CHAOS, COMPLEXITY, AND CRISIS MANAGEMENT:

A NEW DESCRIPTION OF THE INCIDENT COMMAND SYSTEM

EXECUTIVE LEADERSHIP

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ABSTRACT

The Incident Command System (ICS) is one of the most tried and tested examples of applied systems thinking ever developed. It originated out of a need for managing some of the most complex problems known: the unstable “chaotic systems” (Prigogine, 1997) presented by emergencies and disasters. In recent years the new scientific paradigm of complexity science has evolved from chaos theory. The understanding and description of so-called “complex systems” is considered by one of the world’s leading scientists to be the most important challenge facing science (Wilson, 1999). The author has found that many of the principles of chaos and complexity theory come into play in the kinds of environments that gave rise to ICS, and in which ICS routinely functions. The problem addressed in this paper is to use the first quarter-century of ICS experience in California to shed light on the role of chaos in complex human-centered crises, and to explore some management implications.

The purpose of this paper is to provide the next chapter in a multi-year, systemic review of ICS (Cole, et. al., 1993; Cole, 2000), and to suggest a strategic vision of its future. A combination research method was used, including evaluative and historical methodologies, to derive key lessons from of California’s most experienced practitioners of ICS. The following questions were addressed:

1) What lessons can be learned from the collective experience of practitioners of ICS as it has evolved through its first 25 years?
2) What kinds of problems does ICS address most successfully?
3) Can ICS be described In the context of complexity science?

A questionnaire evaluating ICS attributes was distributed to current and recent command and general staff members of all 17 major incident teams in California. More than 4,000 data elements were subjected to rigorous statistical analysis, and the results were presented to a subset of the sample population for a follow-up Delphi analysis in which the attributes were consolidated into four overarching principles of ICS: predetermined internal alignment, scaleability, teamwork synergy, and progressive adaptation.

This analysis by California practitioners was then evaluated in the context of chaos theory and complexity science. The author describes the ICS *system* using concepts from systems theory, chaos theory, and complexity science, including where and how ICS works to “order chaos.”

Based on the performance evaluation by California’s veteran ICS practitioners and an exhaustive Literature Review, the author offers three recommendations for the strategic future of the Incident Command System. The first of these is to manage ICS at the system level with the same “urgency of purpose” that is applied at the incident level. Second, make ICS more generically acceptable by demystifying and “demilitarizing” its terminology. And third, the author recommends that FEMA take the leadership step of sponsoring a systematic evaluation of ICS in coordination with entities familiar with the emerging science of complex systems.

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INTRODUCTION

In *Consilience: The Unity of Knowledge,* evolutionary biologist Edward O. Wilson (1999) calls for nothing less than "the 'jumping together' of all knowledge….beyond science and across the great branches of learning" (p. 8), including not just the physical and biological sciences, but also the social sciences, the humanities, arts, and religion. *Consilience* is the magnum opus of one of the world's greatest living scientists. Its central argument is that there are a small number of natural laws, whose interlocking unites all knowledge. The search for these deep laws, says Wilson, is the most important pursuit of the human intellect, but it cannot be achieved by studying individual sciences or disciplines. Human constructs like physics, biology, mathematics, and language, are simply not adequate to face the emerging challenges to life on earth, which have become too complex for anything but a holistic analysis. Earth's biosphere is the most unique and complex environment in the known universe, and as Wilson writes, "Organisms and their assemblages are the most complex systems known" (p. 96).

In 1970 Wilson was a Harvard biology professor, but if he had been a California fire chief he would have had occasion to witness wildfires raging across suburbanizing landscapes, driven by unpredictable forces of erratic winds and variable fuels, engulfing multiple ecosystems and jurisdictions simultaneously, jumping freeways, consuming housing developments and urban forests, leapfrogging over mountain ranges into new watersheds and communities. Wilson *the professor* may have never witnessed such a wildfire, but Edward O. Wilson, *scientist and theoretician*, would have no trouble recognizing the familiar faces of chaos and complexity. He would recognize that the

term “jurisdiction” represents a human mental model, like the terms “science” and “mathematics.” *Consilience* tells us that it is a mistake to look at a problem so closely that we are blinded by details or semantics, thereby failing to see the global view. Wilson decries “the ongoing fragmentation of knowledge and resulting chaos in philosophy (which) are not reflections of the real world but artifacts of scholarship” (p. 8).

Now imagine Wilson again as a California fire chief at the very first FIRESCOPE[1] meeting in Los Angeles in 1970 (Federal Emergency Management Agency [FEMA], 1987). By changing just three words in the preceding quote, it is not difficult to imagine him bemoaning “the ongoing fragmentation of **resources** and resulting chaos in **operations** which are not reflections of the real world but artifacts of **bureaucracy**.”

If Wilson *the scientist* considered the wildfire scenario above, he wouldn’t get bogged down in concepts like ecosystems and jurisdictions, but would certainly recognize the challenge of *system complexity*. He is one of dozens of scientists who has described the emerging science of complex systems[2] over the past 15 years. There is a growing consensus among the scientific community that complexity may represent a truly new scientific paradigm (Waldrop, 1993; Casti, 1995; Kauffman, 1996).

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[1] FIRESCOPE originally stood for Firefighting Resources of Southern California Organized for Potential Emergencies, but in 1986 the word “Southern” was dropped from the acronym when FIRESCOPE was formally established as a statewide program.The original seven “Partner Agencies” are: California Department of Forestry and Fire Protection, California Office of Emergency Services, Los Angeles City Fire Department, Los Angeles County Fire Department.

[2] This field of science has outgrown its original term, “chaos theory.” Chaos remains a major component of complexity science, though it is only a subset. The relationship between chaos theory and complexity might be compared to the relationship between microbiology and medicine. As complexity science has evolved over the past 40 years, different scientists have used other terms at different times, including “dynamical systems theory,” “nonlinear dynamics,” “network dynamics,” “complexity theory,” “complexity science,” and simply, “complexity.” I prefer the more comprehensive “science of complex systems.” See Literature Review below.

“The greatest challenge today in all of science,” writes Wilson (1999, p. 93), “is the accurate and complete description of complex systems.” The problem to be addressed in this paper is this challenge. This paper represents a preliminary and humble attempt to make a contribution, however small, to an evolving global effort to build an “accurate and complete description of complex systems.”

The approach of this paper is to look at one particular system—in this case, a human management system—and evaluate its performance against a whole array of changing complex systems. The management system to which I refer is the Incident Command System (ICS). The changing cast of complex systems within which ICS has evolved are not easily described (which is exactly the point of Wilson’s challenge), but they include social, technological, and ecological systems that give rise to fire in its many manifestations, as well as geophysical systems, meteorological systems, and many more.

In my Literature Review below, I present a summary description of three primary components of the emerging science of complexity: chaos, self-organization theory, and criticality. I try to show the relevance of these complexity concepts to the specific case of the Incident Command System which, I contend, is an evolving and highly advanced application of systems thinking born out of a human necessity to respond to, and ultimately manage, chaotic systems. The purpose of this paper is to provide the next chapter in a multi-year, systemic review of ICS (Cole, et. al., 1993; Cole, 2000), and to suggest a strategic vision of its future.

A combination research method was used, including evaluative and historical methodologies, to derive key lessons from the first quarter-century’s experience of

California practitioners of ICS. This research has a continuing personal element to it as well. I have used ICS myself for over 20 years, and first wrote about major incident ICS after serving seven years as a Planning Section Chief on a statewide incident management team. I have worked and innovated extensively with ICS on disasters such as the 1989 Loma Prieta Earthquake and the 1991 Oakland/Tunnel Fire (Cole, et. al., 1993). But it wasn't until my first week at the National Fire Academy in 1996 that my research began in earnest, and it has continued throughout the four years of my participation in the Executive Fire Officer Program (EFOP).

I had first come across the term "paradigm shift" several years earlier in the book *Reinventing Government* by Osborne and Gaebler (1992), but had never heard the term bantered about like it was at the National Fire Academy. It seemed that half the articles on our reading list had "paradigm" in the title, and by the end of that first week in September 1996, I had begun to think of "paradigm shift" as an overworked cliché.

After returning home I began to wonder if I was being rash in dismissing the "paradigm shift." I had jotted down the name of a Thomas Kuhn, who someone at the NFA had mentioned as the inventor of the term. I used my online search feature and was surprised to learn that Kuhn is not some passing-fad management guru, but one of the world's leading scientific historians. I ordered his *The Structure of Scientific Revolutions* (Kuhn, 1962), and soon was reading his accounts of the dramatic changes of thinking that happened in physics at the beginning of the 20th century. According to Kuhn, concepts like Planck's quantum theory and Einstein's special theory of relativity, both published in 1905, had utterly transformed our human view of the universe. These concepts were still dominating the discussions of physicists and philosophers more than

50 years later, when Kuhn used them to promote the notion of “scientific revolutions” or “paradigms,” which he defined as “accepted models or patterns that gain their status because they are more successful in solving a few problems that a group of practitioners has come to recognize as acute” (p. 23).

These words immediately brought to mind the Incident Command System, and the problems that had led to its development. As a practitioner of this system throughout my career, I had witnessed ICS evolve from being viewed initially with a great deal of skepticism and doubt, generally greeted as an unwelcome, unneeded, newfangled approach to emergency management. But as the system was put into use, lessons were learned and refinements were incorporated, and with time the system improved and evolved toward acceptance. Ultimately, it emerged as “a better way to do business,” and today ICS is embedded in the corporate culture of the California fire service (Cole, 2000).

Acceptance didn’t come easy, however, as I was reminded with each visit to the National Fire Academy. I had come of professional age at ICS ground-zero, but in Emmitsburg I was meeting fire service professionals from around the world. In many areas ICS was just starting to get a foothold. After years of taking ICS for granted, I again began encountering the familiar old skepticism.[3] I myself was a reluctant user for years. Acceptance, for me, did not come over night; it came over many years, during the course of many routine emergencies and a few complex disasters. Acceptance came to me, as it did to many of my colleagues, for exactly the reason that Kuhn

[3] Though I’ll never forget the chief from Australia who said of ICS, “Aw yeah, mate, we’ve been using it for donkey’s years!”

recognized: because ICS is a system that has proven “more successful in solving the kinds of problems that (we) practitioners have come to recognize as acute” (Kuhn, 1962, p.23).

This recognition provides the inspiration for the first and second research questions addressed in this paper:

1) What lessons can be learned from the collective experience of practitioners of ICS as it has evolved through its first 25 years?
2) What “kinds of problems” does ICS address most successfully?

In order to answer these questions, and then relate them to the more global issue of *complex systems*, I needed to know more about the term “system” itself. The word derives from the Greek *synthistanai* (“to place together”), and to understand things “systematically” literally means to put them into a context, to establish the nature of their relationships (Capra, 1996). As I researched the term “system” I kept coming across references to a Robert Lilienfeld, and it soon became apparent that his book *The Rise of Systems Theory* is something of a classic in the field. When I finally got a copy of this book through interlibrary loan, I turned to Chapter One (“The Emergence of Systems Theory”) and, to my surprise, there was Thomas Kuhn again, in the very first sentence: “Systems theory claims to be a major reorientation of scientific thought, of the type Thomas S. Kuhn describes as a ‘scientific revolution’” (Lilienfeld, 1978).

“The nature of the revolution,” writes Lilienfeld, “is the replacement of analytic atomistic modes of thought by holistic integrative ones” (p. 7). He goes on to quote one of the founders of systems theory, the Austrian biologist Ludwig von Bertalanffy:

> The 19th and the first half of the 20th century conceived of the *world as chaos*. Chaos was the oft-quoted blind play of atoms, which in mechanistic and positivistic philosophy, appeared to represent ultimate reality, with life as an accidental product of physical processes. It was chaos when, in the current theory of evolution, the living world appeared as a product of chance, the outcome of random mutations and survival in the mill of natural selection. But now we are looking for another basic outlook on the world—*the world as organization*. Such a conception—if it can be substantiated—would indeed change the basic categories upon which scientific thought rests, and profoundly influence practical attitudes. (Bertalanffy, 1968, pp. 187-188).

The italics are in the original quote and seem to emphasize two worldview paradigms: the world as *chaos*, and the world as *organization*. As it happens, these same paradigms lie at the root of the emerging science of complex systems, which is based on empirical evidence that complex and ***chaotic*** systems abound, and nature copes with this complexity by forming ***self-organizin*g** systems and processes. There are many examples, including evolution, ecological interdependence, hurricanes, global economic markets, and political movements. These topics will be covered in greater detail in the Literature Review section of this paper.

The two worldview paradigms of “chaos” and “organization” also frame the environment in which ICS was born, and in which it has flourished. This nexus between the science of complex *systems* and the Incident Command *System* inspired the third research question addressed in this paper:

3) Can ICS be described In the context of complexity science?

BACKGROUND AND SIGNIFICANCE

ICS and Systems Thinking

Seven fire agencies came together after the disastrous 1970 wildfire season in California to form the FIRESCOPE coalition, which was chartered by the U.S Congress in 1972 and charged with a national mandate to develop a system for multi-agency coordination of complex “incidents that exceed the capability of any single fire protection agency” (FEMA, 1987). One major product resulting from this mandate was ICS, which was developed with the help of consultants from two Southern California “think-tanks,” the RAND Corporation and Strategic Development Corporation (SDC). RAND had pioneered the method of strategic thinking known as “systems analysis,” which had grown out of operations research, the analysis and planning of military operations during World War II (Capra, 1996). The company was founded in 1946 as a military research and development institution (the name signifies “Research And Development”), and it became the model for numerous “think tanks” specializing in policy making and the brokering of technology (Dickson, 1971). According to Naughton (2000), RAND in the 1940s “prided itself as an institution capable of applying ‘rational analysis’ to what most people regarded as unthinkable scenarios involving the incineration of millions of people and the wholesale pollution of the planet by nuclear warfare” (p. 95).

Interestingly, both RAND and SDC were also pioneers in creation of the Internet and the World Wide Web (Naughton, 2000). RAND’s role was through its work in the early 1960s designing a nationwide “survivable communications system (to provide continuity

of) command and control in nuclear war" (p. 96). And in 1965, when this system was ready for testing, SDC in Santa Monica was designated by the Department of Defense as one of six nodes nationwide[4] that linked up to form "the world's first computer network," (p. 88). The Internet and the World Wide Web, like ICS, developed along a theoretical and technological path that began with cybernetics and the intensive use of operations research during World War II, and continued in the same Southern California research labs where some of the world's most advanced and highly-classified systems analysis work was being done for military, aerospace, and communications applications.

As one of the original seven FIRESCOPE cooperators, the California Department of Forestry and Fire Protection (CDF) has participated in the development and deployment of ICS since the very beginning. CDF was among the first agencies to test the earliest versions of ICS in the mid-1970s, and in 1980 it was one of the first to adopt ICS as the standard system for managing emergencies of all types (FIRESCOPE, 1982). The department now has a DNA-like institutional linkage to ICS,
as demonstrated by the fact that anyone who has come into the organization since 1980—the majority of today's CDF—has not used an emergency management system or paradigm other than ICS. Today ICS is arguably the department's most important "core competency" (Drucker, 1999).

[4] The others were at the Universities of Michigan and Illinois, MIT, Harvard, and Carnegie-Mellon in Pittsburgh.

Now in my third decade working with CDF, I am more convinced than ever that there is no more global issue to the fireground, or for disaster management, than how we respond to and manage the chaos of crisis. The primary product of this collective approach for bringing order to chaos has been the development of a system (i.e., ICS) to do just that: to respond to, organize, and manage—that is, *bring order to*—chaotic systems (Prigogine, 1997). Today it can be said with a great deal of confidence that no management system in history has ever been deployed so often and so successfully for the implicit purpose of ordering chaos.

The Incident Command System is first and foremost a *system*. Specifically it is a human planning and management system. But the term "system" covers a lot of territory, so before addressing the purpose of this paper—the evaluation of ICS in particular—it might be helpful to take a more global view of systems in general.

Before reading Peter Senge's *The Fifth Discipline* (1994), my experience using ICS meant little more to me than the working context in which I had always functioned during periods of acute chaos—the wildfires, floods, earthquakes, and other incidents that form the most vivid memories of a career. I don't remember ever giving much thought to what it meant that ICS was "a system" until I read about the fifth discipline of Senge's title, the one that ties the other four together. The fifth "discipline of learning organizations" is **systems thinking**.[5] According to Senge:

> Systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change

[5] The other four are: personal mastery, mental models, shared vision, and team learning.

> rather than static "snapshots." It is a set of general principles—distilled over the course of the twentieth century, spanning fields as diverse as the physical and social sciences, engineering, and management—for seeing the "structures" that underlie complex situations (Senge, 1994, p. 68).

The Incident Command System is one of the longest-running exercises in applied systems thinking, and is likely the world's most highly-evolved application of systems thinking for the purpose of organizing and managing complex, dynamic operational problems. It is a systems design-in-progress that has been applied worldwide to many thousands of what Senge calls "complex situations" during the past quarter-century. It is a framework not just for "seeing" the interrelationships and structures that underlie crises, but also for managing them.

Senge's quote above has direct parallels with systems theory founder Ludwig von Bertalanffy's (1968) two "basic outlooks on the world." Senge's "set of general principles for seeing structures" coincides with Bertalanffy's "world as organization," and Senge's "complex situations" coincide with Bertalanffy's "world as chaos" (Senge, 1994, p. 68; Bertalanffy, 1968, pp.187-188). The ICS environment is where these "worlds" collide and/or come together, although it is more accurate today to speak in terms of *systems* rather than *worlds*. Using 21st century terminology, ICS can be seen as a "system of organization" for dealing with "complex and chaotic systems."

Complex Systems

To illuminate the larger stage upon which ICS acts, it is necessary to explore some background on the concepts of *chaos* and *complex systems*. Perhaps the first and most

influential description of complexity and the role of chaos came from the Russian-born chemist and physicist Ilya Prigogine, who was awarded a Nobel Prize in 1977 for his pioneering work in non-equilibrium thermodynamics and complexity. Prigogine, who is currently Director of the Center of Statistical Mechanics, Thermodynamics, and Complex Systems in Austin, Texas, has “one of the most adventurous scientific imaginations of our time and vision as revolutionary and fundamental as Darwin’s,” according to best-selling science writer Oliver Sacks (1997).

In *The End of Certainty: Time, Chaos, and the New Laws of Nature*, Prigogine (1997) shows that all systems in the entire known universe can be categorized in one of two ways—as either “stable” or “unstable.” The first can be illustrated by a pendulum at rest: a small pertubation is followed eventually by a return to the pendulum’s resting state, representing a system in *stable* equilibrium. By contrast, if you balance a pencil on its head, the smallest pertubation will cause it to fall left or right, and it will not return to its original state. This is Prigogine’s simple model for a system in *unstable* equilibrium (p. 30). With stable systems, slight changes in initial conditions produce correspondingly slight effects, but not so for unstable systems, where small pertubations in initial conditions may be amplified and irreversible. An extreme example of unstable systems, writes Prigogine, are “chaotic systems” in which small changes in initial conditions can amplify exponentially over time.

To illustrate, consider two real-world examples using water and fire. Water predictably flows downhill and collects in rivers, lakes, and the sea because Earth’s gravitational system is a *stable* system. On the other hand, a spark landing in dry tinder on a brushy hillside may (or may not) result in a catastrophic conflagration, depending

on a complex array of initial conditions. Unlike gravity, organic combustion in Earth's oxygen-rich atmosphere represents an inherently *unstable* system.

In the example of gravity, it matters little whether the water originated on the mountaintop or in the valley, as rain or as snow; it will end up in the sea regardless of those "initial conditions" because the system is stable. But in the example of combustion, whether the spark fizzles out cold or amplifies exponentially into a chaotic conflagration depends very much on initial conditions such as fuel bed characteristics, air temperature and humidity, wind speed and direction, slope, sun angle, time of day, etc. Because the behavior of combustion is so dependent on these and other initial conditions, it is an inherently unstable system. At a still higher level of complexity, a fire burning out of control may be considered an extremely unstable system—that is, a complex system exhibiting a high level of chaos—or, in the words of Prigogine, a "chaotic system."

According to Prigogine, unstable systems "evolve spontaneously to a state of increased complexity" (p. 64); in fact instability is prerequisite for "the emergence of complexity at the macroscopic scale" (p. 128). Such "emergence" occurs in California's wildland fire protection system, especially at the urban-wildland interface, where the inherently unstable wildland vegetation complex can be briefly characterized by the following progression: the longer fire-prone vegetation remains unburned in proximity to increasing urban fuel hazards, the more unstable the system becomes, and the more potentially chaotic the combustion when it finally does occur (Cole, 1997).

Uncontrolled fire is but one example of a chaotic system. We could go yet another step higher on the complexity scale in California and consider the entire "fire-flood

cycle," an even more complex system whose elements include not only the chaotic impacts of fire, but also the subsequent impacts of hydrophobic soil conditions, oversteeped slopes, increased potential for mudflows, debris flows, avalanches, flooding, human and ecological impacts, economic loss, and so on. As Casti (1995) points out in his book *Complexification*, systems never occur in isolation, but only in relationship to other systems.

By proactively taking command and control of *one* system—the human management system we call ICS—we have a powerful tool with which to coordinate a response and then manage the chaos of complex systems. The ultimate effectiveness of the management system's performance, however, is very much dependent on the previously mentioned concept of "sensitivity to initial conditions." This central concept of chaos theory is also, I believe, the nexus between ICS and the science of complex systems. This will be discussed further in the Literature Review and Discussion sections of this paper.

Significance

The human management system that grew out of the ashes of the disastrous 1970 wildfire season in California, and which was then propelled in its evolution by congressional mandate and funding, has evolved to become what might justifiably be called the world's most advanced application of systems thinking to cope with the unpredictable. The previously stated purpose of this paper is to provide the next phase in a multi-year, systemic review of ICS. The goal is to distill key lessons from the first 25 years of system experience by "picking the collective brain" (in a manner of speaking) of

the system's senior California practitioners. And the challenge is to try to use these lessons to describe the relationship between the ICS system experience and the emerging 21st century "scientific revolution" (Kuhn, 1962) of chaos theory and the science of complex systems.

There has been perhaps no more significant strategic change in the California fire service over the past 25 years than the universal adoption of ICS. And yet according to the National Fire Academy's "Change Management Model," which is the cornerstone for the Strategic Management of Change (SMOC) course, if change is to be strategically managed it must not merely be planned and implemented, but also formally evaluated (FEMA, 1996). This research paper is the latest in a series of attempts to begin just such a systematic evaluation of ICS from the point of view of California's most experienced practitioners (also see Cole, et. al., 1993; and Cole, 2000).

This research has continued throughout my years participating in EFOP, and has been greatly influenced by the experience. Besides getting to know ICS practitioners from all over the world, I encountered Kuhn's (1962) and Senge's (1994) books for the first time in my EFOP course work. (Senge's *Fifth Discipline* was the required text for my third-year course, Executive Planning.) The presentation I gave on my first day at the NFA in 1996, in fulfillment of an assignment to deliver a 10-minute case study, documented work in progress using ICS on a macro-scale in collaboration with multiple fire agencies and the National Aeronautics and Space Administration (NASA). Input from my fellow Executive Development classmates, including e-mail correspondence for

more than a year, encouraged me to pursue this material through to publication[6] (Cole, et. al., 1998).

With respect to the relationship between ICS and the new science of complex systems, it is perhaps presumptuous to expect to be able to make sense of theoretical concepts that are considered by the likes of Edward O. Wilson and Ilya Prigogine to be the greatest scientific challenge of our time. But I believe that anything we can do as practitioners in the way of system evaluation—even if it is only to discuss among ourselves and learn from each wrestling match with chaos—will have significance for the future evolution of ICS, as well as for its derivations and successors. Along the way, should we be fortunate enough to acquire a better understanding of the relationship between ICS and the new science of complex systems, it can only benefit the system's users, both present and future. The better we understand the functionally-based, problem-solving management system that we ourselves implement to cope with the chaotic problems of complexity (fires, earthquakes, aircraft disasters, industrial spills, etc.), the more effectively we can deploy it when we need it. And the better we understand the nature of chaos and complex systems, the more proficient we will become at unravelling those complex problems using the ICS management approach.

[6]Online at http://www.fs.fed.us/fire/planning/firenote.htm, Vol. 58, No. 4, pp. 26-30.

LITERATURE REVIEW

Chaos Theory

It has been said that 20th century science will be most remembered for three things: quantum mechanics, relativity, and chaos (Gleick, 1987). The first two are associated with some of the great scientific minds of the century just past: Max Planck, Niels Bohr, Albert Einstein. But the field of chaos, despite an increasing crowd of Nobel Laureates, remains somewhat obscure, perhaps because it is so new and still evolving so rapidly.

The mathematical field known as chaos theory didn't originate until eight years after Einstein's death in 1955. Its unlikely debut was an article in the obscure *Journal of Atmospheric Sciences*, titled "Deterministic Nonperiodic Flow" (Lorenz, 1963), by a little-know meteorologist from the Massachusetts Institute of Technology (MIT). The meteorologist, Edward Lorenz, was fortunate to work at MIT because it gave him nearly unlimited access to a state-of-the art computer—something almost unheard of in the early 1960s. Lorenz used his computer access to create a primitive kind of graphical program to make the patterns of changing atmospheric pressures and airstreams plain to see. Years before the first satellite weather photographs, Lorenz's graphics were a real novelty. After inputting some initial weather parameters into a sequence of equations, he would print out long rolls of paper depicting the evolution of meteorological systems, traced in wavy lines that swung back and forth in long series of hills and valleys, representing the way the jetstream would swing north and south across the oceans and continents (Gleick, 1987).

One day in the winter of 1961 Lorenz took a shortcut that was to have revolutionary consequences. He wanted to examine a particular sequence at greater length, but

instead of starting the whole run over, he started midway through. To give the computer its initial conditions, he typed the numbers straight from the earlier printout. “Then he walked down the hall to get away from the noise and drink a cup of coffee,” writes Gleick (p. 16). “When he returned an hour later, he saw something unexpected.” The new weather pattern perfectly traced the earlier version as expected, but only for a while. Then it began to diverge slightly. Lorenz was puzzled; he had only picked an interim point from an earlier run, so the overlapping portions of the two runs should perfectly match: they used the exact same data. At first he thought he had made some kind of mistake, but then he realized that the numbers he had typed from the first printout had been rounded to three decimal points.[7]

Lorenz figured this difference—one in a thousand—was inconsequential, but playing a hunch, he decided to let the computer continue its run overnight. When he returned to work the next day he was amazed to see that the two runs no longer diverged slightly, they diverged wildly, even *chaotically*. They seemed to be representing two entirely different sets of data: a high pressure system that was planted over Canada on the first run was over the South Pacific on the new run. In reality the two computer runs represented identical data, but only to a point, at which a very slight change had been made—in this case, rounding the original outputs to the nearest thousandth. Lorenz took this revelation and, using his weather models, went on to show that, theoretically anyway, the flapping of a butterfly’s wings in, say, South America could set into motion a series of atmospheric events that would result in a tornado in

[7] Lorenz’s data are presented graphically in Figure 1in the Discussion section of this paper. See p. 53.

Kansas several days later. The so-called “Butterfly Effect” became the classic illustration of amplification through chaos (Briggs and Peat, 1999).

Lorenz’s paper made quite a stir, but not so much among weather professionals as among mathematicians. His Butterfly Effect planted the seed of a new scientific paradigm in which even very slight changes can have inconceivably large consequences. This “central idea” of the new theory of chaos soon acquired a technical name: “sensitive dependence on initial conditions” (Gleick, 1987, p. 23).

Mathematician Ian Stewart (1989, p. 138) has written that “the culture of chaos is the computer culture.” The mathematical description of chaos could not have happened much sooner than it did because it simply was not possible without computers. Albert Einstein might have had an inkling about chaos as he labored the last 25 years of his life over his never-finished Unified Field Theory, his quest “to construct a bridge between quantum theory and relativity” (Barnett, 1968, p. 110). But in his lifetime Einstein never had the computational power at his disposal to run the hundreds of equations and millions of numbers through the countless iterations that would have allowed him to begin to examine the mathematics and patterns of chaos.

The fact that MIT meteorologist Edward Lorenz was first to demonstrate chaos may have had more to do with his access to unlimited number-crunching computer time than to his cosmic insight. In the years following publication of his 1963 paper, computers became more common and more powerful, and soon scientists were demonstrating the properties of chaos everywhere. Ecologists showed that a slight tweaking in the ratio of foxes to rabbits could have astounding consequences to the “emergent properties” of complex ecosystems. Microbiologists noted that minuscule changes in nucleic acid

sequences in genes could amplify into mutations, cancers, and even the creation and extinction of entire species (Kauffman, 1996). Economists and sociologists showed how seemingly inconsequential rumors or bits of misinformation could lead to stock market collapses, political revolutions, and wars (Mandelbrot, et. al., 1984).

Chaos theory tells us what chaos *is*, but as the theory was applied to more and more systems, it began to become evident that a new science was needed to understand and explain how chaos *behaves*—or more accurately, how it induces systems to behave. Thus was born the science of complex systems.

Emergence of a New Scientific Paradigm

Throughout the 20th century, relativity and quantum mechanics defined science with respect to the behavior of *physical* systems, from the macroscopic systems of the cosmos to the microscopic, even subatomic, systems of particle physics. Thanks to the classical science of Newton, Galileo, and Einstein, we have equations and physical laws that explain the motion of planets, moons, and distant stars down to the smallest details. With these laws we can predict the ocean's tides, eclipses, and the arrival of comets centuries into the future. According to cosmologist Stephen Hawking (1994, p. 143), "There are certain situations in which we think we can make reliable predictions, and the future of the universe, on a very large scale, is one of them." Why? Because the physical universe is overwhelmingly characterized by *stable* systems.

But predicting the behavior of *unstable* systems is a different matter. "With unstable and chaotic systems," writes Hawking:

> There is generally a time scale on which a small change in initial state will grow into a change that is twice as big. In the case of the earth's atmosphere, this time scale is on the order of five days, about the time it takes for air to blow right around the world. One can make reasonably accurate weather forecasts for periods up to five days, but to predict the weather much further ahead would require both a very accurate knowledge of the present state of the atmosphere *and* an impossibly complicated calculation (Hawking, 1994, p. 143-144).

Until Lorenz mathematically modeled his Butterfly Effect in 1963, chaos existed only, in the words of Webster's Collegiate Dictionary (1995), as "a state of inherent unpredictability and confusion." Before 1963, chaos was mysterious, even awe-inspiring, but not quantifiable—at least not quantifiable by the kinds of deterministic laws of gravitation and electromagnetism that governed classical physical science and its emphasis on order and stability. "In the classical view of quantum mechanics and relativity," writes Prigogine (1997, p. 4), "laws of nature express certitudes." But with the mathematics of chaos we can "now see fluctuations, instability, multiple choices, and limited predictability at all levels of observation" (p. 4).

The pre-chaos laws of science could not fully account for all the instability and complexity that was emerging in the new digital laboratory. As Gleick (1987) observed, "For as long as the world has had physicists inquiring into the laws of nature, it has suffered a special ignorance about disorder."

This began to change with the mathematics of chaos theory and the new ways of looking at complex system behaviors that computers made possible. By the 1990s

every serious scientist had a desktop computer. For the first time in history, as M. Mitchell Waldrop (1993) points out in his book *Complexity*, scientists were able “to drink from the firehose of data.” More and more of them, from all kinds of disciplines, “were beginning to think about complex systems because they *could* think about them,” thanks to ever-more powerful computers (p. 63). Chaotic scenarios could now be modeled and predicted (the Human Genome Project is a good current example), and as chaos theory and computer simulations were applied to traditional scientific disciplines, new ways of (in Senge’s words) “seeing the structures that underlie” the old sciences began to emerge. Basic paradigms of science came into question, including the linchpin of the physical sciences: classical thermodynamics.

The celebrated “second law” of thermodynamics was formulated by the 19th century French physicist, Sadi Carnot, in terms of the thermal efficiency of engines. No matter how efficient an engine’s performance, Carnot showed, it can never convert all of its energy into useful work. Some energy is inexorably lost as heat (Masterton and Slowinski, 1973). According to the second law, any equilibrium, or "closed," physical system will proceed spontaneously in the direction of ever-increasing disorder, or “entropy,” as the physicists named it (Capra, 1996).

This idea that all systems trend from order to disorder was the dominant operable paradigm in the physical sciences throughout the 20th century. It tells us that the universe is running down to “the ultimate heat death (where) all the processes of nature will cease…and all space will be the same temperature” (Barnett,1968, p. 102). Energy will no longer be available, says the second law, because it will have dissipated uniformly throughout the cosmos. Order, which requires energy for its formation and

maintenance, is therefore the most unlikely and unstable of all conditions and will inevitably disappear (Kauffman, 1996). The apparent contradiction posed by life's "surge toward order" (p. 10) has been explained away for more than a century as a transitory aberration in the universal scheme of things. By this view, life on Earth is merely a temporary island of order in a sea of disorder and it is only a matter of time before entropy will prevail and our planet will again be cold and lifeless as the moon. The laws of physics allowed for no other possible outcome—that is, until chaos theory came along, and scientists began to question whether the absolute laws of classical science tell the whole story after all.

Chaos theory suggested that the universe may actually be even more complex—and at the same time more ordered—than previously believed. The complexity was always there, this thinking goes, but it took the vast computing power of recent years to begin to make sense of it, and to unveil the deeply ordered patterns that exist within. One revelation is that complexity and order are actually consistent with one another, and the closer we look at complexity, the more order we see. But the bigger revelation is that the most complex and highly ordered systems in the known universe are "organisms and their assemblages" (Wilson, 1999), and of the these, the most complex, highly-evolved, and improbable of all are *human systems*.

Complexity science has arisen out of the need to make sense of that realm of unpredictability and disorder where chaos reigns: disorder in our atmosphere, in the turbulent sea, in the fluctuations of wildfire occurrences and intensities, in the oscillations of the heart and brain; in what Gleick (1987, p. 3) called "the irregular side of nature, the discontinuous and erratic side."

All of the systems on this “irregular side of nature” exhibit several key properties that are not seen in the stable physical systems of classical science. One of these properties is *emergence*, “the appearance of complex phenomena not predictable from the basic elements and processes alone” (Wilson, 1999, p. 94). The “Kansas tornado” of Lorenz’s chaos theory is one example of such an emergent phenomenon, but other examples now abound in every scientific discipline. The emergence of unpredicted complex phenomena is the basis of complexity theory, which Wilson defines as “the search for algorithms used in nature that display common features across many levels of organization.” Complexity, says Wilson, arises from the surprisingly simple concept that commonalities emerge “when passing from simple to more complex systems” (p. 95).

With fire, for example, there are basic commonalities that apply across “many levels of organization,” from the tiniest match flame to a raging forest fire, and from the molten core of the Earth to the cosmic fire of the sun and stars. The science of complexity entails the search for those commonalities that “might lead to deep new laws that account for the emergence of such phenomena as cells, ecosystems, and minds” (Wilson, 1999, p. 95).

Just as Wilson (1999) recognized the “unity of knowledge,” Gleick (1987) observed that “chaos breaks across the lines that separate scientific disciplines.” The new theory of chaos brought together thinkers from fields as diverse as mathematics, biology, ecology, and economics. When Gleick called chaos “a science of the global nature of systems” (p. 5), he came very close to predicting the evolution of chaos theory that would occur during the 1990s with the emergence of the even more global science of complex systems. As the global picture of this emerging science has begun to come

into focus, scientists like Edward O. Wilson and Ilya Prigogine have recognized that chaos is only part of the “complexity story.” If “Chaos” is Chapter One in this story, then the second chapter might be something called “Self-Organization.”

Self-Organization

As mentioned above, the second law of thermodynamics says that the universe is governed by inexorable entropy: the one-way tendency toward disorder, dissolution, and decay. Atoms and molecules will mix and randomize as much as possible, so iron rusts, for example, because atoms in the iron are forever trying to mingle with oxygen in the air to from iron oxide (Waldrop, 1993). A cup of coffee cools because fast-moving molecules on the surface of the water collide with slower-moving molecules in the air and gradually transfer their energy until the coffee is the same temperature as its surroundings. Forests and brushfields release the solar energy stored in the organic bonds of their biomass, whether over decades and centuries through decomposition, or in seconds through the pyrolitic combustion process we call wildfire.

And yet there is plenty of order and structure to be found. Forests may burn, but trees also grow. In fact, there is order and structure at every level of the universe—galaxies, stars, planets, hurricanes, organisms, brains, atoms—which seems to contradict the second law’s “cosmic compulsion for disorder” (Waldrop, 1993). This apparent contradiction has led complexity theorists like Wilson and Prigogine to propose perhaps the millennium’s first “new law of nature,” something called “spontaneous self-organization.”

Prigogine was the first proponent of self-organization, and he demonstrated it with a simple experiment in thermal diffusion. He constructed a dumbell-shaped hollow apparatus with a chamber at each end and an open passageway connecting the two chambers. After filling the apparatus with a mixture of hydrogen and nitrogen, he heated one chamber while cooling the other. This system evolved naturally to a steady state in which one element was concentrated in the hot chamber and the other in the cold one, demonstrating that "the entropy produced by the irreversible heat flow leads to an ordering process." The energy from Prigogine's bunsen burner did not merely dissipate into entropic space, but drove a process of molecular self-organization "to a new form of coherence," an outcome that seemed to contradict the second law of thermodynamics (Prigogine, 1997, p. 26).

As the mathematical ability to analyze complex systems has become more sophisticated, it has become evident that the propensity for spontaneous order is enormously greater than previously supposed. Only since the advent of powerful computers has it been possible to begin to simulate the behavior of complex systems, with their many independent agents interacting with each other in so many different ways. "Think of the quadrillions of chemically reacting proteins, lipids, and nucleic acids that make up the living cell," writes Waldrop (1993), "or the billions of interconnected neurons that make up the brain."

In such complex systems, complexity itself seems to trigger self-organization. Kauffman (1996) calls it "order for free." He contends that if enough different "agents" pass a certain threshold of complexity, they begin to self-organize into a new entity. Thus, people trying to satisfy their material wants and needs unconsciously organize

themselves into an economy through myriad individual acts of buying and selling; it happens without anyone being in charge or consciously planning it. The Internet and the World Wide Web are “self-organizing” even now, in much the same way. And it could be argued that the outcome of the presidential election of 2000 was a “self-organization” response to chaos in which the “agents” included multiple laws, courts, and legal actors, the public, media, political parties, and the candidates themselves. Each of these examples—the economy, the Internet, Election 2000--exhibits the emergent phenomenon of collective and spontaneous crystallization to a higher degree of order, something Kauffman (1991) called “antichaos.”

Forty years earlier, Norbert Wiener (1950) called it “anti-entropy.” Wiener, the digital computer pioneer and founder of cybernetics, may have been the first to recognize that a self-organized compulsion for order exists in physical and biological systems alike. The key, he said, was *information accumulation*, a process that is most familiar to humans as “learning.” Wiener believed it was possible “to control entropy through feedback,” which he defined as “the property of being able to adjust future conduct by past performance” (p. 33).

Scientists in every discipline have awakened to the complexity in their midst—complexity that the great 20th century scientists undoubtedly sensed, but lacked the number-crunching wherewithal to explore. Before complexity science, none of the “laws” of science could explain why the genes in a developing embryo organize themselves in one way to make a bone cell, and in another way to make a brain cell; or why flying birds adapt to the actions of their neighbors, forming themselves into flocks (Casti, 1995). But the new science of complexity suggests an explanation: in complex systems,

groups of agents seeking mutual accommodation and self-consistency somehow manage to transcend themselves, acquiring collective properties such as life, thought, and purpose that they might never have possessed individually. They self-organize (Waldrop, 1993).

One final concept is necessary to complete the connection between complexity science and the Incident Command System: *criticality*.

Criticality

Biological systems exhibit self-organization on all scales, from cells to ecosystems, and from human brains to human societies. But the phenomenon is not limited to living systems. Physical systems also self-organize across all scales. The swirling vortex organizes itself in a draining bathtub in much the same way that a dust-devil appears in a farmer's field or a hurricane forms over the Gulf of Mexico; and all have structural and behavioral similarities to the way distant galaxies from in the vortex of billions of stars and planets.

It appears that all such self-organizing systems exhibit a property that the Danish-born physicist Per Bak calls "criticality." Bak and his co-workers at the Brookhaven National Laboratory have applied chaos theory to the phenomenon of self-organization and concluded that many complex "interactive systems evolve to a critical state in which a minor event starts a chain reaction that can affect any number of elements in the system" (Bak and Chen, 1991, p. 46). Such a chain reaction might result in nothing at all, or it might result in an unpredicted catastrophe. Or it might result in a totally unexpected synergistic creation: a new species, for example, or a technological

breakthrough. In the vast majority of cases, such minor events do not result in unforeseen chain reactions, but because of the element of chaos, this can never be predicted with certainty from the initial events themselves.

To illustrate this Bak and Chen proposed a simple experiment that serves as a paradigm for self-organized criticality: a pile of sand. Writing in *Scientific American* (Bak and Chen, 1991), they describe an apparatus they constructed “that pours sand slowly and uniformly, one grain at a time, onto a flat, circular surface.” Their sandpile experiments and computer simulations showed that for a while the pile grows higher, but there always comes a point where it can’t grow anymore: old sand cascades down the sides as fast as the new sand dribbles from above. The sand pile is *self-organized*, in the sense that it reaches a steady state all by itself without anybody explicitly shaping it. And the state it reaches is one of *criticality*, in the sense that sand grains on the surface are just barely stable (Waldrop, 1993). As each new grain of sand lands on the top of the pile, there is no way to know what will happen: maybe nothing, maybe just a shift of a few grains. But sometimes a tiny collision leads to another in just the right chain reaction, and a “catastrophic” avalanche will collapse one whole face of the sandpile. In reality, all of these things happen at one time or another. Big avalanches are rare and small ones are frequent, but the steadily-drizzling sand triggers cascades of all sizes—a fact that manifests itself mathematically in what Bak and Chen (1991) call “power-law behavior,” whereby the average frequency of a given size of avalanche is inversely proportional to some power of its size.

The sandpile system paradigm has become a cornerstone of complexity science, not because it is a “complex” concept—on the contrary, it is very simple—but because it

explains so much of the complexity in nature. For example, the size distribution of earthquakes follows a power-law, with many small quakes and few large ones. Historic flooding patterns of the Nile follow a similar power-law, with many small floods and rare large ones (Kauffman, 1996).

Forest fire behavior also exhibits criticality as “sequences of fires propagate as avalanches” (Bak, et. al., 1990). Just as with earthquakes and floods, there are many small fires in nature and only a few catastrophic ones. But when they happen, they can “self-organize” on a localized scale into what wildland firefighters call a “blow-up,” or on larger scales of criticality, into firestorms, holocausts, conflagrations, or simply “mass fire” (Pyne 1982).

Forty years before Bak’s critical sandpiles, scientists at Los Alamos, New Mexico had learned to use criticality with masses of plutonium, in which the chain reaction is just barely on the verge of chaotic behavior. Such critical, or crisis, points abound in nature. At such points of criticality, change can proceed gradually and in an orderly fashion, as in a nuclear reaction, or they can proceed in abrupt, quantum, chaotic fashion, as in a nuclear explosion.

PROCEDURES

A 16-element questionnaire was distributed by electronic mail to current and recent command and general staff members of the 17 major incident teams[8] in California (Appendix A). These include 12 statewide Major Incident Command Teams comprised of representatives from state and local government, and the five federal Type 1 Major Incident Management Teams assigned to California. Questionnaires were sent to each team's command and general staff,[9] and to about 50 veteran ICS practitioners who have rotated-off team assignments, but who are still active and available for overhead assignments as needed. A total of 206 questionnaires were distributed. This sample population was selected for its knowledge and expertise, and represents some of the most experienced practitioners of ICS anywhere. It is only after years of training, certification, and successful completion of ICS assignments at progressively higher levels of incident management responsibility that one can qualify for appointment to these teams at the command and general staff level. In CDF, for example, fewer than two percent of the department's emergency response personnel are assigned to Major Incident Command Teams.

The respondents were asked to consider a hypothetical scenario in which a health care administrator had been exposed to the use of ICS on a major disaster, and was considering adoption of an ICS approach for managing major medical emergencies at her company's hospitals. In the given scenario, the administrator is aware of the

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[8] As of this writing, teams comprised of representatives from state and local government go by the name Major Incident *Command* Teams. Federal teams are termed Major Incident *Management* Teams. For purposes of this paper, the generic term "major incident teams" is used.

[9] Command staff consists of the Incident Commander, Information Officer, Liaison Officer, and Safety Officer. General staff consists of Operations Section Chief, Planning Section Chief, Logistics Section Chief, and Finance/Administration Section Chief. Some teams field two Operations and/or Planning Chiefs.

respondents years of experience using ICS, and asks for a candid evaluation of the system's strengths and weaknesses. To perform this evaluation, the respondents were asked to rate16 attributes of ICS, gleaned from an exhaustive review of ICS literature and a scoping process (Cole, 2000). Respondents were also given an opportunity to add comments of their own, and 48 did so. A statistical analysis was performed on the more than 4,000 data elements received in response to the questionnaire.

In the second phase of the study, a Delphi survey technique was used based on the approach presented by Chin and Schario (1992). In this phase questionnaire results were distributed to a subset of the sample population with whom follow-up interviews were then conducted. The purpose of the Delphi technique is to allow expansion of individual perspectives that are formulated upon further study and discussion, and with "the benefit of the knowledge of other participants' perspectives" (p. 51). Interviews were also conducted with experts outside the sample population, including consultants that were members of the initial ICS development cadre, and with Robert Murgallis, program chair for Emergency Incident Policy and Analysis at the National Fire Academy.

In addition to the foregoing, the author has conducted a continuous review of literature pertaining to chaos and systems theory, complexity, and management science. This is part of an ongoing research project in which the author has been engaged for nearly ten years. The current research paper is a part of that larger project, and constitutes the first attempt to make a connection between the emerging science of complex systems, and the real-world experience of ICS practitioners.

Limitations

A generic comment that is sometimes made regarding ICS is that it is “the California system,” probably because ICS originated in California in the 1970s, and has been applied in California longer than anywhere else. One limitation of this study is that only California practitioners were surveyed. A benefit in using such a sample population lies in the sheer amount of ICS experience it represents: It is not likely that a sample population this large, with this much experience using ICS during the system’s first 25 years, could be found anywhere else. And yet a limitation of using this sample population is that the results may be seen to exhibit a “California bias.” As such, it is important to emphasize that this study does not purport to be a comprehensive analysis of ICS, but rather an evaluation from the point of view of the first generation of California practitioners.

A second limitation of this study pertains to the use of e-mail for sampling purposes. A handful of the target sample population could not be reached by e-mail, either because they had no e-mail address or because a correct one could not be located.

Another potential limitation that deserves mention concerns the conclusions derived from the Delphi phase of the research. The Delphi process is not based on a large enough sample population to yield robust statistical analysis, but rather, is meant to represent a degree of “expert analysis” upon review of statistically sound data (Shields, et. al., 1987). In this case, Delphi findings have been merged with theoretical concepts from chaos theory and complexity science. As such, the conclusions rest heavily on theoretical and applied research, in addition to evaluative and historical research techniques.

Definitions of Some Selected Terms

Alignment: Phenomenon exhibited by groups of people functioning as a whole so that a commonality of direction emerges, and individuals' energies harmonize (Senge, 1994).

CDF: California Department of Forestry and Fire Protection

chaos: 1. Uncertain and unpredictable disorder. 2. (Math.) Nonperiodic behavior occurring in a deterministic system (Lorenz, 1963).

Command and general staff: The command staff consists of the Information Officer, Safety Officer, and Liaison Officer; the general staff consists of the Operations Section Chief(s), Planning Section Chief, Logistics Section Chief, and Finance Section Chief. All of these incident management personnel report to the Incident Commander.

Feedback: The property of being able to adapt future behavior based on past performance (Wiener, 1950).

Feedback loop: A closed cycle of causal influences, within which the alteration of inputs are caused by outputs. A causal loop that reinforces or amplifies a change is a *positive feedback loop*, whereas a loop that limits or constrains a change is a *negative feedback loop* (Richardson, 1999).

FIRESCOPE: Firefighting Resources of California Organized for Potential Emergencies.

ICS: Incident Command System

Scaleability: The ability to be expanded or contracted as needed to fit dynamic operational requirements. ICS is scaleable in at least three dimensions: spatial (e.g., branches, divisions, etc.), functional (e.g., functional groups, span-of-control,

applicability of system to various types of incidents), and temporal (i.e., operational cycles can be customized to the nature of the problem). See Discussion below.

Self-organization: A phenomenon of complex systems whereby groups of agents seeking mutual accommodation and self-consistency somehow manage to transcend themselves and acquire properties that they may never have possessed individually (Waldrop, 1993).

Synergy: A combined action or operation that collectively is greater than the sum of its parts.

RESULTS

Sample Population

A total of 122 completed questionnaires were returned, representing a 60 percent response rate. The sample population (Table 1) averaged 27 years in the fire service and nearly 18 years using ICS to manage incidents of all sizes. The typical respondent is a senior incident management executive[10] who has spent significant time in the later stages of a career as a member of a standing major incident team[11] deployed to manage some of the most complex emergency incidents anywhere.

For the purpose of this study "major incidents" were defined as those lasting for three or more consecutive operational periods. Wildfires, floods, and earthquakes accounted for the majority of such incidents. As a senior executive team member, the average respondent had been deployed to 14.5 major incidents, or just over two per year on average.

Table 1: Average Experience of Sample Population (n=122)

ACTIVITY	EXPERIENCE
Fire Service Employment	26.6 years
Using ICS	17.7 years
Member of Major Incident Team Staff	6.5 years
Major Incident Team Deployments	14.5

[10] Peter Drucker (1999) defines an executive as a manager "who can think through what action commitments a specific decision requires, what work assignments follow from it, and what people are available to carry it out."

[11] Teams typically have 8-12 members who are on one-hour callback one week per month, year-round, for dispatch to major incidents anywhere in North America.

Evaluation of ICS by Practitioners

The rank order of the 16 attributes (from Question 6 in Appendix A) is displayed in Table 2. Each of the attributes was analyzed using mean, mode, standard error, coefficient of variance, and 95% confidence intervals (Wonnacott and Wonnacott, 1985). Modal tendency and coefficient of variance provided minimally useful information. The employment of confidence intervals, on the other hand, provided a useful measure of the range of actual population norms.

Table 2: Rating of ICS Attributes (10-point scale)

ATTRIBUTE BY RANK ORDER n = 122	Mean Rating	Standard Error	Statistical Significance (P=95%)*
1. Predefined hierarchy	8.80	0.105	A
2. Uniform terminology	8.73	0.115	A, B
3. Modular organization structure	8.70	0.113	A, B
4. Incident Action Plans	8.68	0.126	A, B
5. Span of control	8.42	0.140	B
6. Standardized forms	8.17	0.152	C
7. Delegation of authority	8.06	0.131	C
8. Cross-jurisdictional relationships	7.78	0.154	C, D
9. Communications plan	7.73	0.158	D
10. Decision-making process	7.67	0.145	D
11. Transition of authority	7.50	0.196	D
12. Resource mobilization	7.27	0.183	E
13. Integration of non-fire agencies	6.84	0.189	F
14. Consistency of implementation	6.61	0.175	F, G
15. Integration of non-government	6.27	0.205	G
16. Agreement on system modifications	6.23	0.231	G

*Those attributes with the matching letters in Column 4 are NOT statistically different at the 95% confidence level. All others are. For example, Items 1-4 are not statistically different from one another (all have A's), nor are Items 2-5 (all have B's). But Item 1 has a statistically higher rating than Item 5.

One significant result is that none of the ICS attributes received a mean rating in the lower half of the 10-point scale, and thus the data does not support stratification of attributes as absolute strengths or weaknesses. In fact, statistically speaking, none of the ICS attributes is considered a weakness by the sample population. Even the lowest-rated attribute, with a mean rating of 6.23, is significantly greater (P=95%) than the

presumed neutral value of 5.5, which is the statistical midpoint of the 10-point scale used.

The high degree of statistical overlap at the 95% confidence level suggests that a comparison of confidence intervals in conjunction with the rank order of attributes allows for a more realistic interpretation of the data than by using rank order alone to evaluate attributes. Viewing the data in this manner suggests that ICS attributes should be placed in tiered groupings of roughly equal levels of significance rather than on an absolute scale of 1 through 16 (Table 3).

Table 3: Tiered Groupings of ICS Attributes

CATEGORY	ICS ATTRIBUTE
First Tier Strengths (A, B)*	Predefined hierarchy, uniform terminology, modular organization structure, Incident Action Plans, span of control
Second Tier Strengths (C, D)*	Standardized forms, delegation of authority, cross-jurisdictional relationships, communications plans, decision-making process, transition of authority
Third Tier Strengths (E, F, G)*	Resource mobilization, integration of non-fire agencies, consistency of implementation, integration of non-government, agreement on system modifications

*Letter codes indicate statistical significance at the 95% confidence level. They are taken from Table 2.

The three groups are mutually exclusive in that the attributes in each have significantly different ratings than attributes in the other two groups (P=95%). The terms assigned to these groups are first, second, and third tier strengths. They provide the basis for the answer to the first research question: “What lessons can be learned from

the collective experience of practitioners of ICS as it has evolved through its first 25 years?"

Based on the initial evaluation of the data, the author proposes two preliminary findings or "lessons" from the sample population of ICS practitioners. The first pertains to "alignment", and the second pertains to "scaleability" (Cole, 2000).

Alignment

The attributes in the first tier collectively constitute what the author calls "predetermined internal alignment" (Cole, 2000). It is *predetermined* because practitioners know the rules by which the system functions even before the incident begins. In CDF, this is true not just for command and general staff, but for all personnel on an incident. Since ICS is incorporated into the most basic training, even the rookie firefighter knows the basic system rules and operates in "ICS mode" on a routine basis. The first tier strengths work best *internally*; that is, within the system, where practitioners share common purpose and terminology. They know their own roles and where their own specific responsibilities begin and end, and have an understanding where they fit within the system's hierarchy and span of control. They all "play from the same sheet of music," so to speak, and are in *alignment*, which, according to Peter Senge, is a phenomenon that occurs "when a group of people function as a whole so that a commonality of direction emerges, and individuals' energies harmonize" (Senge, 1994, p. 234).

But while internal alignment is one of the strongest features of ICS, the system is not as strong in effecting *external* alignment; that is, alignment with forces outside the

system structure itself. External forces change from incident to incident and often include organizations that are not familiar with ICS, as well as political, economic, social, environmental, legal, and cost factors that are not entirely within the system's ability to manage (FEMA, 1999).

Scaleability

The second ICS lesson from the sample population data pertains to what the author calls "scaleability"—that is, the system's ability to expand or contract as needed to fit the operational requirements of a particular incident (Cole, 2000). Because ICS was built on modular and functional principles, it became apparent during the early years of its deployment that the system could work equally well for non-fire disasters, including earthquakes, floods, riots, and hazardous material incidents (FEMA, 1992). With repeated use, departments found that it made sense to use this management system not just for major disasters, but for everyday emergencies as well. In CDF, for example, ICS is used from the moment of initial dispatch to an incident. An Incident Commander is established for *every* incident, even if it is a single resource response. The system then evolves, as needed, to accommodate the needs of the incident: If a fire or other emergency is not controlled during initial response and requires additional resources, ICS allows the system response to "scale up" and "scale out" to keep pace with the changing needs of an expanding incident without having to switch operational modes. Similary, the system can "scale down" as the incident resolves.

In the second phase of the study, when follow-up interviews were conducted to elicit further discussion and analysis, it quickly became apparent that while the 16 attributes

were indeed considered important and representative features of ICS, something was still missing. The difficulty lay in treating the 16 attributes as independent factors when in fact they are too interdependent to be evaluated in isolation. The Delphi interviews and discussions strongly supported the consolidation of attributes into the overarching principles of “alignment” and “scaleability” in the first phase of the study, but a consensus developed that at least two more overarching “lessons” emerge from the sample population’s 2,200 years of collective ICS experience. These pertain to “teamwork synergy” and “progressive adaptation.”

Teamwork Synergy

At every scale of implementation ICS fosters teamwork, and in turn, the system benefits from it. Such teamwork follows a classic positive feedback loop pattern of self-perpetuation and self-reinforcement (Richardson, 1999). The pattern goes something like this: stronger teamwork leads to better results, which make the team stronger and capable of yet better results, leading to an even stronger team, etc. There is no way to measure or describe this by looking at any of the single factors listed in Table 2. This unquantifiable phenomenon, which came up again and again in discussions among veteren ICS practitioners, is *synergy*.

Teams are more than the sum of their parts, and teamwork synergy is the result of a highly self-organized process in which an individual’s contributions are valued, recognized, and incorporated into team behavior from day one. Those who excel at teamwork are given more challenging opportunities, and if they continue to excel they “move up the ladder.” Because such people are assets to any team, whether the team

work product is a station paint job or a five-alarm response, they get more practice. And the more practice they get, the better they tend to perform: the positive feedback loop again. The importance of practice to performance cannot be overemphasized. “Imagine a championship sports team without practice,” writes Senge (1994, p. 238). “The process by which such teams learn *is* through continual movement between practice and performance.”

As important as teamwork is to a championship basketball team, it is even more important in emergency operations, where the stakes can be life and death. ICS provides a framework for systemic “natural selection” that favors the development and promotion (i.e., to greater responsibility) of those who are best able to adapt to, and perform particular tasks within, high-chaos environments. A person becomes a Planning Section Chief, for example, only after years proving his/her ability to manage intelligence (situations, status) and resources, and to coordinate accurate, real-time action planning efforts. But most important, they have had to prove their ability to work well as part of a team under constantly changing and unpredictable conditions.

Adaptation

In their book *The Wisdom of Teams*, Katzenbach and Smith (1999) define two requirements for effective team problem-solving: common purpose and common approach. By nature, ICS has a built-in commonality of *purpose*, which is to mitigate the particular crisis (and its unique set of problems) that the system has been deployed to manage. The system does not fully “kick in” unless a problem has reached a critical point of urgency (“crisis”) that requires a higher level of cooperation and coordination,

whether the crisis is a vehicle collision with unknown injuries, or a 7.9 earthquake during the World Series. According to Katzenbach and Smith (1999), the establishment of "urgency and direction" is the first principle of building team effectiveness. "All team members need to believe the team has urgent and worthwhile purpose," they write, "and they want to know what the expectations are" (p. 119).

ICS was custom-built for urgency. At times of crisis deployment, system practitioners know to "tune out other work duties and focus on this crisis until it is mitigated." They are able to "hit the ground running" because system features like predetermined internal alignment and scaleability provide a built-in, systemic *approach*.

But by themselves, these structural system features do not guarantee an effective team problem-solving effort that is equal to the complexity of chaos. For ICS structure to work, somehow the information of chaos has to be processed continuously so that the system can move from initial *reaction* to *action*, and ultimately to "*proaction*"—that is, anticipation, management, prediction, pre-positioning of resources, etc.

The name for this type of information-processing in nature is *adaptation*, and it is the fundamental process of all self-organizing systems. "Self-organizing systems are adaptive, in that they don't just passively respond to events the way a rock might roll around in an earthquake," writes Waldrop (1993, p. 11). Rather, "they actively try to turn whatever happens to their advantage." Thus the human brain constantly processes its billions of neural connections through mental feedback loops to learn from experience. Species evolve to optimize survival in a changing environment—and so do institutions and industries. The marketplace responds to changing tastes and lifestyles, demographic and technological developments, shifts in the price of raw materials, etc.

Similarly, ICS provides a formalized structure and evolving process for *adapting* to the changing conditions and variable requirements of the unpredictable environment of chaos. To accomplish this, ICS uses not only internal alignment, scaleability, and teamwork, but also an ensemble of planning and coordination tools, including systematized action plans and standardized operational planning cycles built on performance measurement and accountability. These tools constitute a systematic and continuous process of feedback, in which each successive operational planning meeting and resultant Incident Action Plan are used to “adjust future conduct on the basis of past behavior” (Wiener, 1950). ICS uses this operational planning feedback process to respond and “actively try to turn whatever happens to management advantage” (Waldrop, 1993). Former California State Fire Marshal Ronny Coleman calls this feature “constant course correction,” and considers it to be perhaps the most valuable aspect of ICS (personal communication, September 22, 1997).

The term I propose is “progressive adaptation,” and it has parallels “across many levels of organization” (Wilson, 1999) in biological systems at all scales, from cellular development to genetic evolution and socioeconomics. Like all these self-organizing systems, ICS exhibits adaptation and “learning” characterized by the progressive gathering of information through a systematic rolling-horizon of sequential operational planning cycles. The system applies the accumulated “intelligence” to the task of systematically and relentlessly “eliminating the uncertainty” posed by chaos (Holland, 1998).

DISCUSSION

In this section I will discuss ICS in light of the data presented in the Results, above, and with the view of addressing what Edwin O. Wilson (1999) calls science's "greatest challenge today": the development of meaningful descriptions of complexity. In the process I will attempt a brief description of ICS in the context of the concepts of chaos and complex systems presented in the Literature Review above.

What ICS Is, and Where it Works

As described above, a new science of complex systems has emerged in recent years to address the question suggested by chaos theory: How does order arise in a universe ruled by entropy? ICS arose out of a need in the emergency services to address this same challenge.

ICS is a system that can be considered a human management paradigm, if not for *creating* order, at least for *controlling* chaos. I use the term "control" not in the context of domination or the imposition of human will on natural systems, but in the sense of management and regulation, as in the way a thermostat "controls" temperature within a range of comfort, or in the way a steering wheel is used to "control" the course of a moving vehicle. In human terms, it is the sense of having our lives "under control." In this context, ICS "command and control" is used not to *dictate* conditions, but to manage chaotic systems (e.g., emergencies, disasters) with the goal of bringing their actual system performance into line with "desired" performance.

Capra (1986) generalized Kuhn's definition of a scientific paradigm to that of a "social paradigm," which he defined as "a constellation of concepts, values, perceptions,

and practices shared by a community, which forms a particular vision of reality that is the basis of the way the community organizes itself." I contend that ICS and its system practitioners constitute such a social paradigm, but a very specialized one—a *management* paradigm. Specifically, it is a system for managing people and resources under uncertain and often unpredictable conditions. As a system, ICS was "born and raised" in a high-chaos environment; it has evolved, or "self-organized," to address perhaps the most complex and chaotic systems of all: human-centered crises.

When I say ICS has "self-organized, I don't mean to suggest it has done so passively or in the absence of leadership. Quite the contrary: ICS exists only because of inspired, even visionary leadership. But this leadership has been a creative group effort that has self-organized within the emergency services around one clear and overriding purpose: to control—or "order"—the chaos of crisis.

In the emergency services these crises occur at all scales, from the proverbial cat-in-the-tree all the way up to the mega-disasters thrust upon us by Mother Nature. But even at its most elemental, human-centered crisis is characterized by unpredictability and uncertainty—at least until the crisis is resolved. Chaos, therefore, is not only one of those "commonalities that occur across all scales" of incidents for which ICS is deployed; it is also the rarefied environment in which the system evolved.

I would go so far as to suggest that ICS must continue to evolve if it is to be able to keep up with inexorable entropy. ICS is a true *evolutionary system*, a self-organized design-in-progress, for use in the most complex environments known, and for the purpose of systematically managing chaos when it begins to spin out of control.

As mentioned earlier, the “central idea” of chaos presented by Lorenz (1963) is “sensitive dependence on initial conditions.” This idea is most often used to describe the phenomenon of systems losing control to chaos (as in the Butterfly Effect) but it can also be viewed as the point at which deliberate management may most effectively *bring control* to chaos. While conditions are still sensitive to change, the application of well-orchestrated efforts may induce a very disordered system to “crystallize” to a higher degree of order (Kauffman, 1991).

The second research question posed in the Introduction was: “What kinds of problems does ICS address most successfully?” The answer I propose is that at its core, ICS is a control system for cooperative problem-solving—not just any problem, but the particular set of complex problems that emerge in systems at criticality, where they face a “chaos crisis.” According to the Encarta World English Dictionary (2000), “crisis” has two roots: the Greek *krisis* “decisive moment,” and *krinien* “to decide.” ICS addresses crisis at two levels of meaning. First, crisis as a “dangerous and worrying time;” and second, as a “critical moment: a time when something very important for the future is decided.” In medicine, for example, Encarta defines crisis as “a point in the course of a disease when the patient suddenly begins to get worse or better.”

In the context of complexity theory, this critical or decisive moment is sometimes called “the edge of chaos” (Kauffman, 1996; Wilson, 1999). In a recent bestseller, it has been called the “Tipping Point,” defined by Malcolm Gladwell (2000, p. 12) as “the moment of critical mass, the threshold, the boiling point…at which little changes can have big effects.” In the terminology of chaos theory, it is the stage where “sensitivity to initial conditions” is at its maximum. It is at this stage, where systems are still “sensitive”

to condition change, that ICS deployment can be used to get off to a fast start in the race against entropy.

This is not to suggest that there is a single point at which ICS is effective, but rather to indicate that in a crisis, there is generally a time frame and set of circumstances that represent a critical period for influencing system behavior. Figure 1, which depicts Lorenz's (1963) weather data, can be used to illustrate a generalized "chaos crisis" for system behavior over time. To the left of critical point **A**, actual system behavior and expected system behavior are identical. At **A** initial conditions are changed as some minor input initiates chaos in the system; actual behavior begins to diverge from expected behavior. Between critical points **A** and **B**, system behavior is still sensitive to condition change; it is easy to visualize relatively small countervailing inputs "nudging" actual and expected behaviors back into unity by "squeezing" the chaos out of the system. Beyond **B**, all bets are off as chaos behavior escalates.

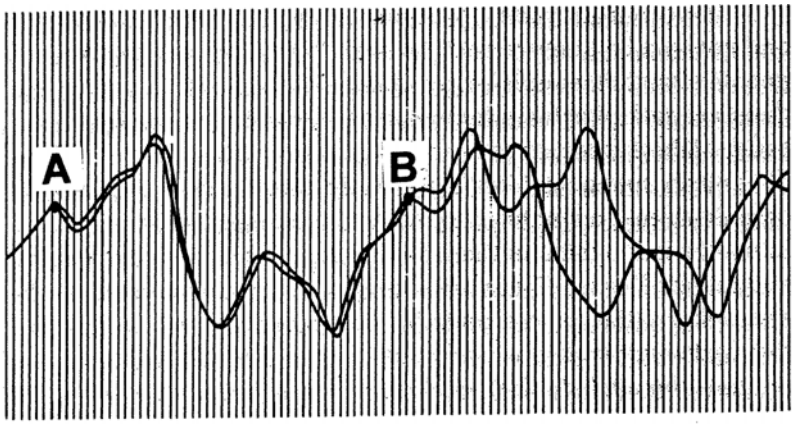

Figure 1. How two weather patterns diverge over time: a model for a "chaos crisis" (figure from Gleick, 1987, p. 17).

Now if we let Figure 1 represent the system behavior of a theoretical human-centered crisis (e.g., a natural disaster), then the **A-B** segment of the curve represents the critical period during which the timely application of countervailing management inputs can most easily control the chaos of crisis. ("Apply ICS, and the patient gets better.") Of course, absent such timely management action, a crisis may "tip" into chaos that can amplify out of control. To the right of **B** on the curve, chaotic system behavior increases: The mere flapping of a butterfly's wing results in a tornado, a single grain of sand unleashes an avalanche, or a routine fire erupts into conflagration.

These ideas of criticality and sensitive dependence on initial conditions existed long before chaos theory demonstrated them mathematically. Consider the old proverb from folklore (Wiener, 1981):

> "For want of a nail, the shoe was lost;
> For want of a shoe, the horse was lost;
> For want of a horse, the rider was lost;
> For want of a rider, the battle was lost;
> For want of a battle, the kingdom was lost!"

ICS represents an implicit recognition of this progression. Metaphorically speaking, ICS was developed only when the "kingdom" was threatened. But as it has evolved, and in areas where it has become institutionalized so that it is deployed even for everyday emergencies, ICS has been tested time and again. Mistakes have been made, to be sure, but the evolutionary response has been to learn from them, to adapt and innovate. With time and practice, the system continues to self-organize so its effectiveness

improves at multiple levels of complexity. Should the kingdom become threatened, ICS will be there; but in the meantime, it can also be used to save some horses and riders!

How ICS Works to "Order Chaos"

ICS has proven its effectiveness in countless thousands of human-centered crises during its first quarter-century. It provides managers tools to hold their own against entropy—against the runaway chaos of crisis. Let us turn now to the third and final research question: "Can ICS be described in terms of complexity science?"

Complexity theorists argue that the most sophisticated, highly-evolved systems known are self-organizing systems, which have a sort of system intelligence that allow them to "learn" and adapt to changing conditions. Nobel Laureate Ilya Priogine (1997) notes that "the maintenance of organization in nature is not—and cannot be—achieved by central management (but only) by self-organization." There is no central management entity that coordinates the behavior of individual cells to form multi-celled organisms, ecosystems, or even economic or political systems. In nature, says Prigogine, "Self-organizing systems allow adaptation to the prevailing environment, i.e., they react to changes in the environment with a thermodynamic response which makes the systems extraordinarily flexible and robust against pertubations from outside conditions" (p. 71).

ICS constitutes such an adaptive self-organizing system. By its very nature, the system exists for the purpose of managing the sensitive conditions at "the edge of chaos." To be effective at the edge of chaos, such a system must be stable enough to collect and store information, but also dynamic enough to adapt to it and to act upon it.

If a system meets these tests, then it can be organized to perform complex operations, “to react to the world, to be spontaneous, adaptive, and alive” (Waldrop, 1993, p. 293).

To visualize how ICS functions at the edge of chaos, it may help to picture a simplified conceptual model suggested by Kauffman (1991). He relates system behavior to the phases of matter, where ordered systems are compared to solids, chaotic systems are gases, and intermediate systems are liquids. He compares the edge of chaos to “phase transition” which, it may be remembered from physics, is the phenomenon where a liquid changes to a gas if heated, or to a solid if cooled. It is at the intermediate liquid phase, where systems are poised between order and disorder, that they are most malleable and adaptable. (The analogy should not be interpreted too literally, of course: true liquids are a distinct phase of matter and not just a transitional regime between gases and solids.)

Viewed with this model, highly ordered systems are too rigid and brittle to coordinate complex behavior, while highly chaotic systems are so disordered that control of complex behaviors cannot be maintained. But systems poised in the fluid transition state seem to have “the flexibility to adapt rapidly and successfully (and) the optimal capacity for evolving” (Kauffman, 1991, p. 82).

Interestingly, in my interview with Robert Murgallis, the National Fire Academy’s Program Chair for Emergency Policy and Analysis, he used the term “fluid” to describe how ICS works (personal conversation, July 18, 2000). Using this analogy, ICS can be viewed as a fluid system for “painting the problem;” that is, a system for covering crisis with a “coat” of solutions appropriate to the circumstances. The challenge is do this as

efficiently as possible, with a minimum of “drippage” (i.e., wasted energy and resource use).

Robert Murgallis and I discussed our respective experiences in the aftermath of the Loma Prieta Earthquake, which occurred on October 17, 1989, just as a World Series baseball game was about to get underway at Candlestick Park in San Francisco. [12] The capabilities of ICS were immediately tested to extremes as dozens of major incidents occurred simultaneously over a 10,000 square-mile area. In San Francisco, blocks of wood-frame structures burned in the Marina District, while across town a section of the Bay Bridge had collapsed. On the other side of the Bay In Oakland, a double-decked freeway had pancaked, killing or trapping untold dozens of victims. Fifty miles to the south, the cities nearest to the quake’s epicenter, Santa Cruz and Watsonville, had sustained devastating damage. Hundreds of buildings were destroyed, including a department store in downtown Santa Cruz, where a dozen were killed and scores were trapped in the rubble. Thousands of private homes and businesses in 10 counties had sustained major damage, and public utilities were damaged to the point that fire fighting capabilities and communications were compromised in many areas. This was a massively complex human-centered crisis, and ICS was deployed more widely, and with the participation of more entities, than ever before.

In standing up to the chaos of the 1989 earthquake, “ICS showed how fluid it is,” Murgallis said. “It showed that if you understand a few building block principles, you

[12] We both worked in the San Francisco Bay Area at the time and responded to the quake: Murgallis from Santa Clara Fire Department, Cole from CDF in Napa County.

can assemble the system you need to control any incident scene."

Four of these "building block principles" are suggested by the data presented in the Results section of this paper. Consider how these principles, working in concert, gave ICS the "fluidity" to address the extreme complexity of the Loma Prieta disaster.

Thanks to the **predetermined internal alignment** of the ICS management structure, minimal time was wasted transitioning from reaction to action and, ultimately, to anticipatory action, or "proaction." Within hours of the initial shock of the earthquake, thousands of emergency workers were able to hit the ground running on dozens of major incidents. The primary reason for this quick transition to "chaos control mode" is that every system worker, whether an executive officer on a standing major incident team or a crew member on an engine strike team, knew his/her role going into "battle." With ICS, this is more than knowing one's rank—it is knowing the functional expectations of the position one fills. Predetermined alignment means each worker knows this going in, and their co-workers know it also; they are functionally "aligned" with one another. It made little difference that the nature of the crisis was an earthquake rather than the more commonly encountered fire or flood. My 15-person Planning Section, for example, spent the first few days after the quake supporting search and rescue operations in Santa Cruz, then moved 30 miles down the road to help implement relief efforts in Watsonville. We turned out Incident Action Plans every 12 hours for two weeks, then switched to 24-hour plans. But while the working conditions, incidents, time frames, and information fed into the plans changed continuously, the process and the players remained stable—we stayed in alignment. In complexity terms,

our job was to work systematically to bring order to chaos by applying a stable system (the operational planning process) to a chaotic system (our assigned “incident”).

The fluidity of the ICS response to the Loma Prieta quake was further enhanced by the system’s **scaleability**, which allowed it to manage the crisis and order chaos on multiple fronts simultaneously. It enabled the management structure to self-organize spatial, temporal, and structural subsystems so as to optimize management inputs, and thus build customized solutions to match the variable nature of the numerous crises. For example:

- ***Spatial*** scaleability allowed deployment of multiple parallel-functioning incident command structures over a large geographical area, encompassing countless jurisdictions. Each of these incident or branch “subsystems” had scaleable flexibility to grow or contract as the situation changed (within the constraints of resource availability, of course).
- ***Temporal*** scaleability allowed fluidity on management time frames. While most incidents used 12-hour operational periods, some found that 24-hour shifts worked better due to re-supply and transportation constraints imposed by infrastructure damage. One incident, a hazardous material spill at the quake-damaged University of California chemistry building, used four-hour op-periods due to operations contraints posed by exposure limits and working conditions.
- ***Functional*** scaleability was especially in evidence in the rescue and recovery of victims from collapsed buildings and other structures. The Interstate 880 collapse—the so-called Cyprus Structure Incident—required nearly a week of around-the-clock management of resources and challenges not routinely

encountered, yet the scaleability of ICS allowed for adaptation and innovative accommodation of novel resource coordination needs (McCoy, 1990).

The Loma Prieta Earthquake demonstrated that the alignment and scaleability features of ICS provide a management structure that can be effectively applied to even the most complex human-centered crises. This structure allows the “chunking” of extremely complex sets of problems into a finite number of components that can be effectively managed.

The third and fourth building block principles, **teamwork synergy** and **adaptation**, lie at the heart of what makes ICS an *evolutionary system*. Together they form an adaptive learning process that is key to transitioning from response mode to control mode. When Loma Prieta struck Northern California in 1989, it was the strongest earthquake to hit the continental U.S. in more than 80 years. None of the thousands of emergency workers who responded had any experience working in the immediate aftermath of such a tectonic incident. Yet ICS provided the structure and process for the system to be able to learn and adapt to novel and dynamic crisis conditions, and to do it in real time.

Holland (1998) defines adaptation as “any process whereby a structure is progressively modified to give better performance in its environment.” In concert with team synergy, adaptation becomes a group learning process for optimizing problem-solving under conditions made difficult by complexity and uncertainty. Holland calls this “adaptive learning,” which is characterized “by a sequential gathering of information and the useage of current information to eliminate uncertainty created by insufficient *a priori* information” (p. 54).

Adaptive learning is one of those “deep laws of nature” that occur across “many levels of organization.” At a very complex level of organization, for example, adaptive learning occurs as biological evolution produces increasingly fit organisms in environments that are initially hostile to them. Species that evolve successfully do so by testing environmental options and exploiting the best at every step. They systematically reduce the uncertainties in their immediate futures while rapidly increasing their knowledge of available options. Unless information is “exploited as acquired so that performance improves apace,” a species will not survive (Holland, 1998, p. 1). Every successful species, therefore, has developed what Holland calls an “adaptive plan” (usually a reproductive strategy) that gives rise to “structures that perform well (i.e., are fit) in the environment confronting it” (p. 3).

According to Nobel economist Kenneth J. Arrow (1998), “Adaptation by natural selection has many analogies with adaptive learning to the environment in the higher animals and in human individuals and society.” At the human individual level of complexity, adaptive learning occurs to each of us individually through the knowledge we acquire in the course of our life experiences, and what we do with it. Move up one level on the social complexity scale, and the same adaptive learning process occurs at the family level where, for example, we learn through a network of communications that exhibit inherent feedback loops. The results of conversations we have as family members give rise to questions and further discussions, leading to still more feedback and learning. With time this results in a shared system of beliefs, values, traditions—a worldview that is sustained and reinforced by yet further conversations and interaction

(Capra, 1996). In the process we learn our roles within the family, as well as the context in which we and our family interface with the world at large.

The same adaptive learning process happens with working teams, something that is implicitly recognized in a growing body of literature devoted to “team learning” and the “learning organization” (Senge, 1994; Katzenbach and Smith, 1999). Adaptive team learning has existed from the very beginning in ICS, where teamwork is not only the predominant action paradigm, it is also a collective and continuous learning process. Adaptive learning is vital to the evolutionary nature of the system we call ICS—a system that must always be ready to handle the unpredictable and unprecedented. There is no blueprint or “how-to” manual that works in every chaos crisis. Each crisis is unique and chaos appears in many forms; we must learn as we go. ICS gives us the tools to do this *systematically*. An Incident Action Plan (IAP) is nothing more than an “adaptive plan” (Holland, 1998) with tightly defined temporal parameters, feedback processes, and mechanisms for tracking performance. As an adaptive plan it is ceaselessly and relentlessly evaluated and updated to meet the dynamic challenges of crisis. When ICS functions properly, each IAP progressively incorporates “incident learning” that makes it more “intelligent” than its predecessor.

Summary

The management system we call ICS was created after the system complexity facing California’s emergency services hit criticality during the catastrophic fire season of 1970, when the rigidly “ordered regimes” of individual institutions proved too isolated, frozen and slow for the complex behavior demanded by the unpredictable and rapidly-

changing “chaotic regime” of disaster. With the help of a Congressional mandate, ICS has developed and thrived at the phase transition between order and chaos, where it has evolved an adaptive framework for responding to, and then managing, the sensitive conditions at “the edge of chaos.”

I suggest the following proposition: ICS works as effectively as it does because it follows two “deep laws of nature” that occur across many scales of complex systems: self-organization and adaptive learning. The structural framework for system practitioners to “self-organize” for each unique bout with chaos is provided by the operational hierarchies and control mechanisms so highly valued by California’s veteran practitioners, as exemplified by *internal alignment* and *scaleability*. And the framework for “adaptive learning” comes from the dynamic and evolutionary processes of synergistic, function-based *teamwork* and the feedback of *progressive adaptation*. Applied together as a whole, these features allow ICS practitioners to “synchronize watches” and synergize efforts, to systematically “tip” conditions away from uncontrolled chaos and toward predetermined management objectives for *ordering* chaos.

RECOMMENDATIONS

Based on nearly 10 years of strategic review of this unique management system, including the statistically robust performance evaluation by California’s veteran practitioners, the author offers three recommendations for improving the Incident Command System.

1. ICS should be managed at the system level with the same "urgency of purpose" that is applied at the incident level.

The primary challenges facing ICS today, I believe, are not where the "rubber meets the road," but at the system administrative level. ICS practitioners have done an excellent job of scaling system applications to multiple levels of crisis and complexity. For example, in California, where ICS originated to cope with the management complexity of major disasters, it has been found to be almost seamlessly flexible for dealing with "everyday" complexity as well. In departments like CDF, the system is deployed as standard operating procedure, not just for major disasters, but also for countless routine fires, car wrecks, medical aids, highway fuel spills, and other incidents emergency responders face on a daily basis.

To an extent, these successes have created a crisis at the system's top level. Twenty years ago ICS was the incident management system of choice for only a handful of fire departments, starting with the original FIRESCOPE Seven. Today it is the most widely used system of its type in the world, and no longer used solely by the fire service. It is has been used by the Department of Justice, the FBI, and the State Department (e.g., for terrorist and hostage joint operations). The U.S. Coast Guard uses ICS for environmental responses and search, rescue, and recovery operations, and the U.S. Department of Energy is adopting ICS for use in responding to nuclear emergencies. It has been adopted by health care and public works agencies, among others. As the use of ICS expands throughout the fire service and beyond, to a wide range of disciplines, new users often "customize" ICS to fit their particular needs. While ICS is designed to be adaptable, unilateral changes can potentially compromise the

general set of principles that underlie the system. This can lead to conflict and confusion when disparate entities are brought together on major incidents.

A systems level management process should be established that follows the same system protocols used for multi-agency command (MAC) on large incidents. This “top level” should follow ICS structure and process as closely as possible. It should use the system’s action planning approach, including defined operational planning cycles (perhaps monthly or quarterly), specific roles and assignments, and most important, relentless feedback accountability.

Lacking a committed approach that has the same urgency of purpose common to ICS deployments in true crises, this system level management may go the way of so many strategic planning efforts: the rubber seems to hit the road, but the wheels just spin. ICS has come to far to let that happen; the system needs governance.

System-level management would most appropriately be coordinated by FEMA and should include an oversight board with representation from the various geographical regions and ICS user groups. These should include representatives from a full spectrum of disciplines, including the fire service, law enforcement, medical and health services, public and private utilities, environmental protection, relief organizations, the National Guard, and others as deemed appropriate. Such a multi-disciplinary national oversight board is necessary for providing ongoing policy guidance and direction if ICS is to be an effective national system standard for managing emergencies. A primary function of this board would be to act as a “court of authority” for reviewing and arbitrating any unresolved issues of system standards, compliance, implementation, operation, and training.

2. ICS terminology should be demystified and “demilitarized”.

ICS has its own system culture. It even has its own language, what Casti (1995, p. 276) calls a “linguistic description of the system in the real world.” ICS is not unlike a computer program or a musical score, with its own particular set of signs, symbols, codes, routines, and subroutines that allow system practitioners to “play from the same sheet of music without missing a beat.”

There may be a downside to this, however, if the linguistic description of the system is so esoteric that it needlessly excludes, or even alienates, the non-initiated. Whenever ICS is deployed there is likely to be a systems interface between those who are indoctrinated to function within the parameters of the system (ICS users) and those who are not. It is simply a given that the system will have to interact with non-system users, including the myriad agencies, volunteer and relief organizations that are not indoctrinated to ICS, as well as the general public, the media, and others. This issue of “external alignment” (Cole, 2000) is further complicated by the fact that it is often impossible to anticipate in advance who these non-system users will be. Major incidents vary widely in their scope and impacts, and it is not always possible to know beforehand what agencies and which personnel will be thrust together, nor the nature of the crises they will confront.

Perhaps the most common problem encountered when introducing ICS to new users is the difficulty in communicating key concepts and procedures to cooperators who may not have a fire background, or who may not even be emergency responders. This can necessitate a virtual translation of terminology, principles, and working relationships to those cooperators who have little or no experience with ICS. The midst of crisis is no

time to be burdened with making translation and explanations: how much better if our potential cooperators had a better intuitive understanding of the system “going in.”

System practitioners should have the confidence to recognize that ICS can serve as a true paradigm for human-system response to the sensitive conditions encountered at the “edge of chaos.” The fire and emergency services may have more practice than most, but we are not the only entities having to confront conditions of chaotic instability. As with any true paradigm, the lessons of ICS may be generically adaptable to a range of applications far beyond what the “first adopters” ever imagined. We should take the valuable lessons we have leaned during the 25 year evolution of ICS and make them more widely available, not more esoteric. We can start by translating the system’s standard terminology from its largely military origins to the more common and accessible language of business and civilian social institutions.

3. FEMA should sponsor and/or support a systematic evaluation of ICS by entities familiar with the concepts of complexity science.

In California, ICS no longer represents a paradigm shift; the shift has happened. According to Kuhn (1962) a paradigm shift can be verified after the old guard passes and “a new generation grows up that is familiar with it” (p. 151). This is now true in most of the major fire departments in California, where ICS can be said to have entered the post-shift phase that Kuhn calls the “maturing paradigm.” Judging from the results of the research, the new generation that has grown up with ICS in California has expressed the overwhelming sentiment that “ICS works.” There is no better evidence of this is the system’s rapid and widespread adoption since 1980.

And yet how do we know what works and what doesn't, and what improvements need to be made? As new disciplines adopt the ICS approach, how do we know what adaptations need to be made to make ICS a truly universal system for emergency management? Is such a universal system even practical? And how do we know which problems encountered by ICS users are *system* problems, and thus need to be addressed through further refinement or redesign, and which of these problems are inherent in the chaotic nature of emergency management?

These and many other questions have no easy answers, but one thing seems evident: ICS is in need of a systematic evaluation. Collectively, the system needs to step back, take a deep breath, and understand that a quarter-century is a long time to be breaking new ground. There have been successes, to be sure, but the system may now be suffering from a "surfeit of success." With the number of new ICS-converts and users growing every day, there is increasing pressure to accommodate so many adaptations and innovations that the system threatens to take on an unwieldy, chaotic life of its own. These and other "growing pains" must be addressed, just as we would address them in our own personal lives.

It may be time to seek "professional advice." FEMA should consider striking a strategic alliance with researchers at one or more of the institutions at the cutting edge of complex systems science. Candidates might include Ilya Prigogine's Center for Complex Systems at the University of Texas, MIT's Sloan School of Management, and the Santa Fe Institute. It is clear to me, from the readings I have done and my own experience using ICS, that many of the theoretical concepts of chaos and complexity science have already been tried, tested, and in many instances, proven by the ICS

experience. A relationship with one or more of the above research institutions would undoubtedly be mutually beneficial.

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APPENDIX A

ICS QUESTIONNAIRE

(should take no more than 10 minutes)

I am doing a research project for the National Fire Academy that evaluates the Incident Command System from the point of view of veteran ICS practitioners. If you would like your input included in this research, please complete the survey below.

Just type in your answer after each question. When you're done, **REPLY** to dana_cole@fire.ca.gov.

Thanks in advance for your participation.

Dana Cole, CDF.
(707) 963-3601 ext. 108
email: dana_cole@fire.ca.gov

Directions:

Type the appropriate number after each question.

1. How many years of experience do you have in the fire service?

2. How many years of experience do you have using the Incident Command System? (approximate if you're not sure)

3. How many years of experience do you have as a member of a major incident command/management team? (if none, enter “0”)

4. In your career, approximately how many incidents with duration of 3 or more consecutive operational periods have you been assigned to as a team member at the Command & General Staff level?

5. How many of these incidents were non-emergencies (conference, project, etc)?

6. Please read the following scenario and then rate the listed features of ICS.

SCENARIO: Imagine that you are contacted by a health care administrator with whom you have worked on a major disaster. She saw ICS applied and is considering adopting an ICS approach for managing major medical emergencies at her company’s hospitals. She knows you have years of experience working with ICS, and she wants to discuss your perception of its weaknesses and strengths .

Directions:

Rate **each** of items A-P below on a scale of 1 to 10 to indicate its relative WEAKNESS or STRENGTH as a feature of ICS. (For example, a score of 2 is a more significant weakness than a score of 3; an 8 indicates a more significant strength than a 7)

Remember, there are no right or wrong answers. I am just looking for your honest opinion.

1	2	3	4	5	6	7	8	9	10
WEAKNESS									STRENGTH

A. Uniform terminology for identifying resources and organizational functions.

B. Resource mobilization effectiveness.

C. Modular organization structure that is expanded or contracted as needed.

D. Consistency of implementation among various agencies.

E. Communications plan that is coordinated among responding agencies.

F. Incident Action Plans that are updated for each operational period.

G. Agreement among agencies about who has authority to modify the ICS “rules of the game.”

H. Manageable span-of-control.

I. Clear decision-making process.

J. Cross-jurisdictional and cross-functional working relationships when ICS is used.

K. Standardized forms used for all incidents.

L. Predefined hierarchy, including chain-of-command and delineated responsibilities for every position.

M. Ample flexibility and authority are given to staff for accomplishing incident objectives.

N. Process for transitioning command authority from one level of government to another as incident complexity changes.

O. Effectiveness of integrating non-fire government agencies (e.g., law enforcement, public works) into ICS structure.

P. Effectiveness of integrating non-government organizations (e.g., relief organizations, private citizens, and businesses) into ICS structure.

THANK YOU! Please feel free to add any comments below.

When you are finished, merely click the **REPLY** button on your email menu bar.

Note: If this was forwarded to you by someone other than Dana Cole, please send to:

dana_cole@fire.ca.gov

(v. 1)