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Multi-Phased Criticality Analysis and Prediction Using Strategic Planner Integrating Regional Infrastructure Technology (SPIRIT)

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ABSTRACT

Homeland Security efforts have focused on procurement of emergency equipment continuing a reactive, response oriented tradition historically proven ineffective in large-scale disasters. To date, infrastructure analysis and predictive modeling for disaster impacts are largely academic studies with little operational relevancy. Hindsight has shown that broad predictions and warnings of damage have not improved local planners' and emergency managers' capability. An operational process is needed whereby local decision makers can understand and predict the time-phased, dependency-driven impact of regional infrastructure failures.

INTRODUCTION

The world's infrastructure systems have evolved from isolated pockets of technology to interdependent networks spanning continents. Meanwhile, the global population has continued to concentrate in dense clusters near urban industrial centers. These populations depend on the support infrastructures that are straining to keep up with demand for energy, water, communications, etc. Disruption of the support infrastructure, through natural or man-made disasters, can initiate complex reactions that have been difficult to predict and understand.

PROBLEM SPACE

Homeland Security efforts have traditionally focused on procurement of first responders' equipment and command and control systems. This has continued the reactive, response-oriented methods shown to be ineffective in the large-scale disasters of the recent past. To rise above the reaction process to the level of prediction and prevention will require systematic research and analysis. To date, infrastructure analysis, predictive modeling and planning for disaster impacts are largely academic studies with little operational relevancy.

Hindsight has shown that broad predictions and warnings of damage from natural and man-made disasters have not prepared local planners and emergency managers to protect their local populations. Events throughout the Hurricane Katrina disaster illustrate the importance of preparation and effective response. Federal, state, and local officials tracked the hurricane for days prior to arrival. All the responsible officials were informed 56 hours prior to the initial landfall [1], but this highly accurate information did not result in any unified execution of plans. Instead, there was a series of uncoordinated and ineffective actions (and *inactions*) that failed to protect and restore from the storm's immediate and subsequent effects.

Similar potential disasters loom all over the country. This paper focuses on the potential failure of the levees surrounding the city of Sacramento, CA. Rapid population growth in the American and Sacramento Rivers' flood plains has coupled with an aging levee system to create a unique opportunity for planning and readiness that will almost certainly be put to the test in the next few decades. Sacramento area emergency managers must be conservative and prepare for both short and long-term effects of the flood. This preparation must not be limited to flood plain mapping and insurance rate adjustment; the risks to critical infrastructure and corresponding mitigation strategies must also be carefully assessed. An operational process is needed whereby local planners, first responders, and emergency managers can understand and predict the impact of regional infrastructure failures.

HYPOTHESIS

Emergency management officials will make better decisions if they are better informed. This can be accomplished through an in-depth assessment of regional infrastructures, resulting in prediction of initial and subsequent, cascading effects of infrastructure failures. For example, Sacramento's emergency manager, faced with rising waters and damaged infrastructure, must deal with an explosion at an industrial plant. The immediate reaction is to rescue and transport the injured victims to the nearest hospital trauma center. However, the missing information for the emergency manager is which hospitals' access roads will soon be impacted by the rising water. Taking victims to a hospital that will potentially be isolated by the flooding sets up a new crisis when the hospital and patients must be evacuated. This case shows the effects of interdependencies of infrastructure (the hospital function depends on clear transport routes), and how better situational awareness of these relationships can help the emergency manager to make informed decisions. A better understanding of subsequent events could lead the emergency manager to possibly stopping the cascade of failure by proactive actions, such as using a trauma center in a non-impacted area. Analysis and prediction of a disaster's extended impacts, like the loss of sections of a transport system, can be tested in drills and exercises, and then be proactively included into policies and doctrines.

APPROACH

To establish a standard terminology, some terms first need definition. An *asset* will indicate a specific facility, like an electrical substation, a water treatment plant, a fuel pipeline, a bridge, or a hospital. A group of assets that combine to deliver a collective support service is called a *segment*. Fire Stations, police, ambulance services, and HAZMAT teams are assets that combine to form the First Responders segment. The Department of Homeland Security (DHS) has divided Critical Infrastructures (CI) into thirteen segments, e.g., energy, water, telecommunications, public health, waste water, transportation, etc. Finally, the segments combine to form the CI *System*. The study of the interlocking mesh of these segments comprises CI System Interdependencies analysis.

The Strategic Planner Integrating Regional Infrastructure Technology (SPIRIT) consolidates disparate data, implements National Incident Management System (NIMS) compliant policies, overlays existing infrastructure data onto a geospatial display, and provides a user-friendly, "Video game," interface to model and analyze potential impacts of natural disaster or terrorist attack for emergency planning and real time response [2].

The SPIRIT process uses a three-part analysis to resolve these issues: analysis of discrete segments, analysis of whole systems' interdependencies, and analysis of the effects of dependencies and time on cascading infrastructure failures. (SPIRIT methodologies and analysis are proprietary to General Atomics Corp.)

Segment Analysis

SPIRIT's first step is to analyze each infrastructure segment to identify the nodes critical to its "mission." A segment's mission is the operational benefit derived from the segment and its collection of assets. For example, the mission of an electrical transmission system is to move electric power from a generating station to distant substations for local distribution to electrical consumers.

Segment Specific Assets (SSAs) are assessed for criticality using density, capacity, and structural analysis methods [3], and are assigned ratings of "Mission Compromised," "Mission Devalued," or "Mission Uncompromised" status, and are correspondingly colored red, yellow, or green. The rating of an SSA indicates its importance, and the likely impact of its loss to the segment's mission. For example, loss of a water treatment plant rated as Mission Compromised will prevent the water segment from achieving its mission of delivering potable water.

Figure 1 illustrates a low-resolution functional view of an electrical segment. Symbols used for generation sources are squares, transmission circuits are lines, and substations are triangles. Objects colored black are not listed as critical assets, though they may connect objects that are critical. Figure 1 provides valuable information about the function and hierarchy within the segment and can be used for an analysis of power systems and current flow. But this view does not address spatial or *whole system*-wide relevance of the electrical segment.

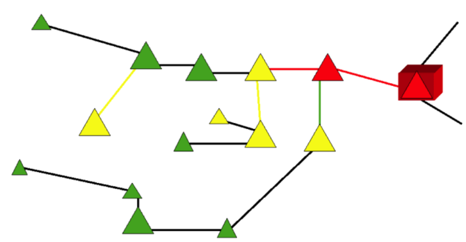

Figure 1. A functional view of an electrical segment.

In Figure 2, these segments are overlaid onto a Geospatial Information System (GIS). This has two advantages; first, a geographic rendering of multiple segments closely shows their interdependencies due to proximity. Figure 2 exhibits a part of Sacramento's electrical segment superimposed on a geospatial image of its urban location.

System Analysis

To illustrate the second phase of SPIRIT analysis, Figure 3 is a small-scale example of a whole-system view. The colored backgrounds show the areas, or zones, supplied by specific infrastructure segments (in this case, an electrical substation). Within each zone, icons mark the major CI locations. Local first responder stations, hospitals, transportation hubs and important economic sites are indicated. (All data for this paper was drawn from open sources.) When available, the locations and right-of-ways used for electricity transmission circuits, gas, water, and petrol pipelines are drawn. Zones can also be drawn for water systems, telecommunication networks, natural gas, and other segments.

Within this view, the zone supplied by substation “a” is highlighted making interrelationships of infrastructure better understood. The water and waste-water treatment segments, the health segment, transportation links, and numerous civic buildings shown to depend on a single primary source for electrical power. If a casualty to the substation “a” interrupted electrical service in this zone, reference to this view would reveal the neighborhoods and support services impacted.

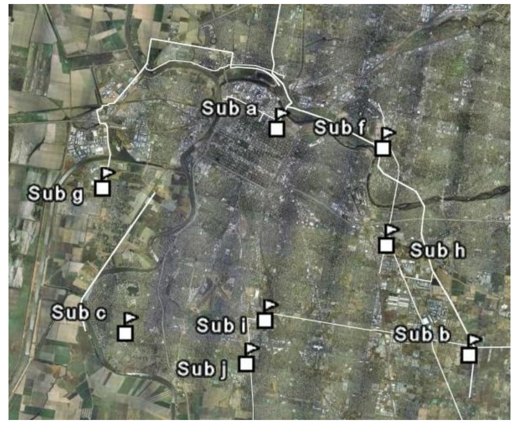

Figure 2. Single-segment infrastructure geospatial view.

Figure 3. Sacramento whole system view.

This event would present the emergency manager with several challenges; how to communicate to first responders, continuity of hospital operations, and traffic management are only a start. Combining the research of each individual segment with the geospatial layout of the segments is only part of the solution. The SPIRIT process then analyzes the interdependencies of the CI system and summarizes the effects in a meshed, cause-and-effect matrix (Table 1).

Some segments, like fuels and electricity, are mutually dependent. In the metropolitan area studied, half of the electricity is produced from power plants that burn natural gas. Conversely, electricity is needed to compress and transport natural gas over the lengthy pipelines from source to customer (in this case, the power plant). Similar matrices can be drawn for other segment failures.

Table 1. Interdependency Matrix

Rows Depend on Columns	Electricity	Fuels	Water	Waste	Public Health	Transport
Electricity	X	Power plant	Hydroelectric	NA	NA	Parts and fuel deliveries
Fuels (petrol)	Pumps, processing	X	For refining process	NA	NA	Pipelines, local trucking
Water	Pumps, processing	For emergency generators	X	Some grey water supplies	Testing and certification	Pipelines, chemical deliveries
Waste	Pumps, processing	For emergency generators	For processing	X	Testing and certification	Pipelines
Public health	Operation of hospitals, medicine storage	For emergency generators and vehicles	For drinking, cleaning, and sterilizing	Testing and certification	X	Emergency services, evacuations
Transport	Traffic signals and controls	For vehicles and aircraft	NA	NA	NA	X

Returning to the emergency manager's problems once more, the interdependencies briefly outlined in Table 1 will quickly add more disruptions to be addressed. The loss of a key segment (electricity in this case) can lead to subsequent, *cascading* casualties across the entire infrastructure system. The challenge for the emergency manager is to identify current and impending casualties, allocate resources and take proactive steps based on some situation-relevant prioritization.

Table 1 is an instantiation of the effects of an event, or a series of events comprising a major disaster, but it is merely a snapshot in time. With a few exceptions, disasters do not have discrete start and end points. Rather, there are recognizable timelines associated with nearly every disaster. The emergency manager must have available reasonable representations of these timelines to manage his resources effectively. Table 2 summarizes the timelines associated with infrastructure failures.

Table 2 makes clear the importance of interdependency and time. The initial impacts of lost electricity are lessened by emergency generators that are often installed in major facilities like hospitals and larger water treatment plants. But these generators may offer a false sense of security (Appendix).

Time-Dependency Analysis

The third phase of the SPIRIT process uses data similar to that in Table 1 to *predict* infrastructure failures based on some generalized interdependencies, and many region-specific details, input to relational models. The SPIRIT process then uses time-dependencies like those shown in Table 2 to identify the most pressing, *most critical* issues. This analysis identifies and critically ranks the main infrastructure, *whole system* nodes.

Figure 4 is just one approach to represent the whole system status in a manageable format. It incorporates the important information in an organized, prioritized, time-phased structure. Criticality, and thus priority, is shown as a function of time to reflect the eventual failure or depletion of backup systems. This provides a time-phased prediction list, from which the emergency manager can work to forestall impending casualties, and actually get ahead of sequential cascading failures.

While the mission criticality of an SSA can be assigned, and for all intents is a constant rating, the actual time-dependent effects of cascading casualties can change the Operational Status of the SSA in predictable ways. The complex process of prediction results in a scheme that is simplified for ease of visualization and use.

Figure 4 is a condensed report of the effects of an event (loss of a primary electrical substation) and its impacts across the other segments in the CI system. The segments are listed in the left column, with their component SSAs in the center and each listed SSA's mission criticality indicated by the colored background surrounding the SSA's title. The right-most header lists the operational status for each SSA, over a three-day period. The immediate effects of losing the electrical substation are listed in the first column labeled "Day 1." Subsequent, cascading effects on operational status are listed in the "Day 2" and "Day 3" columns. The operational status of

Table 2. Infrastructure Failure Timelines Event: Electrical Failure

Segment	Initial Impact	Extended Impact	Time to Ex. Impact
Electricity	Loss of electricity, emergency generators start	Generators fail (mechanical failure or fuel exhaustion)	12 hr
Fuels (petrol)	Pipelines stop deliveries, service station pumps fail	Fuel shortage	6 hr
Water	Pumps and treatment fail	Potable water shortage	6 hr
Waste water	Pumps and treatment fail	Sewage back ups and spills-health issues	2 hr
Public health	Backup systems at hospitals can minimize impact	No water: no sterilization No fuel: generator fails No waste: public health issues	1-3 days
Transport	Traffic jams	Loss of air traffic control, significant transport delays	6 hr

-UNCLASSIFIED-

Event:	"a" Substation Failure
Report Issues:	1145 AM PDT 18 MAY, 2007
Communities Affected:	Sacramento
Population:	113,000
Public Safety issues:	Flood Control, Transportation, Water

Sector	Mission Criticality Rating	Operational Status: Day 1	Day 2	Day 3
Waste Water	Sewage Plant			
	Sewage Pump #2			
Water	SRWD Plant			
Transportation	HWY 50 (Details)			
	I-5/I80 Intersection (Details)			
Emergency Response	SPD HQ			
Health	Mercy General Hospital (Details)			
	Sutter Memorial Hospital			
	Kaiser General Hospital			
Emergency Response	Fire Station 1			
	Fire Station 6			
	Fire Station 10			
Energy	Ramos Fuel Depot			

Figure 4. Time-criticality view.

an asset is classified as operations failed if it is incapable of performing its mission, and the status block for that timeframe is black. Similar ratings of operations impaired and operations unaffected respectively indicate assets running in temporary support (grey) or assets that are unaffected (white).

A scan of the time-criticality view in Figure 4 would show that the emergency response sector has been rendered inoperative (operations status is black), while the public health segment will continue to function normally until Day 2, when Mercy General Hospital fails operationally and the remaining hospitals will shift to an operations impaired status (white shifts to grey on Day 2). With this report, the emergency manager has a snapshot of the immediate and impending effects of the loss of a key infrastructure asset. The emergency manager can now take action to restore the initial casualty and take steps to prevent or mitigate the cascading failures.

INFRASTRUCTURE ANALYSIS & OPERATIONS

Many local and regional emergency command centers have invested in expensive command and control systems. These systems typically display the real-time Global Positioning Satellite (GPS) coordinates of first responder units overlain onto GIS displays. The command centers are usually well equipped with communications and computer equipment.

In addition to local government officials and first responder leadership, the command center also hosts local utilities engineers to provide expertise on their respective infrastructures. These representatives provide data on the status of segment damage and answer questions about capabilities and repair efforts.

The weakness of this system is while each engineer is a subject matter expert in his segment, it is unlikely that this group trains together as a unit, or exchanges enough data to form their own interdependency matrix. A water district representative will likely know everything about his water processing and distribution system, but informal research has shown that he will not know much about the electrical substation his district depends on, or the point of origin for his repair parts.

The next evolutionary step for the emergency command center is a map overlay system that can superimpose the critical infrastructure zones (Figure 3) over the operational, real time GIS plot. With this, the emergency manager can visualize the growing threat of fire or flood, potential infrastructure loses, and locations of first responders that may be affected. This information view can be augmented with the deeper time-dependency analysis of the affected segments and zones to show the consequences of the impending damage. Armed with this, the emergency manager can make highly informed decisions and proactively mitigate the consequences. The command center is no longer reacting, it is now *predicting* and *preventing*.

SACRAMENTO FLOOD DISASTER MANAGEMENT

Applying the SPIRIT process to the estimated Sacramento 100 Year Flood is an excellent application of theory to a real-world threat. Unlike the effects of Hurricane Katrina, a flood in Sacramento would not be preceded by a devastating hurricane, but a period of heavy rains could build river levels to flood stage. Additionally, levee erosion and failure could cause a flood without significant weather effects. The potential flood effects will vary by the river level, extent of levee damage, and the preparedness of the local emergency responders. There is plenty of conjecture about the causes and extent of any likely flood, which is not the objective of this analysis. It is likely that streets and buildings in the shaded areas will experience slowly moving flood waters that rise to three feet in depth or more, so the analysis will begin at the three foot flood level. An approximation of the flood area is overlaid as a blue area on top of a partial map of downtown Sacramento in Figure 5 [4].

Effects of Infrastructure

The progress of the floodwaters, and the resultant damage to infrastructure, will be steady but predictable and slow. The damage caused by the flood waters, on a much slower timescale than an earthquake or major fire, makes this disaster a challenge of logistics as much as control and restoral. The flood plain area has more than two hundred thousand residents, more than 20,000 of whom work in the downtown Sacramento area [5]. The floodwaters will impact their abilities to remain in their homes, travel to work, and remain healthy. The critical infrastructure affected includes governmental offices, telecommunications access points, levees, interstate highways, and flood control sumps, each with its own mission and interdependencies. Table 3 lists the particular interdependencies relevant to the Sacramento 100 Year Flood.

As the flood progresses, the emergency manager will need to continually assess the state of services throughout the affected area. As the damage spreads, and as the infrastructure workforce is depleted by their family considerations, the emergency manager must try to achieve as graceful a shutdown of services as possible. SPIRIT's analysis and prediction of critical infrastructure interdependencies, and their respective timelines, will allow the emergency manager to proactively task his emergency

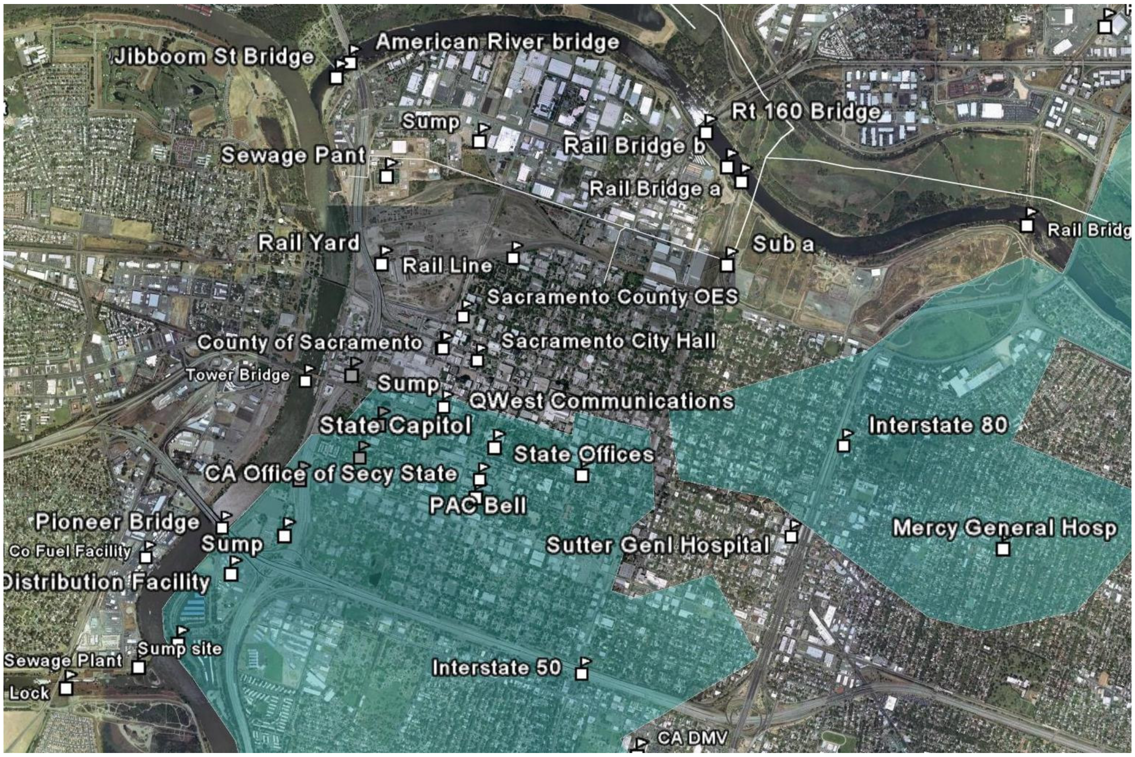

Figure 5. 100 Year Flood coverage downtown Sacramento [4].

teams in planned stages of infrastructure disengagement. With sufficient time and foresight, this may include decoupling and protective isolation of key equipment to prepare the way for accelerated recovery and restoral after the disaster has abated.

Electricity. As a safety measure, the electrical utility will suspend electrical service to the 7 substations threatened with floodwaters. Upon loss of power, numerous emergency generators will automatically start and provide electricity for their assigned facilities. Sacramento is well-provisioned with emergency generator systems, but these are generally intended to serve only temporarily. There are over 20 large diesel generators registered within the flood zone, supporting Mercy General Hospital, the state capital and local government buildings, flood water and sewage pump stations, and numerous office buildings. The generators will provide minimal power, often allowing for lights and ventilation, but their limited capacity will prevent full operational capabilities for major facilities like hospitals. As they operate, the generators must be regularly refueled. Rough calculations indicate that the emergency management logisticians will have to provide as much as thirty-nine thousand gallons of diesel fuel daily to these generators alone. This job is not just to find the fuel, but get the fuel into the respective fuel tanks, all the while dealing with a distressed transportation system.

Without electricity, no gas stations can operate, rail crossing barriers will fail, pharmacies will not have the IT supported needed to dispense prescription, and potable water towers will not be refilled, severely limiting the life-support functions of much of the CI system. Streets will be dark, refrigeration systems will fail, and cellular towers will cease operation.

Transportation. In the general area of Sacramento, the highways and rail lines are supported by raised roadbeds. In the flooded areas, however, the rail lines drop to ground level, as do the on/off ramps for the highways. The highway situation demonstrates the particular challenge of this flood scenario: getting supplies into the area will not be difficult, but the “Last Mile” of the supply chain will literally be inundated and dysfunctional. Due to the circumstances of the flooding effects, the push of supplies will be more useful if delivered to planned evacuation centers away from the flood zone.

The immediate challenge for the emergency manager will be to transport evacuees out of the affected areas to the optimal receiving centers. The Hurricane Katrina experience once again provides useful lessons: those with the capability to leave will do so, while citizens without cars or sufficient funds will stay behind. Additionally, valuable transport resources, like school busses, may exist

Table 3. Sacramento 100 Year Flood Interdependency Matrix

Rows Depend on Columns	Electricity	Fuels	Water	Waste/Flood System	Public Health	Transport	Evacuation
Electricity	X	Emergency generators need 39k gal/day	Diesel engine coolant	Pump out flooded generators/substations	NA	Fuel deliveries,	NA
Fuels (petrol)	Pumps, processing	X	For refining process	Pump out flooded facilities	NA	Pipelines, local trucking	NA
Water	Pumps, processing	For emergency generators	X	Pump out flooded facilities	Testing and certification	Pipelines, chemical deliveries	NA
Waste/flood system	Pumps, processing	For emer-gency gen-erators	For processing	X	Testing and certification	Pipelines, outfalls	NA
Public health	Operation of hospitals, medicine storage, IT	For emer-gency gen-erators and vehicles	For drink-ing, clean-ing and sterilizing	Mercy General Hos-pital flooded, testing and certification, sanitation	X	Emergency services, evacuations	NA
Transport	Traffic signals, controls, lighting	For vehicles and aircraft	NA	Clear off roads and access	NA	X	NA
Evacuation	Cooking, refrigeration, lighting, public information	For trans, cooking	Minimum: 0.5 gal drinking water/ person/ day	Flood drives the evacuation Dewater/decontaminate homes, sanitation	Direct evacuation, 10,000+ w/med issues, disease prevention	Transport to evacu-ation center	X

but their utility can be overlooked. Roads will be flooded with low lying points too deep to safely ford with a private vehicle, inducing an indistinct but real deadline for evacuation out of the most vulnerable areas.

Health Services. The prime mover of the health crisis will be the noxious combination of floodwater and sewage rising in the affected areas. Present also will be agricultural chemicals and waste from the surrounding farmlands. The enormous potential for disease outbreak will drive a large-scale evacuation.

Mercy General Hospital, situated squarely in the flooded area, will best serve its public by moving the occupants of its three hundred beds to other facilities and shutting down. Additionally, Sutter Memorial (360 beds) is very near the flood area, and Shriners Hospital (70 beds, burn center and pediatrics) is in the center of a dry pocket, virtually surrounded by flooded areas. If these additional facilities are closed, the sole major hospital in a unthreatened area, Kaiser General (460 beds), could not support the population on its own.

The areas impacted by a one hundred year flood are home to over 200,000 residents. While specific medical data is held secret, it is likely that five percent, or 10,000 of these people have some persistent, but manageable, medical condition (diabetes, hypertension, emphysema, vision or mobility impairment, etc.). Conditions brought by the flood emergency will quickly drive many otherwise functional people into dangerous medical conditions. These municipal health departments must plan to closely monitor and potentially move these cases ahead of the impending breakdown of critical infrastructure support.

On a smaller scale, emergency transport services for medical emergencies will be highly stressed throughout the flood and evacuation period. While 3–5 ft of floodwaters will not directly injure many citizens, the stress of the event coupled with the likely failure of pharmacies and home refrigerators will cause many functional, stay-at-home medical patients into critical health conditions, challenging the medical transport services.

Recovery

Floods of this type spread on a slower timeline than many disasters, with a gradual onset exceeded only by the even longer recovery process. The SPIRIT analysis and prediction process readily applies to the task of mitigating hazards to CI, as well as rough estimation of recovery timelines. Table 4 lists mitigation and recovery processes and the predicted timelines for system restoral.

Table 4. Infrastructure Failure and Recovery Timelines Event: Sacramento 100 Year Flood

Segment	Initial Impact	Extended Impact	Time to Ex. Impact	Mitigation	Recovery	Recovery Timeline (after Flood)
Electricity	Loss of electricity, emergency generators start	Generators fail (mechanical failure or fuel exhaustion)	6-12 hr from startup	Deliver 39k gals diesel daily	Repair/replace damaged elec. gear	3 months to replace all damaged gear
Fuels (petrol)	Tanker trucks stop local deliveries, service station pumps fail	Fuel shortage in flooded area	6 hr	Get gas from unaffected area	Test fuel stocks, repair and replace	2 weeks
Water	Pumps and treatment fail	Potable water shortage	6 hr	Deliver bottled water to aid stations	Repair, test and certify system	3 months
Waste/flood system	Pumps and treatment fail	Flood waters advance, sewage backups and spills-health issues	2 hr	Seal pumps from flood. Evacuation	Repair, pump out, decontaminate	3 months
Public health	Backup systems at hospitals can minimize impact	No water: no sterilization No fuel: generator fails No waste: public health issues 10,000+ with med issues	1-3 days	Close affected facilities. Track and medicate medical issues	Open hosp when support systems are fixed, med issues seek support at evacuation site	2 months (must have electricity and water)
Transport	Traffic jams	Loss of air traffic control, significant transport delays	2 hr	Public transport for evacuation, counter flow on highways	Clear roads, fix electrical gear, clear waterways	2 months

Using this listing, the emergency manager (now the *recovery* manager) can quickly assess the relative benefits of any given course of action, and get more "bang for the buck" in the recovery process. In this phase of the incident, the recovery manager's mitigative actions will be rewarded by reduced repair and recovery periods.

The two highest priorities should be to stop the inflow of floodwater and the restoral of the pump systems that will drain the flooded areas. Coupling the topographical pockets of the flooded areas with SPIRIT listings of critical infrastructure locations *and* the relative criticalities of the assets will help shape a list of priorities for repair and restoral. An important precaution that can be taken today is to ensure the pumps themselves are protected from floodwaters that will not only stop the pump but damage their electric motors beyond repair. Temporary power can be provided by generators until normal electrical service is restored. Once the gaps are plugged and the dewatering process is underway, most other recovery tasks can start. The next priority will be the need to restore electric power to the flooded areas as quickly as possible. Again, the mitigative actions taken early in the disaster will pay huge dividends in recovery efforts. Electrical equipment that is disconnected from the grid before it is immersed in floodwaters will be easier to repair, and prompt cleaning and drying of the gear will help further. As repair crews will be stretched, and progress of restoral will be a sensitive subject for the recovery manager, priority should be assigned to health services, potable water systems, and public safety facilities. Potable water systems will be particularly challenging to repair. Pumps will need repair or replacement, clean water sources must be tested and certified, pipes must be flushed, and an exhaustive administrative process must be completed prior to full restoral. This process will start early and end late; it took thirteen months for water to be certified in New Orleans' Lower Ninth Ward.

Concurrent with the material repairs required, a thorough environmental survey must be executed to identify and quantify the contaminants left by the flood. There are no environmental superfund sites in the immediate area of downtown Sacramento, but the indiscriminant mixing of the substances found in gas stations, fertilizer plants, farms, and port facilities will contribute to a complex and problematic contamination problem.

Lastly, the population will return to the area, most likely well before the full recovery is complete. Initial small groups will later be joined by a throng clamoring for normalcy and fully capable critical infrastructure support. SPIRIT can help plan and project timelines for the clearance of damaged areas and reestablishment of critical infrastructure support. A clear plan of action with publicly visible milestones will go a long way to establish credibility and respect for the restoration efforts. To reduce the difficulties this will entail, a strong public health information drive must take place at the evacuation centers and also within the flood areas.

INFRASTRUCTURE ANALYSIS AND TRAINING

Because of indefinite goals and obscure metrics for success, disaster planning has always been an abstract subject. Two important aspects of disaster planning are training and policy development.

Training particularly applies to first responder teams and emergency command center staffs. These training programs have historically addressed the skills the individual fire, police, HAZMAT and medical teams require. An example would be fighting an isolated warehouse fire with all support services intact. This is a useful drill for development of frontline skills, but it is does not reflect the chaotic conditions that will accompany a large-scale disaster.

For a higher level of realism, responders and command centers should address whole system effects.

An example scenario: an earthquake or industrial accident has eliminated water pressure and ruptured gas mains over a large area, followed by the same warehouse fire. This scenario can be made more credible through the structured analysis of the actual water and gas grids in the community. This approach can generate realistic scenarios for tabletop discussions and large scale drills.

By "video gaming," or the exploration of cause-and-effect failures through structured analysis, the time-phased repercussions of an event can be spelled out for constructive discussion and policy analysis. Cross-jurisdictional coordination can also be strengthened through table top exercises of cascading failures and subsequent analysis of mutual support agreements and system-wide operational doctrine.

Use of a structured analysis process can standardize situational reporting procedures and can vastly improve the preparation and situational awareness of rescue and assistance teams arriving from outside the area.

INFRASTRUCTURE ANALYSIS AND PLANNING

Like the period between all disasters, now is the best time to plan and rehearse for the emergencies that are most likely to strike in the foreseeable future. Because it is not tied to a specific deadline or impending disaster, planning is a difficult activity to "sell" to budget-minded civic leaders.

Specific funds have been allocated to harden public transportation, establish buffer zones around chemical plants, and to procure new fire fighting equipment. These enhancements are helpful, but ultimately serve to perpetuate the culture of reaction, and contribute little for preparation and planning. The inexact art of planning and prediction must improve to direct funds to the most important projects.

It has been delegated to the states, counties, and cities to argue for their share of security funding. To improve the chance of support, a regional planner's funding proposal should include a sound cost benefit analysis. In addition to the obligatory graphs and charts, a time-dependency analysis of the infrastructure system can add significant value to the proposal package. The benefit of the requested improvements can then be shown by altering the values used to compute asset criticality, and comparing the results of successive time-dependency analyses.

By bolstering planning with sound analysis, real infrastructure resiliency can be measured and qualitatively improved. For example, a telecommunications data center for an urban economic zone can be made more resilient with the establishment of an added fiber optic pathway and backup storage networks. With proper modeling, the benefits of resiliency could be demonstrated for inclusion to the funding proposal. The risk of lost telecommunications, possibly caused by cascading damage to a right-of-way or a major facility fire, can then be minimized, and the cascade cycle can be cut short. Another example could be funding for an emergency medical helicopter service, which would also benefit the region long before any disaster strikes.

SUMMARY

Preparation efforts for unpredictable disasters are poorly understood and poorly supported. To augment the steady stream of funding spent for new fire hoses and conference phones, some capability must be developed to assess major infrastructure systems. Prediction of the patterns in which events may combine to interrupt or destroy the critical support services will add valuable direction and balance to planning and prevention. Assessment of static relationships between infrastructure segments is only a start; what must be achieved is a flexible representation of the time-relevant interdependencies that drive the sequential failures of critical infrastructure.

ACKNOWLEDGMENT

SPIRIT supported by General Atomics discretionary funds.

APPENDIX: GENERATORS

The typical generator set is a diesel engine coupled to a 1.5–2 MW ac generator, with a fuel tank capacity for 12 hr of operation. The electrical circuitry of the system will automatically start the generator when voltage to the supported facility drops toward a blackout level.

Research indicates that generators may not be a foolproof backup. Studies have shown that even fully maintained and supported generator systems fail at the rate of 15% after less than a day of operation [6]. There are several possible reasons for this. First, startup circuitry may not be effective, so the generator may never be "commanded" to start. Also, emergency generators are seldom started, run, *and loaded* with the power demand for the facility supported.

This is a significant shortfall in regular maintenance and reliability testing, analogous to idling a high performance sports car, but never running it at high speed. Without a test of real performance, there is no guarantee that the generator system is capable sustaining and maintaining high power output.

Finally, once a generator successfully starts and carries the electrical load for its facility, it will run on the limited fuel supply in its tank. Length of the generator's operation is not just an issue of the fuel tank capacity, but more an issue of the fuel volume actually *present in the tank.*

Referring back to Table 2, it becomes apparent that a major challenge for an emergency manager is to replenish fuel tanks for emergency generators to forestall complete infrastructure collapse.

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