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# INFRASTRUCTURE INTERDEPENDENCY AND THE CREATION OF A NORMAL DISASTER
## The Case of Hurricane Katrina and the City of New Orleans

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*This article examines the impact of Hurricane Katrina on the infrastructure of the City of New Orleans. Hurricane Katrina set in motion a devastating series of failures in the critical infrastructure of the City of New Orleans and the surrounding region. The authors argue that Katrina can be viewed as a "normal" disaster, involving the complex interaction of interdependent infrastructures resulting in the unanticipated failure of multiple infrastructure systems. Key characteristics of infrastructure interdependencies are explored in relation to the case of Hurricane Katrina and New Orleans. Understanding the nature of normal disasters and the tight coupling of infrastructure systems provides infrastructure managers with important lessons. These lessons involve the need for risk and vulnerability assessment; coordination, cooperation, and communication; and the need for flexible response to disasters.*

***Keywords:*** *Hurricane Katrina; infrastructure interdependency; disaster; New Orleans*

### The Big One

By any yardstick, the City of New Orleans was a city highly vulnerable to the effects of a hurricane. Not just any hurricane, of course, but a hurricane of sufficient magnitude—a Category 4 or 5—or even a slow-moving Category 3. The levees were fragile, and the City sited in a natural bowl with most addresses several feet below sea level. To paraphrase Dr. Walter Maestri, emergency manager for neighboring Jefferson Parish, "Bienville just made a bad choice" (when recalling the founding of New Orleans in 1718; McQuaid & Schleifstein, 2002).

At the outskirts of the City, years of coastal erosion resulted from the creation of a levee system that constrained Mississippi River floodwaters, keeping this sediment-laden water from spreading its wetland-renewing deposits throughout the delta. For thousands of years, these floods reinforced the barrier islands of the delta with alluvial soil and restored the wetlands that effectively diminished the impact of storm surges (Louisiana Coastal Wetlands, 1998). Although effectively protecting the region from the disaster of river flooding, the levee

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system inadvertently resulted in significant loss of Louisiana's protective marshlands, building a "bridge to Cuba" off the continental shelf with the river's sediment. According the U.S. Geological Survey (2005), Louisiana has had a net loss of 1,900 square miles (about 1.2 million acres) of coastal wetlands in the past century alone.

Oil extraction contributed to accelerated soil subsidence, lowering levee height by as much as 4 feet. The levees surrounding New Orleans were built in the wake of Hurricane Betsy in 1965—a Category 3 hurricane. Since the 1960s, soil subsidence has steadily diminished the effectiveness of the levees against even a moderate Category 3 storm surge (U.S. Army Corps of Engineers, 2004). In the intervening years new canals have penetrated into the heart of the City. The Industrial Canal, the 17th Street Canal, and the London Avenue Canal were all breached as a result of Hurricane Katrina. The Mississippi River Gulf Outlet, which was designed to improve shipping access from the City to the Gulf of Mexico, also contributed to levee failures by shortening the path of storm surges into the City.

New Orleans had weathered severe storms before; however, leaders and residents would often talk of their fear of "the big one," a storm that would come in from just the right direction and at the right strength to produce the wind and subsequent storm surge that would wipe out major portions of the region (Nussbaum, Arnst, & Weber, 2005). That "big one" was Katrina.

On August 28, 2005, Hurricane Katrina landed a devastating blow to the infrastructure of New Orleans and surrounding areas of the Gulf Coast. Katrina set in motion a series of failures in the region's critical infrastructure that rendered significant areas uninhabitable for many months—and indeed many areas will remain as such. Some portions of the region will be returned to wetlands, other neighborhoods will be rededicated to uses that are less vulnerable such as theme parks, golf courses, and maritime businesses. More than 1,000 drinking water supply systems and 172 sewage treatment plants in Louisiana, Mississippi, and Alabama were affected (Environmental Protection Agency [EPA], 2005). Levee failures in New Orleans resulted in significant disruptions of electrical power and widespread contamination of floodwaters by raw sewage, chemical and petroleum leaks, and the leaching of industrial waste sites. At least one Superfund site was completely submerged in the New Orleans floodwaters (Benfield, 2005). According to at least one source, the quantifiable costs associated with Hurricane Katrina are approximately U.S. $300 billion in damage and 1,000 deaths (Berman, Lynch, Lynch, & Berman, 2005).

### The Nature of Normal Disasters and Infrastructure Interdependencies

The concept of *normal disasters* is an adaptation of the work of the distinguished sociologist Charles Perrow. In his seminal book titled *Normal Accidents: Living With High-Risk Technologies*, Perrow argues that, because of the characteristics of high-risk technologies, there is a form of accident that is inevitable or "normal." The term *normal accident* is meant to signal that, given the nature of complex systems, multiple and unexpected interactions of failures are inevitable (Perrow, 1999, p. 5). Normal accidents, or system accidents, involve the unanticipated interaction of multiple failures in such components as design, equipment, procedures, operators, and environment. Perrow points out that generally with normal accidents the interactions between the components are not only unexpected but also are incomprehensible for some critical period of time (p. 9).

There are two key ideas in the work of Perrow (1999) that will aid us in understanding the nature of infrastructure interdependencies. The first is the distinction between complex and linear interactions, and the second involves tight or loose coupling. Linear interactions, according to Perrow, are those in expected and familiar production or maintenance sequences and are quite visible even if unplanned. Most water treatment plants, for example, have largely linear interactions. Complex interactions are those in which one component can interact with one or more other components outside of the normal production sequence and are either not visible or are not immediately comprehensible (p. 78). The second key idea we borrow from Perrow is the classification of system linkages as either tight or loose. *Tight coupling* implies that system components are highly dependent on one another and that there is no slack or buffer between them. A disturbance or problem with one component can propagate rapidly across tightly coupled systems possibly resulting in the failure of the entire system. *Loose coupling*, on the other hand, implies that components of the system are relatively independent of one another and that a problem with one component will not necessarily lead to a failure of the entire system (p. 94).

Using Perrow as a starting point, we posit that a normal disaster occurs when there is an event, disturbance, or problem that involves the complex interaction of interdependent infrastructures resulting in the unanticipated failure of multiple infrastructure systems.

The term *infrastructure* has a number of different meanings. To provide a common point of reference we use a standard public works definition provided by Hudson, Haas, and Uddin (1997). Infrastructure refers to

> physical systems or facilities that provide essential public services, such as transportation, utilities (water, gas, electricity), energy, telecommunications, waste disposal, park lands, sports, recreational buildings, and housing facilities. Infrastructure can also include the management and human resources associated with providing a physical facility. Infrastructure consisting of physical systems can be owned and managed by either or both public agencies and private enterprises. (p. 30)

The term *critical infrastructure* is often used in the emergency management literature. Critical infrastructure

> includes systems, facilities, and assets so vital that if destroyed or incapacitated would disrupt the security, economy, health, safety, or welfare of the public. Critical infrastructure may cross political boundaries and may be built (such as structures, energy, water, transportation, and communication systems), natural (such as surface or ground water resources), or virtual (such as cyber-, electronic data, and information systems). (The Infrastructure Security Partnership, 2005, p. 8)[1]

It is also necessary for the purposes of this article to describe the term *interdependency*. The term implies that two or more infrastructures depend on each other. Such linkages may vary in scale and complexity. There are four principal classes of interdependencies according to Peerenboom, Fisher, Rinaldi, and Kelly (2002):

- Physical interdependency occurs when the material output of one infrastructure is used by another.
- Cyberinterdependency occurs when an infrastructure depends on information transmitted through the information and communications infrastructure.
- Geographic interdependency occurs when two or more infrastructures are colocated in the same area and can be affected by a local event.
- Logical interdependency occurs when the state or condition of an infrastructure is dependent on the state of another infrastructure in a way that is not physical, cyber, or geographic (e.g., linkages through financial markets or government-funding programs) (p. 3).

It is the expanding use of information technology and computer-based systems that has increased the importance of cyber- and logical interdependencies. The use of advanced technologies and the computer-based automation of systems have led to the increased efficiency and reliability of many infrastructures (Rinaldi, Peerenboom, & Kelly, 2001). Technology is also primarily responsible for the tightly coupled, interdependent infrastructures we enjoy today. The extensive use of technology has, however, dramatically increased cyberinterdependencies across all infrastructures and has contributed to their increased complexity (Peerenboom et al., 2002; Rinaldi et al., 2001). In a telling observation, Heller (2001) points out that as automation of infrastructure systems increases, system behaviors are becoming complex beyond comprehension and more far-reaching in their consequences than was ever anticipated. The stage has been set for a normal disaster.

**. . . as automation of infrastructure systems increases, system behaviors are becoming complex beyond comprehension . . .**

## The Case of New Orleans

### THE IMPACT OF INFRASTRUCTURE INTERDEPENDENCIES

The major risk of a normal disaster for the City of New Orleans stemmed from vulnerabilities in the complex and interdependent infrastructure that was meant to defend it from Gulf Coast storms. This risk had not gone unrecognized. In fact, for several years federal, state, and local agencies have made progress in their understanding of the interdependencies of the region's infrastructure. A series of regional "tabletop" exercises were conducted in the Greater New Orleans region for the past few years, each exercise examining the physical, geographic, and cyberinterdependencies of much of the region's infrastructure (Thompson, 2004). Dubbed the "Purple Crescent" series, these exercises were designed to raise regional awareness of the types of security threats, attacks, and disruptions that could affect not only health and human safety but also economic and national security as well.

Approximately 170 people representing organizations from the local, state, and federal governments, as well as the private sector, participated in the Purple Crescent exercises. The exercise series was sponsored by the Gulf Coast Regional Partnership for Infrastructure Security, a nonprofit group, and were based on fictitious attacks and the subsequent disruption of various public utilities and services such as electrical power and telecommunications. The exercises also involved an examination of how vulnerabilities and associated infrastructure interdependencies could affect operational systems, business practices, and response and recovery operations. (Note: One of the authors served as exercise evaluator for this series of exercises.)

It is interesting to note, the scenario for the planned October 2005 Purple Crescent III exercise was centered on a man-packed nuclear device devastating the Huey P. Long Bridge (a critical national infrastructure priority). As that scenario was developed during the late Spring and early Summer of 2005, planners became concerned that such an explosion would devastate the levees in the vicinity of the bridge, which would result in the flooding of vast portions of the City of New Orleans. Many of the emergency managers responsible for planning the exercise urged that an "artificiality" be considered for purposes of exercise play—that the levees remain intact—to ensure that first responders and energy and communications restoration technicians would have something to do, reasoning that if the levees were broken, first responders would not be able to realistically do much for at least a month. As Rinaldi et al. (2001) point out, the simplistic use of such an artificiality effectively decouples the supported infrastructure from its supporting infrastructure and results in a focus on the dependencies rather than the interdependencies of the infrastructure in question. In other words, it causes participants to overlook the true complex nature of interconnected infrastructures, which could lead to incorrect and potentially disastrous results.

The Purple Crescent III exercise did not take place in October of 2005 as planned because parts of the City remained inaccessible because of the impact of Hurricane Katrina.

### FAILURE TO IMPLEMENT EXERCISE LESSONS

Certainly, the Purple Crescent exercises that did take place were very useful for instilling in participants a need to consider the physical, geographic, and cyberinterdependencies of the region's infrastructure. The exercises regularly brought together participants from the public and private sector to consider infrastructure interdependencies. There is no doubt that exercise participants took back to their agencies a number of lessons learned. Participants learned to appreciate how quickly portions of the City would flood if pumping stations operated by the City's Sewer and Water Board became inoperable, how the resultant flooding could potentially contaminate the drinking water supply requiring a shutdown in water service, and how that in turn would affect the fire department's ability to fight fires.

Myriad other critical infrastructure interdependencies were identified in the exercises and at meetings of the City's Local Emergency Planning Committee (one of the authors is a member of this committee). Special attention was given to the transportation infrastructure, and the fact that the City would have a significant number of "immobile" citizens in an evacuation—citizens with no means of transportation out of harm's way. About 100,000 to 130,000 people were in this category. In addition, it was expected that large numbers of tourists would also be rendered immobile. Exercise play demonstrated that, if electricity was not available, the electronic room key cards utilized in most hotels would not work, and it was hotel policy not to allow access to the facility in such situations. Many hotels, too, relied on powered lifts to store guest vehicles, and so an interruption in electricity made access to these vehicles impossible. Further complicating the problem, tourists would not have access to additional funds because ATMs would be rendered inoperable.

The U.S. Army Corps of Engineers and various levee boards were rarely, if ever, in attendance at local and regional exercises, and so levee failure was not given appropriate weight in local emergency plans. However, in 2004, at a major simulation exercise held in Baton Rouge called "Hurricane Pam," engineers and scientists did participate and demonstrated just how quickly the City's levee infrastructure could be overwhelmed by even a relatively small storm (Federal Emergency Management Agency [FEMA], 2004). Yet no action was taken by local governments in the Greater New Orleans region (Williams, 2005). Emergency plans, formulated at the local and state levels, failed to extend beyond municipal boundaries (exceptions are mutual support agreements) and failed to be consistently updated with new risk factors arising from external threats, such as eroding coastlines and subsiding levees.

Unfortunately, many of the potential problems identified in the Purple Crescent exercises had not been adequately addressed in the Greater New Orleans region by the time Katrina struck. Yet in fairness to local and state governments, it should be pointed out that in many cases there were no "quick fixes" for the region's infrastructure vulnerabilities. For example, weaknesses in the levee system were known for many years—the problem had been identified to the federal government; however, federal funding was inadequate. The lack of a viable transportation system for immobile citizens had been the subject of many initiatives; however, no explored alternative could guarantee transportation for 100,000 citizens. This was a City with a large population of urban poor, and a lack of adequate shelters in the flood plain. (Author's note: during Katrina, fewer than 20,000 citizens were stranded in New Orleans. Although an unacceptable number, this would indicate that 80,000 of the expected 100,000 citizens did escape Katrina's wrath.)

One promising initiative, dubbed "Brother's Keeper," sought to link immobile citizens with those willing to share transportation through churches, synagogues, and mosques in the City's less affluent areas. Yet a major blow to this initiative came when the state's legislature refused to extend "Good Samaritan" status to drivers providing transportation, in turn causing the Archdiocese of New Orleans to refrain from participating (New Orleans is a predominantly Catholic city). This resulted in less-than-ideal implementation of the initiative.

Despite having the full involvement of the Department of Homeland Security (DHS) and FEMA in each Purple Crescent exercise, the intergovernmental response to Katrina was inadequate, fragmented, and characterized by a lack of understanding of agency capabilities (problems identified as early as 2003 in the Purple Crescent I exercise report). Extraregional communication was often ineffective because of not only technical problems but also the human and political failures of communication.

## THE HUMAN AND POLITICAL DIMENSIONS OF INFRASTRUCTURE FAILURE

**The network of complex critical infrastructure is, at some point in every system, dependent on human factors**

The network of complex critical infrastructure is, at some point in every system, dependent on human factors. Katrina exposed several vulnerabilities that contributed significantly to the disaster, all stemming from human frailty. The first to emerge post-Katrina was the unfortunate reliance on human operators in several pumping stations. Immediately prior to Katrina, Jefferson Parish President Aaron Broussard relieved of duty the human operators of several important pumping stations, fearing for their lives and ordering them to safety well beyond the region (Krupa, 2005a). In fairness to President Broussard, his decision was not undertaken lightly and was indeed a standard procedure in the long-standing Jefferson Parish emergency plan. Unfortunately, when Katrina struck, several important pumping stations were therefore left without operators, contributing to significant flooding from levee failures (Krupa, 2005b).

A second human factor contributing to the disaster in New Orleans resulted from a lack of technical competence on the part of the local levee boards. The City's fragmented oversight of its levee system rested in the hands of several local government levee boards, entities that oversee the 125 miles of levees and floodgates designed to protect New Orleans and the surrounding areas from rising waters. Appointments to levee boards have traditionally been awarded at the discretion of the mayor, often to those without the technical expertise to carry out their duties in a competent manner.

Yet a third vulnerability factor stemmed from the lack of understanding of critical infrastructure interdependency across municipal boundaries. As the levee system began to fail, and water started rising in the City, adjacent parishes hastily called on their public works departments to construct temporary levees along parish lines, with little reliance on accurate flood maps (Brown, 2005). The result was that in some places rising water was effectively slowed; however, in other locations barriers were useless, consuming valuable time and the limited resources of already stressed public works departments in their construction. Many of these temporary levees served to effectively block evacuation routes from the City, hindering the exodus of city residents. This, combined with an aggressive law enforcement presence in some of the City's neighboring municipalities, exacerbated racial tensions and further crippled timely evacuation of New Orleans (Fletcher, 2005).

Although dependent on a system of regional infrastructure for protection, oversight of this infrastructure was fragmented among various municipal governments and agencies, many with long histories of mutual distrust and even animosity. Many of the region's parishes had a tradition of behaving more like independent fiefdoms than good regional citizens. Risks to the infrastructure were well known to the political leadership of the region, to scientists and scholars, and to emergency planners. However, few adequately predicted how the cascading adverse impact of multiple failures in critical infrastructure could combine to cause such a devastating blow to the region.

## The Lessons of Hurricane Katrina

### RISK AND VULNERABILITY ASSESSMENT

Clearly there is a need to better understand how cascading and common-cause failures of infrastructure systems hinder response and recovery efforts. Infrastructure assets must be identified that, if lost or degraded, could adversely affect the performance of other infrastructures (Fisher & Peerenboom, 2001). Vulnerability assessments must be conducted from an infrastructure interdependency perspective. It is essential for managers of each infrastructure system to determine which other infrastructure systems they must depend on to continue in operation and which other systems must be involved in the restoration of service following a major disruption. Each infrastructure system must also be prepared to assess the risks of potential environmental impacts resulting from system failures. McEntire, Fuller, Johnston, and Weber (2002) advocate a holistic, comprehensive vulnerability management approach directed toward reducing susceptibility to disasters and building resilience into infrastructure systems. In a holistic approach, environmental scientists, scholars, planners, and engineers could play an important role in assessing these risks and contributing to the development of strategies for infrastructure protection.

### COORDINATION, COOPERATION, AND COMMUNICATION

In a normal disaster all infrastructure systems are tightly coupled. Essentially, these disasters create common-cause failures where two or more infrastructure networks are disrupted at the same time. Coordination for infrastructure recovery must be a key priority. In late 2003, a major finding resulting from Purple Crescent I was that the Greater New Orleans region had "several individual Emergency Operations Centers, and many organizations, including utilities, have some type of EOC, impeding necessary coordination of response and recovery activities" (Gulf Coast Regional Partnership, 2003, p. ii). Yet a White House inquiry into the Katrina response noted that there was a "Lack of comprehensive national strategy and plans to unite communications plans, architectures and standards" (Waterman, 2005, n.p.).

In the aftermath of the 9/11 tragedy the bipartisan 9/11 Commission recommended that emergency response agencies across the country adopt a management structure known as "incident command" (Swope & Patton, 2005). Under this type of structure the chief of one service is put in charge of the overall response to the crisis or disaster, and all the other chiefs report to him or her. Although incident command is clearly the right direction in terms of coordination, experts are also discussing the idea of creating an Infrastructure Support Integration Center that would serve as an interagency group to handle key infrastructure recovery issues and coordinate offers of assistance (Rubin, Winston, & Korman, 2005). Many infrastructure managers across the country have dealt with and learned from their own disaster response activities. Their expertise could and should be utilized in major disasters.

Walters and Kettl (2005) note that "When Hurricane Katrina struck New Orleans the only thing that disintegrated as fast as the levees were the intergovernmental relationships that were supposed to connect local, regional, state, and federal authorities before, during, and after such a catastrophe" (p. 20). Katrina exposed gaping holes in intergovernmental capabilities to deal with emergency response, including severe breakdowns in emergency communication networks and failures to act on reducing or mitigating identified risks to the public relating to a powerful hurricane (Benfield, 2005). Intergovernmental communication, cooperation, and coordination are essential elements of effective response to disasters. Interdependent infrastructures have little or no cushion in the event of failure and few, if any, alternative sources of service. There must be agreement beforehand as to who will do what in the event of disaster. Logical interdependencies take on greater importance in disasters because of the fact that federal government funding programs influence the priorities and pace of infrastructure recovery efforts. The coordinated effort of all infrastructure systems will be required for effective disaster recovery, and a plan to accomplish this vital activity must be in place prior to the event.

### FLEXIBLE RESPONSE

The central feature of all crises is a sense of "urgency," and urgency often becomes the most compelling crisis characteristic according to Farazmand (2005). He notes that crises scramble plans and paralyze normal government operations (p. 6). Infrastructure managers will need to understand that they cannot prepare for everything or figure it all out ahead of time. The military has long known that dealing with the "fog of battle" requires the ability to improvise and that flexibility and nimbleness must be highly valued. The development of training scenarios that place a premium on flexibility and nimbleness would increase the effectiveness of disaster response. As Swope and Patton (2005) observe, officials need to develop workable response structures or plans that are nimble enough to allow them to respond to all types of disasters (p. 58).

## Conclusion

**. . . the trend toward greater infrastructure interdependency in the United States has accelerated in recent years and shows little sign of abating.**

Rinaldi et al. (2001) point out that the trend toward greater infrastructure interdependency in the United States has accelerated in recent years and shows little sign of abating (p. 24). The importance of identifying, understanding, and analyzing these infrastructure interdependencies must be recognized if we are to respond effectively to normal disasters. Whenever possible the goal must be to find ways to allow for decentralization of infrastructure systems to promote rapid recovery from disasters. Loosely coupled systems are inherently less susceptible to catastrophic failure than those that are tightly coupled.

Infrastructure managers must find a means to balance the competing demands for efficiency and cost-effectiveness during normal operations with resiliency and sustainability of operations during and after disasters. Excess capacity or "slack" resources must not be seen as wasteful, but rather as prudent, if related to plans to meet unusual peak demands or the special needs that disasters inevitably bring. Certainly some customers or utility regulators will tend to view excess capacity as a form of "gold plating" of utility systems. System redundancy, however, promotes a more loosely coupled system that can more easily recover from disaster. Infrastructure and public utility managers need to convince customers that a small percentage of their utility payments or taxes should serve as an "insurance" payment targeted to providing some excess capacity or system redundancy in times of crisis.

The truth is that few infrastructure systems currently maintain any substantial level of excess capacity or redundancy in their systems. In 1981, Choate and Walter published *America in Ruins: The Decaying Infrastructure* in which they assert that the United States was seriously underinvesting in its infrastructure and that the infrastructure was wearing out faster than it was being replaced (p. 1). Despite the widespread publicity that the book received in the 1980s, not much has changed in the intervening years. Plant (2005) notes that even though physical infrastructure plays a critical role in today's society, it has fallen out of our national debate about priorities. The combination of normal disasters, such as Hurricane Katrina, and complex, interdependent, aging infrastructures does not bode well for the future. Substantial investment in infrastructure systems must once again become a national priority.

## Note

1. This guide is currently being developed through a Regional Disaster Resilience Task Force established within The Infrastructure Security Partnership (TISP). The Task Force on Regional Disaster Resilience (RDR) was officially established at the 4th Annual TISP Congress on Infrastructure Security for the Built Environment (TISP, 2005), October 18 to 20, 2005, in St. Augustine, Florida. The impetus behind the Task Force is the growing recognition of the need for organizations and jurisdictions to have validated guidelines to ascertain what needs to be accomplished in order to cost-effectively and expeditiously deal with major disasters from all hazards, including terrorism. The goal is to tap the extensive expertise of interested practitioners, technical experts, researchers and policy specialists from across the nation from all disciplines and sectors. The Task Force Action Plan Guide was approved at the ISBE 2006 Conference in Washington, D.C., February 15 to 17, 2006. One of the authors is a member of the Task Force.

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