessons depends on the similarity of key conditions. For END, a perfectly similar crisis implies an outbreak of the same disease in a similar area, during a similar time period, and under similar conditions. For instance, APHIS staff who had worked in California during the 2002–03 outbreak proved invaluable in helping the END incident command in Arizona during the same period.

Any difference in conditions across outbreaks would reduce the ability to transfer lessons. The major barrier for the network was the lack of relevant parallels, what Levitt and March (1988) refer to as a "paucity of experience" problem. There had been no major outbreak of END in the United States since the early 1970s. Although the 1970s outbreak had involved the same disease in the same state, the passage of three decades and the backyard aspect of the most recent outbreak limited the applicability of the previous experience. Members of the network did read reports from that outbreak and brought back a manager from that period to offer insights. But the past could only teach the current network so much because information from that period was limited, technology and biosecurity had changed dramatically in the intervening period, and the previous network had not been consistently well managed. One lesson that did emerge from the previous outbreak was the importance of biosecurity training because it was suspected that government employees had inadvertently helped to spread the disease in the 1970s because of lax biosecurity procedures.[4]

As noted previously, more routine crises allow the effective transfer of SOPs from one crisis to another, but there is also a risk that routines from one crisis will be inappropriately applied to another. Because of the unusual nature of the crisis, the END network lacked SOPs and therefore avoided both the advantages and disadvantages of previously developed routines. Responders were not constrained by inappropriate rules, enhancing their ability to design processes that matched the environment. However, responders initially lacked a formal basis for response, and the scope of learning required was great.

The END network faced a paucity of experience problem, but the END experience provides lessons for future emergency networks on how to manage exotic animal diseases. In the aftermath of the END crisis, the U.S. Department of Agriculture commissioned both an internal after-action review, as well as an external review. APHIS hopes that the SOP manual developed during the outbreak can, with appropriate modifications, be applied to other exotic animal disease outbreaks. Advances made on the EMRS system during the END outbreak are likely to be reused in the future.

Management systems such as the EMRS and the ICS are generic forms of knowledge that are relatively easy to transfer. The ICS was developed in the early 1970s to help coordinate the response to forest fires, and it has since been used in a wide variety of crises. Because it is not specific to forest fires, forest service officials were able to adapt ICS principles to eliminate an avian disease. For the same reason, the ICS experience developed among APHIS personnel is likely to be the most crucial knowledge transferred to other animal disease outbreaks. As a result of END, APHIS has developed emergency management teams—specific groups of people with complementary ICS experience—that can be deployed together during future outbreaks.

Conclusion

This article has detailed how networks learn under conditions of uncertainty, using the experience of a network of crisis responders. Starting with limited relevant experience and high uncertainty, the network primarily learned its job while on the job. The establishment of SOPs documented the creation, ongoing adjustment, and diffusion of procedures intended to govern network actions. Learning of generic management systems also occurred, specifically the development of the EMRS and application of the ICS to manage exotic animal diseases.

The ability of the END network to learn may reinforce the conventional wisdom that the ICS is an appropriate and widely applicable approach to emergency management (DHS 2004). However, it is a mistake to generalize from any single type of crisis to all others or to expect patterns of learning to occur in exactly the same way. The forms of crisis learning identified in the END case are relatively broad, and some will be applicable to more time-intensive crises. One obvious caveat is that the ability to create new situation-specific SOPs will be more limited in time-intensive emergencies. Another relevant caveat is that the success of network forms depends on their legitimacy in the eyes of members. While network legitimacy is ultimately helped by external legitimizing efforts, Human and Provan (2000) find that legitimacy is best built initially by showing members the practical benefits of the network form. As the Department of Homeland Security mandates the ICS format, it risks promoting an approach without first convincing responders of its merits. As a result, the ICS model may not always work as well as it did in the END case.

It is also important to consider the applicability of case findings to other networks. Even though networks vary in terms of their degree of centralization (Provan and Kenis forthcoming), the use of a hierarchical structure is unusual. Two points can be made here. First, the findings are important because these crisis response networks are relatively and increasingly common because, for many crises, no single organization or jurisdiction has the capacity to offer a comprehensive response (Hillyard 2000). Because of the efforts of the Department of Homeland Security to promote crisis response networks that use the ICS, we can expect such hierarchical networks to become even more relevant.

Second, the findings should be generalized to other forms of networks with care, especially if networks are highly decentralized, depend on voluntary forms of coordination, and deal with noncrisis situations. Less centralized networks will be less likely to need or be able to impose SOPs as a method of learning. Noncrisis networks will have less need to utilize centralization to ensure rapid coordination, as well as less need for virtual experience forms of learning since they can rely to a greater extent on trial and error learning. However, other forms of learning used in the END case appear particularly relevant to the network form. To the extent that networks rely on information as a form of coordination, information systems are important. Learning forums and other forms of interaction are consistent with network values of establishing relationships and trust that foster coordination (Brass et al. 2002). Perhaps it is an obvious point, but the ability to learn from other network members is one of the basic advantages of network membership and has been observed in other forms of networks (Kraatz 1998).

The END case raises two additional points that merit further discussion: (1) the role of structure in learning, and (2) the balance between exploration and exploitation of knowledge in a crisis context. Returning to Koppenjan and Klijn's (2004) threefold categorization of substantive, institutional, and strategic uncertainty, what does the case tell us? Consistent with the claims of Koppenjan and Klijn and other network theorists, the case supports the idea that networks provide a functional way of managing substantive uncertainty and fostering learning. However, Koppenjan and Klijn also point out that the network form increases strategic and institutional uncertainty, high costs given the time constraints of a crisis. The case evidence shows the role that network structure can play here. Hillyard (2000) has proposed that the nature and structure of the network will be contingent on the nature of the tasks faced and the organizational members involved and should be consistent with operational challenges and desired communication flows, whereas Dror (1989) has argued for hierarchical decision structures for crisis response networks. The case findings support these propositions. The use of the ICS structure reduced much of the strategic and institutional uncertainty that any network faces. Many network members still had to learn what the ICS was and how to adapt it to the particular context of END. This process was not without disagreement and conflict, but it was a more expeditious and harmonious solution than allowing the network actors to come to some agreement about how to organically coordinate with one another and resolve conflict. By reducing institutional and strategic uncertainty, the ICS reduced the learning challenge that the network faced. This finding is of interest because it runs contrary to recommendations from the organizational learning literature that centralization inhibits learning (Fiol and Lyles 1985) and from the network literature, which suggests that more decentralized networks are useful for dealing with complexity and uncertainty (Brass et al. 2004). It is important to note that this finding does not dismiss these earlier propositions, but instead it suggests that they have limited applicability for crisis response networks.

ICS is a structural design that reduces uncertainty and provides an easily understood architecture for action. Structure can also be understood as rules (Lynn 2003). Indeed, this is what Lipshitz, Popper, and Oz mean when they argue for a more structural approach to learning: "institutionalized structural and procedural arrangements that allow organizations to systematically collect, analyze, store, disseminate, and use information that is relevant to the effectiveness of the organization" (1996, 293). The most basic structural approach to learning is through the use of SOPs, and SOPs were crucial in ensuring clarity, standardization, and consistency in operations as the network grew.

The importance of SOPs in this case informs Milward and Provan's (2000) argument that networks must find a balance between rigidity and flexibility. We so frequently hear of the constraining impact of red tape on managers that it becomes easy to dismiss any type of formalized routine as a barrier to learning and innovation. However, in the evolution of every organization or network, there is a point when there is little organizational memory beyond what is carried about in the heads of employees. This period occurs early in the development of the organization or network, or when new tasks or uncertainty are prominent. At this point, formal routines represent a way of institutionalizing lessons learned and disseminating them to others. The challenge for established organizations and networks is to keep institutionalized learning from becoming so embedded that it acts as a barrier to new learning.[5]

In the END outbreak, there was no organizational memory. More pressing than the risk of inflexibility was the need to convert individual and group level learning into established routines that transferred the advantages of new lessons to the entire network.[6] The END case demonstrates that the need for formalization is particularly pronounced when the degree of uncertainty faced by the network is high. This insight is relevant to one of the basic tensions in the organizational learning literature—that between exploration for new knowledge and exploitation of old knowledge (March 1991). In situations of high uncertainty, such as crises, there is little choice but to explore for new routines before the organization or network is in a situation to exploit learned routines.

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Notes

1. Such forms of virtual experience work best when they include actual responders, including top executives and partner organizations (Lagadec 1990). Learning from simulations is improved when participants also engage in postsimulation intercrisis learning, examining how well they responded, the cumulative strengths and weaknesses of the response network, and what should be changed for an actual crisis response (Dror 1989).
2. March points out, "Since there is a positive relation between length of service in the organization and individual knowledge, the greater the turnover, the shorter the average length of service and the lower the average individual knowledge at any point" (1991, 78). In some cases, turnover can strengthen learning if the actors involved enter with new knowledge and the knowledge of the actors exiting has been incorporated into organizational routines. Given that much of the knowledge in dealing with END was learned on the job and that the tenure of members was so short, these conditions do not apply.
3. The SOP manual covered vehicle use, the reporting of accidents and injuries, the policy on media contacts, and the policy on overtime. Under finance, the manual covered the processing of purchase orders, the processing of indemnity claims, and budget reconciliation. There were mobilization and demobilization SOPs aimed to help orient employees. There was a section on personnel conduct and interacting with the public, and another section covered animal control, human health, pet bird protocols, biosecurity and safety, noncommercial site surveillance, commercial site surveillance, quarantine, diagnostics, epidemiology, regulatory enforcement in quarantines, disposal, euthanasia, cleaning and disinfection, movement and permitting, indemnity, sentinel birds, area quarantine release, and commercial poultry planning.
4. Another past experience that informed the taskforce was the foot-and-mouth disease outbreak in the United Kingdom in the late 1990s, which prompted state officials in California to plan for outbreaks of exotic animal diseases. This plan identified some lessons from the foot-and-mouth experience, such as the need for continuous surveillance, early detection, and working with the media (OES and CDFA 2001). But the guidance arising from preplanning was relatively vague.
5. Levitt and March (1988) refer to this as a "competency trap." Organizations may adapt routines that are initially superior but become fixed and, over time, are inferior to newer alternatives. In such situations, employees who discover superior alternative procedures may surreptitiously work around the formal SOPs (Ban 1995).
6. As Crossan, Lane, and White note, "Organizations naturally outgrow their ability to exclusively use spontaneous interactions to interpret, integrate and take coherent action. Relationships become formalized. Coherent action is achieved with the help of plans and other formal systems. If the plan produces favorable outcomes, then the actions deemed to be consistent with the plan become routines" (1999, 529–30).

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Appendix 1 Main Network Participants and Skills

Agency	Skill
Animal Health and Food Safety Services (part of the California Department of Food and Agriculture)	Veterinary expertise Understanding of END; how to identify disease, cleaning and disinfectant procedures Local knowledge Preplanning for animal disease response in California
Veterinary Services (part of the U.S. Department of Agriculture)	Veterinary expertise Understanding of END; how to identify disease, cleaning and disinfectant procedures Experience with other types of animal disease outbreaks
California Department of Forestry and Fire Prevention, U.S. Forest Service (part of the U.S. Department of Agriculture)	Experience with applying ICS in emergency situations Hiring flexibility Expertise on emergency logistics Experience in training and managing large number of emergency workers Experience and expertise in emergency planning
Office of Emergency Services	Awareness of the emergency resources available in different parts of the California state government Authority to coordinate the actions of state agencies toward emergency response Preplanning for animal disease response in California
Temp agencies	Personnel management of temporary workers Hiring flexibility
Temporary employees	Volume of work support Continuity at frontlines Knowledge of local environment, language, and customs
California Animal Health and Food Safety Lab and National Veterinary Services Laboratory	Ability to identify disease Development of rapid diagnostic test
National Response Management Team (part of the U.S. Department of Agriculture)	Coordination of federal agencies Develop interagency cooperation agreements with other Agriculture Department agencies Develop financial requests and reports for U.S. Office of Management and Budget
California Highway Patrol	Ability to enforce quarantine: created checkpoints at weigh stations to ensure that commercial vehicles observing quarantine; inspected trucks stopped for routine traffic violations
California Environmental Protection Agency	Understanding of disposal and decontamination procedures
California Department of Health Services	Understanding of health risk to humans Understanding of risk communication to the public