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Restoration and Impacts From The September 8, 2011 San Diego Power Outage

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Abstract

This case study discusses post-event reconnaissance research of the September 8, 2011 power outage that left San Diego County, CA without electricity for up to 12 hours. The objective of this case study is to synthesize and analyze the impacts of the outage and responses to the event. Understanding the outage's impacts and responses helps to reveal restoration practices and contexts that promote meeting both technical and non-technical goals. This study reveals several issues related to restoration decision-making and communication related to critical customers, particularly those responsible for health care, wastewater and potable water management, fuel provision, and food service. Restoration did not occur and was not communicated in such a way to avoid impacts to dependent critical infrastructure, reflect state restoration criteria, or meet expectations of a variety of power customers. Insight from this case study suggests three themes to guide research and development of best practices for power restoration: 1) emergency preparedness and public information, 2) power continuity, and 3) protocols and planning. Assessment of these themes are put in context with other studies of contemporary power outages and restoration to argue that power restoration protocols, policy, and planning are an important area for inter-disciplinary research.

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Introduction

This case study discusses post-event reconnaissance research of the September 8, 2011 power outage that left San Diego County, CA without electricity for up to 12 hours. The blackout also affected additional parts of California, as well as Arizona and Mexico. This work focuses only on San Diego County, which was the largest and most densely populated jurisdiction impacted. The power outage affected San Diego Gas & Electric's (SDG&E) entire service area. SDG&E provides electrical service to about 3.5 million people through 1.4 million electric meters—all of whom lost power. SDG&E was responsible for power restoration within their service area, which spans 4,100 square miles of Orange and San Diego Counties.

The objectives of this case study research are threefold. First is to document the outage and analyze its social, economic and infrastructure impacts. Second is to characterize the range of impacts and restoration responses related to SDG&E and their customers. Third is to discuss the case study and present recommendations for policy reform, additions to best practices, and directions for inter-disciplinary research into customer-oriented power restoration. The research employed a mixed-methods approach to data collection and analysis. The remainder of this paper is comprised of sections describing the study's data collection strategy, an overview of the outage, the lifeline impacts of the outage, the socio-economic impacts, and discussion of the case study.

Data Collection Strategy

For this research we used a mixed-methods data collection strategy. Collected data included interview transcripts, content from news and social media, and government documents and databases. We identified representatives of SDG&E customers to interview including public agencies, hospitals, schools, and businesses.

After a short phone interview and initial emails, SDG&E declined to be interviewed in depth or provide information of any kind for this study, citing ongoing federal, state, and private investigations of the company related to their role in and response to the outage. While we were not able to collect data directly from SDG&E representatives, we were able to collect SDG&E data through indirect sources. These include public statements available through press releases, news media, social media, and data from SDG&E provided on their website or logged into the County of San Diego Office of Emergency Services' (OES) WebEOC system. SDG&E is required by the federal government to provide dynamic load profiles on their Web site, which assisted in describing the outage and restoration. We obtained a dataset of all SDG&E Twitter posts during the power outage, including the post text and timestamp. The dataset was created using the system of Butts et al. (2011). SDG&E used Twitter exclusively for social media-based public relations and, in part, as a means of communicating with public agencies. SDG&E used Twitter to announce when regions of their service area had been restored.

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Outage and Restoration

According to the California Public Utilities Commission, the power outage began at the 500kV North Gila substation in Arizona (CPUC, 2011). At 3:27:39pm on September 8, 2011 the substation went off line. Eleven seconds later, all of the power was out in San Diego County. With the substation off line there was a loss of power on the Southwest Powerlink (SWPL) transmission line, which runs into San Diego County across the southeast border. Because of the loss in current on the SWPL there was increased current on the Path 44 transmission line that enters San Diego County from the northwest. With the SWPL offline, Yuma, Arizona, Imperial Valley, California, Baja Norte, Mexico, and San Diego were wholly dependent on Path 44. This exceeded the safety setting of Path 44 and shut down the San Onofre Nuclear Generation Station (SONGS) switchyard. This stopped the current into San Diego County from the northeast (Path 44) and the southwest (SWPL). Local generation in San Diego County could not meet demand so was disconnected to prevent damage as well.

All of San Diego County is within SDG&E's service area and so restoration within the jurisdiction was conducted by SDG&E (SDG&E, 2011b). According to public information from SDG&E, as well as various public testimonies (e.g., California Legislature, 2011; California State Assembly, 2011; City of San Diego, 2011), the first instance of restoration occurred around 8pm on September 8. According to the same sources, all but a few isolated customers were restored in about 12 hours—no later than about 3:30am on September 9, 2011.

Figure 1 shows two different types of recovery curves—one based on the number of customers restored and one calculated from SDG&E dynamic load profiles. The fraction of total customers restored over time is derived from OES WebEOC logs. In addition, the figure shows the dynamic load profile of the SDG&E service area by economic sector. The load profile data in Figure 1 starts at Hour 20 (or 8pm. on September 8) and ends at Hour 48 (or 12am on September 9). The load profile data are normalized using the load profile data for the same two days of the week for the week prior (September 1 and 2). Thus, a value of one indicates the load is back to the "normal" load compared to the week before—that is, the load has recovered. The load from the prior week was compared to other past weeks and found to be representative.

On the top of Figure 1, the communities mentioned in SDG&E's Twitter feed are plotted. The communities are shown in order of the last time a restoration update was given for the respective community. Figure 2a presents the same information in map form, but is expressed as the estimated time that the power was out for each community. Unfortunately, SDG&E did not provide updates on Twitter for all communities within San Diego County.

According to SDG&E Twitter posts, the first mention of any customers being restored occurred on September 8 at 7:05pm but did not describe the location: "A few customers on tonight, but most on tomorrow afternoon." The first Twitter post describing a specific location was posted at 7:12pm on the same day, indicating that some customers in Orange County were with power: "Some #OrangeCounty customers have been restored because they are closest to areas with power." The first post for San Diego County locations

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occurred at 9:06pm: "Power restored to parts of Mission Viejo, San Clemente, Escondido, Otay Mesa, Oceanside, Carlsbad. We're making progress!" Sequential updates of restoration were posted on Twitter, such as "Areas of Rancho San Diego, El Cajon, Encinitas, National City getting power now." In Figure 1, communities are plotted along the timeline based on the timestamp for the final update for each community. The final "tweet" – Twitter post – plotted in Figure 1 corresponds to the first mention that all power had been restored: "In 12 hours we connected 100 percent of our substations." This post occurred at 3:32am on September 9, which is the time that sources cited above indicate power was fully restored. Twitter timestamps of posts informing the public of community restoration are not the actual times of restoration. This is because it took time for information to be communicated to SDG&E public relations and then posted to Twitter. SDG&E tweets do specify that their restoration updates were intended to be sequentially accurate. SDG&E was given a chance to review this paper and verify the restoration timeline, but declined.

Public statements by SDG&E and interviews with the former director of OES and CPUC (2011) indicate the technical requirements of restoring the system meant that power along Path 44 and SWPL had to be restored first at the SONGS and North Gila substations, respectively. Once SONGS and North Gila substations were back online, SDG&E reportedly restored power toward the middle of the county while taking into account the ease or technical need to restore specific circuits. In other words, the restoration was circuit-based, rather than substation-based or customer-based. Given these technical constraints of the restoration pattern, specific customers were restored in groups based on when each circuit in the distribution substation was restored, as well as when a distribution transformer near the customer location was repaired, if damaged.

Based on Figure 2a, it does not appear that restoration started in the southwest with the North Gila substation and then, soon after, the northwest with the SONGS substation before progressing inwards to the central part of the county. For example, Fallbrook (Polygon 10 in Figure 2a) is located near the SONGS substation in the north, but was restored well after Torrey Pines (Polygon 38), which is along the central part of the coast much farther away from SONGS or North Gila. Lemon Grove (Polygon 17) was restored well before Chula Vista (Polygon 4) and National City (Polygon 25), though these municipalities are close together in the southern-most part of the county. The first two municipalities with restored power were Escondido and San Marcos according to updates from SDG&E posted on Twitter and logged into the OEC WebEOC system. These municipalities are in the central part of the county.

Figure 2b presents a map of the population of each community mentioned in SDG&E Twitter posts to help give insight into whether SDG&E's approach resulted in restoration to the largest number of customers in the shortest amount of time. Of the mapped communities, the largest populations are located in Carlsbad (Polygon 3 in Figure 2b), Chula Vista (Polygon 4), El Cajon (Polygon 7), Escondido (Polygon 9), and Oceanside (Polygon 27). Carlsbad, El Cajon, Escondido, and Oceanside were among the first group of communities that SDG&E announced were restored (Figure 1 and Figure 2a). Chula Vista was among the last group of communities that SDG&E announced had been restored. Chula Vista is the second largest community in San Diego County.

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To provide insight regarding SDG&E restoring power to essential customers, Figure 2 shows the location of all hospitals in San Diego County. There are multiple hospitals in communities that had relatively long outage times, for example in Chula Vista (Polygon 4). The first circuit restored in Chula Vista was at about 12:30am on September 9, 2011 according to interviews and OES' WebEOC log. In other words, the hospitals in Chula Vista had to rely on backup power for longer than any other hospital—over four hours after the first circuits were restored in the county.

Lifeline Impacts

The San Diego power outage caused disruptions to other dependent lifeline infrastructure. Some lifeline types were more impacted than others. The outage's impacts on such a large range of lifelines posed significant challenges to decision makers, businesses, and residents.

Communication Impacts

Communication networks, including emergency communications, telephone, cellular, Internet, and cable service, were overwhelmed in the first 30-60 minutes after the blackout. While some communication systems had backup power, there were several instances where either backup power did not work properly or was insufficient to handle the necessary load. For example, the city manager of El Cajon said the city experienced outages of their emergency communications system because of insufficient generator capacity. As a result, police, fire and emergency management had difficulty communicating in some instances. In these instances, cellular SMS (text messaging) services were used. As a result of communication disruptions and initial miscommunications, agencies sent representatives to other agencies for critical communications. As an example, San Diego County Health and Human Services Agency (HHSA) Division of Public Health Services (PHS) sent someone to City of San Diego Public Utilities (PU) to clear up a miscommunication about required beach closures.

While sources indicated that cellular towers have battery backup for 8 to 72 hours, service was limited, if available at all, throughout the 12-hour duration of the outage. Study participants regularly indicated that certain providers were more reliable than others, particularly related to cellular service. SMS service on cellular networks worked fairly consistently while voice and data services performed poorly. Calls and texts from friends and co-workers about power service and restoration were frequently stated as the best source for information. Many of those that had smartphones and could access their cellular data services used social media to disseminate and find information about the outage until their batteries ran down. Ninety percent of Time Warner Cable Company's customers lost service immediately. Thus, most of the public, including those with only broadcast service, could not access emergency information from local and national television sources, though local news covered the outage extensively.

The 9-1-1-call volume immediately after the outage was three times higher than typical volumes, exceeding surge capacity. The majority of 9-1-1 calls were related to elevators that had stopped working, residents' dependent on home medical systems, traffic issues, and general questions about the power outage. OES, in collaboration with SDG&E, issued

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about 500,000 reverse-9-1-1 calls to the public, particularly those with special medical needs, using AlertSanDiego—a regional public notification system. AlertSanDiego was thought to be relatively ineffective by OES because the phone number database is primarily of landline numbers. OES is currently making a concerted effort to get the public to register their cellular phone numbers and has been advocating for years for homes to have at least one non-cordless phone. The AlertSanDiego system was also used to notify residents and businesses that were in a boil water advisory zone (see water section below).

Transportation Impacts

The power outage had significant impacts on transportation. San Diego's light rail system went down. San Diego International Airport remained open during the blackout, though outbound flights were not permitted, and some inbound flights were delayed or diverted. Backup power only supported about 25% of their operations, prioritized with respect to life-safety and evacuation purposes.

The most critical impact was to traffic and freeway onramp signals, which have little, or in most cases, no battery backup. Signals were either off or had reverted to flashing red. Signal outages in combination with higher than normal traffic volumes led to major delays, particularly along routes to freeway onramps. Study participants estimated a normal 15-minute commute took 2 to 3 hours during the power outage. Traffic began to clear approximately 3 hours after the initial outage. However, traffic signal operations were impaired and unreliable for about two weeks after the event. Traffic delays were exacerbated in downtown San Diego because rail-crossing arms were stuck in the down position. One reason that San Diego County Office of Education (SDCOE) said they made the decision to close all schools in the county was to ensure the safety of the children with respect to traffic accidents. Many study participants noted traffic issues could have been avoided if more traffic signals had backup power.

OES had difficulties getting emergency personnel and county officials from their downtown administrative offices to the county's new EOC located several miles to the north. The California Department of Transportation (CalTrans) traffic management system was impaired because of inoperable cameras. CalTrans used information from media reports in cases where they did not have camera information. In addition, traffic delays also led to difficulties delivering generators to critical facilities.

Fuel Impacts

The outage severely impacted access to fuel service. The former director of OES observed that the most significant impact was on the ability of consumers, repair crews, and law enforcement to access gasoline. Without electricity, gas pumps were inoperable. Some agencies reported being able to operate their own fueling locations for first responder vehicles using manual pumps. Almost all of the roughly 1,000 retail gasoline stations in San Diego County, which account for about $150 million of payroll in the county, were closed during the outage. Clearly there was an economic impact associated with gas station and convenience store closures, but no estimate has been done to our knowledge. For similar reasons, access to natural gas by consumers was also hampered as a result of the outage.

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The natural gas company Kindermorgan said they did not have backup generators and noted that it could take 24-36 hours to have large generators delivered and installed. This means that longer outages in the San Diego region will result in a significant natural gas shortage.

Potable Water Impacts

In some areas that rely on wells for potable water, the loss of power impacted access to potable water. Seventeen of 166 small water systems in rural unincorporated San Diego County experienced low water pressure. These systems serve relatively small populations. Department of Environmental Health (DEH) used a callback system to determine which water networks lost pressure. It took almost two weeks to clear all of the related boil water orders. Within the City of San Diego, 13 small areas experienced reduced water pressure, but there were no reports of contamination. For the most part, these communities lack the ability and resources to monitor the water pressure of their own system. Boil water advisories were issued for these areas and lifted by September 11. According to DEH, this was done as a precaution in all cases and no instances of contamination were reported. The city owned 17 generators to dispatch to their 49 pump stations. In this case, the city dispatched generators to five pump stations located in boil-water zones before power was restored.

There was a lot of confusion among residents and businesses about the boil water advisory. Many were unaware of the advisory, including PHS officials whom we spoke with, because of impaired access to public information. While others who did know about the boil water advisory did not have means to boil water, lacking electricity. DEH gave restaurants three options under which they could operate if located within a boil water zone: close, sell only pre-packaged food, or serve under limited conditions. In large part, businesses were aware of these options before the outage occurred from pre-event educational guidance provided by the department.

Wastewater Impacts

PU operates and maintains 82 pumps stations as part of their wastewater system. The outage led to failures that resulted in sewage spills at two pump stations Los Penasquitos lagoon near Torrey Pines State Park (Pump Station 64) and South Bay (Pump Station 1), respectively. This led to the closure of ten miles of shoreline in the county. Closures and warnings were posted at beaches from the Scripps Pier in La Jolla north to Solana Beach about six hours after the spills started. The delay was caused by miscommunication between agencies, including PU and DEH. About 3.6 million gallons of sewage was also spilled into the Tijuana River in Mexico as a result of power loss outside of San Diego. All beaches and parks in San Diego were reopened by September 14. Power was restored to the pumps in approximately five hours and before SDG&E could deliver mobile generators. Sixty of PU's 82 pump stations had backup generators. Five, including Pump Stations 1 and 64, had dual electrical feeds from separate SDG&E substations, but no backup generators.

Approximately 2.6 million gallons of sewage were spilled into Los Penasquitos lagoon and is considered to be the biggest sewage spill in the county over the past decade. A local environmental group, San Diego Coastkeeper, reported fish kills as a result of the spill (San

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Diego Coastkeeper, 2011). San Diego Coastkeeper also reported elevated fecal coliform and reduced dissolved oxygen levels for at least a week after the outage. PU pumped 15 million gallons of contaminated water from the lagoon over two weeks as part of cleanup efforts. Over 900,000 gallons of sewage were spilled from Pump Station 1 at South Bay into the Sweetwater River and ultimately, the bay.

Socio-Economic Impacts

Although the September 8 power outage was brief and the direct economic loss small, the event had distinct and varied social and economic impacts that can provide lessons for future power restoration efforts and related policies and planning approaches. The impacts documented below relate to the economy, schools, health care services, and social services.

Economic Impacts

The economic impacts varied with respect to type of customer. Government largely was impacted by overtime costs related to increased hours for police, fire and other critical personnel, with some productivity loss. The general public was impacted because ATMs did not have power to operate. Many households threw out perishable food. Those that work at businesses typically open during the period of the outage likely lost wages. Businesses could have suffered from overtime costs, lost productivity, and lost inventory in the form of perishable food. Businesses typically open in the evening or those that operate 24 hours a day were forced to close in most cases. Many bars and restaurants were expecting higher than normal revenue the evening of September 8, 2011 because it was opening night of the National Football League. Many business sectors were not severely impacted by the outage because it occurred in the late afternoon and the majority of the restoration was complete early the following morning.

The National University System Institute for Policy Research (NUSIPR) calculated the direct economic loss of the outage to be between $97 and $118 million. According to the president of NUSIPR, the calculation underestimates actual losses. Their estimate includes $12 to $18 million for food spoilage, $10 to $20 million for government overtime, and about $70 million for lost productivity (NUSIPR, 2011). (Sub-totals do not sum to total maximum and minimum estimates in NUSIPR, 2011). These three estimates were based on estimates for the 2003 Northeast United States blackout, 2007 San Diego wildfires, and 1996 San Diego brownouts, respectively. The original estimates were adjusted for various factors, such as population difference, to arrive at the estimates for this event. The NUSIPR estimate is not specific to this outage. As a result the estimate ignores several sources of direct and indirect losses associated with the outage, such as millions of dollars of losses suffered by medical care facilities and issues with childcare for the day that schools were closed.

Of particular note were food service businesses, which might have thrown out perishable food. According to DEH, there are over 12,000 food service businesses accounting for over 30,000 inspections per year. If each of those businesses discarded only $1,000 of food, the total loss would double the NUSIPR estimate. A personal injury lawyer interviewed indicated the average claim amount he received was about $2,000. The majority of these

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businesses are small and locally owned. The Food and Drug Administration guidelines for a power outage state that refrigerated food can be kept up to four hours if the fridge is not opened. Thus, many restaurants chose to throw away, discount or give away perishables to avoid liability of serving spoiled food. SDG&E also made several public statements that restoration might take several days, which some businesses indicated prompted them to throw out food. Many bars and restaurants with backup generators unsurprisingly saw an increase in business and garnered attention by the news media who described residents celebrated the outage at these establishments.

School Impacts

In response to the outage, SDCOE closed all schools in the 42 districts of San Diego County on September 9—the day after the outage. The SDCOE public information officer said that schools in the area experienced little logistical trouble on the first day of the outage, with students able to get home because of the timing of the outage. At 8pm on September 8 the public announcement to close was made. Schools were closed in part for safety concerns related to traffic signal outages and the impact on bussing, as well as to deal with uncertainty created by SDG&E public information of whether power would be back on the next day. SDCOE said that SDG&E's restoration approach was a factor in their closure decision. SDG&E indicated they could not prioritize the restoration of some schools because it would prevent them from prioritizing other areas. In addition, SDG&E communicated to SDCOE that restoration of schools en masse would lead to a large spike in load that would make stabilizing the electrical network difficult and result in a prolonged outage. To avoid a small budget loss, some school districts petitioned the California Department of Education that the lost day not be considered in calculation of average daily attendance money because it was due to an emergency.

Health Care and Social Services Impacts

There were no deaths or significant injuries reported as a result of the outage. There were several cases of various health care facilities transporting patients to other facilities for precautionary reasons or because of generator malfunctions, including at one large nursing home. There were also instances where homebound residents who use electric medical devices were transported to nearby health care facilities. Because these devices typically have at least six hours of battery backup these instances were relatively rare. SDG&E maintains a list of about 14,000 people who require power for medical devices so they or OES can make contact using reverse 9-1-1 and inquire whether there is a medical emergency requiring assistance.

Two hospitals experienced backup generator malfunctions: Sharp Memorial Hospital in Kearney Mesa and Scripps Mercy Hospital in Chula Vista. Sharp Memorial was never entirely without power. Scripps Mercy was without power for 90 minutes until they brought in mobile emergency generators, according to the administrative director of disaster preparedness for Scripps Health. The permanent backup generator failed to work because of a fuel pump problem. Fourteen patients were evacuated to another Scripps facility. Many of the medical equipment within Scripps Mercy have battery backup that lasted for all or most of the outage. Scripps Mercy had to cancel surgeries, exams, diagnostics, and close clinics serving more than 900,000 customers.

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The CalFresh program issues nearly $30 million in food stamp benefits to about 200,000 low-income residents of San Diego County every month. The HHSA Division of Strategy Planning and Operational Support (SPOS) manages the CalFresh program for the county. The power outage occurred near the beginning of the month when recipients typically use much of their benefits to purchase food. As a result, the county offered to reimburse recipients up to one month of benefits to replace discarded food if they applied within 10 days of the outage. Some reimbursements for large families were in the thousands of dollars. Recipients could apply in person for benefit replacements at 10 county family resource centers using forms available in English and Spanish. Only a small portion of those eligible applied for replacement. According to SPOS, the Iraqi population represented the highest percentage replacement benefit issuances (48%) of all issuances. In one instance, nearly 600 Iraqi recipients showed up simultaneously at the El Cajon family resource center. According to the U.S. State Department, Iraqis represent the fastest growing immigrant population in San Diego County (greater than 80%), followed by Burmese and Somalian immigrants, respectively. As a counter example, the Somali population had a replacement issuance rate of about 3 percent.

Discussion

The criticality of electricity is emphasized by the wide variety of outage impacts described here. Based on interviews, the most unexpected and unplanned for infrastructure interdependence impact was related to access to fuel and the serviceability of gas stations. Secondarily, it was the failure of wastewater treatment plants and ensuing sewage spills. Communications disruption was most widely cited as being expected and planned for well. For socio-economic impacts, food-related issues were the most widely discussed. Most unexpected and unplanned for was the need to facilitate the replacement of food stamp benefits for low-income households. In addition to better understanding power outage impacts, three general lessons are drawn from this case study and discussed below. These lessons relate to 1) emergency preparedness and public information, 2) power continuity, and 3) power restoration protocols and planning

Emergency Preparedness and Public Education

No one interviewed for this case study had expected or planned for such a large power outage, with experience built up from recent wildfire disasters and extensive participation in the large-scale earthquake disaster simulation—Great California ShakeOut. Several participants in this study pointed out that this event served as a county-scale disaster simulation. One notable difference with the San Diego power outage and most, if not all, simulations are the breadth of participation and the focus on electricity and infrastructure interdependence. The former director of OES noted that such a focus on infrastructure within simulations has never been done in San Diego. He suggested that San Diego County require such exercises so that functional and socio-economic goals related to infrastructure disruption can be tested and evaluated. The PU wastewater division director indicated that SDG&E had never participated in city disaster drills. It is hoped that the Lifelines Emergency Coordination Group, recently created by the San Diego County Board of Supervisors, will coordinate infrastructure-focused disaster simulations. Meaningful

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integration of utility service loss and creation of infrastructure-oriented advisory groups can benefit all jurisdictions.

Public information access during the outage largely depended on electricity. Twitter, television, and radio were the primary media for SDG&E to inform the public during the outage. Most customers and agencies, including OES, could not view television during much of the event. As described above, access to the Internet was restricted to people with charged smartphones if they did not have access to emergency backup power. In a public presentation, SDG&E concluded the use of Twitter, as well as their website, was successful and effective (SDG&E, 2012b), noting they plan to incorporate social media more in their emergency procedures. Without emergency backup power, the most likely means of accessing social media and the Internet is with a smartphone. Only 35% of people in the United States own smartphones, with lower than average ownership rates among lower income, older, less educated, and rural populations (Smith, 2011).

Those populations with low smartphone ownership rates need to be informed of essential call centers for accessing public information during a disaster. For people requiring reverse 9-1-1 services, such as AlertSanDiego, or for whom access to disaster call centers will be a primary information source, it is important to ensure they have corded landline phones. Initiatives to increase enrollment of cellular phone numbers in reverse 9-1-1 systems must consider the length of charge for phone batteries if the event involves a widespread power outage of significant duration. In light of the potential for poor access to public information via electricity-dependent means, pre-event public education on emergency preparedness and, specifically, what to expect with respect to power disruption and restoration is made all the more critical. Such information would better encourage households and businesses to secure extra phone and radio batteries, the means of charging batteries, or emergency backup power.

Power Continuity

Issues related to emergency backup generators for maintaining power continuity was common for different types of customers. Most notable were related to critical facilities, small food-related businesses, gas stations, and low-income households. The impacts, practices, and lessons with respect to each customer are different. Customers associated with critical facilities have relatively formal practices regarding power continuity because of their public health and disaster recovery roles, as well as financial resources. In contrast, the latter types of customers have inconsistent and ad hoc practices in part because of difficulty in affording backup power or accurately assessing its benefits.

Lack of power continuity was an issue for several critical services, specifically freeway on-ramp signals, emergency communications, sewage conveyance, and healthcare. Battery backup power needs to be installed for critical traffic signals, particularly at freeway on-ramps. The inadequate capacity of some City of El Centro emergency communication system backup generators highlights the difficulty in calculating required load and the importance of verifying that capacity meets evolving demands of a facility. Jurisdictions can address this by providing technical resources for calculating loads, as well as creating a permit renewal process that requires regularly updated load calculations in order to

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address system modifications and expansions. Several City of San Diego water and wastewater pumps did not have emergency backup generators. The U.S. Environmental Protection Agency (EPA) regulates power continuity for wastewater facilities. Generators are not required if facilities are connected to two different substations (dual feeds). Dual feeds will not provide continuity in widespread power outages. The EPA should require emergency backup power or, at a minimum, require generator quick connections at facilities in areas of high risk to large-scale outages due to natural hazards. Responsible agencies should consider this for other critical facilities, such as natural gas systems, which were largely without backup during this outage. Without more targeted regulation, utility service providers may not be motivated to install adequate backup capacity. For example, prior to the outage, the City of San Diego found that the cost of installing backup generators for the pumps associated with sewage spills, as well as other pumps, outweighed benefits. In contrast, after the outage the City of San Diego reversed their view of the cost-benefit and spent $12 million to install backup generators at the offending pump stations, as well as others (Lee, 2012). California law requires hospitals to have emergency power within 10 seconds of an outage, in addition to enough fuel to run generators for at least 24 hours (CPUC, 1998). The California Air Resources Board allows gas-powered generators, such as used at hospitals, to be run no longer than 96 hours per year, which may be insufficient to identify potential problems. The State of California should review this regulation to ensure adequate testing is permitted for critical facilities using backup power—a lesson applicable to air quality regulations elsewhere.

As described above, the outage impacted small food-related businesses, such as bars and restaurants, gas stations, and low-income households. Sufficient backup generators for typical food service businesses can cost as much as $20,000. This is a large expense for most restaurants and bars, but one downtown bar owner estimated their sales loss to be between $15,000 and $20,000. While small businesses have a proportionately high post-disaster failure rate because of financial marginality and reduced demand (Miles and Chang, 2006), food-related businesses are arguably more likely to maintain demand and so could benefit more from investment in emergency backup generators. State or local jurisdictions need to consider offering incentives to food-related businesses to avoid areas of food scarcity during a disaster. This can be done via financial assistance, such as was offered in Connecticut (Public Act 05-1), offering technical assistance in calculating cost-benefits, or improving generator delivery planning with respect to businesses in critical locations. The inability of low-income households to purchase generators is indicative of financial status, as observed by Green (2011). Given relative priorities then, incentivizing purchases of generators may be ineffective. An alternative solution for power continuity is installation of microgrids, such as the Duke Energy McAlpine microgrid (Ozog and Ratnayake, 2010). It is surprising that the inability to pump gasoline was unexpected and unplanned for, but this was also the case in the aftermath of the 2011 Great East Japan earthquake (Tohoku Electric Power Company, personal communication; City of Sendai Post-Disaster Reconstruction Bureau, personal communication). During the San Diego outage this hampered emergency services. In Japan, this resulted in suspension of emergency water deliveries for five days in Miyagi Prefecture (Kuwata and Ohnishi, 2011), among other impacts. The critical role of fuel in the immediate aftermath of a disaster is such that jurisdictions need to strongly promote power continuity at private gas stations, using potential approaches mentioned above.

It is not realistic for all power customers to have emergency backup generators to prevent inventory and productivity losses. Purchasing insurance can be viewed as a substitute to purchasing a generator for mitigating financial loss. Similar to insurance, replacement of food stamp benefits serves as partial financial mitigation for low income customers receiving benefits. Assuming a customer has adequate insurance, typical business interruption and property insurance policies are not substitutes for backup power because losses due to off-premise power outages are excluded (Torrey and Russell, 2001). Healthcare business disruption insurance generally requires a minimum of 24 hours disruption to health care services before policy coverage applies according to Scripps' manager of risk and insurance. One San Diego personal injury lawyer interviewed for this case study indicated that few who submitted claims knew about the off-premises exclusion. The ability and cost to cover losses related to off-premises power outages using endorsements varies between insurance companies, with few states providing relevant mandates (Johnson, 2001). With increasing frequency of large-scale power outages, the limited relevant case law will expand and better establish the exclusion legality, which has not always been upheld (Torrey and Russell, 2001; Johnson, 2001). States can hasten this process through analysis and potential modification of this aspect of insurance law. With respect to financial insurance via food stamp benefits, the proportion of benefit replacement applications in San Diego suggests that responsible agencies, including those outside of San Diego, should include relevant information in their public awareness campaigns in multiple languages.

Power Restoration Protocols and Planning

Based on the information synthesized for this case study it is not clear that SDG&E approached the restoration in the way they reported. More importantly, their restoration did not meet the expectations of a range of customers, including those in charge of critical facilities. At least three critical customers – Scripps hospitals, City of San Diego Public Utilities, and San Diego County Office of Education – have concerns regarding the consequences if similar restoration protocols and planning occur during a larger disaster with a prolonged power outage.

The disaster preparedness director for Scripps Health indicated that SDG&E and San Diego County OES had plans in place that indicated that hospitals would be among the first customers to be prioritized and restored as a part of critical infrastructure. This was not the case as their facilities were among the last communities fully restored after the outage on September 8, 2011. In the past, City of San Diego PU had communicated their restoration needs to SDG&E and requested their most critical facilities be prioritized. To PU's knowledge, no priority was given in this case, observing that nearby residential areas were restored prior to their critical facilities.

There is no legally required protocol in California for restoration. The California Public Utilities Commission General Order No. 166 does set out "standards [that] will facilitate the Commission's investigations into the reasonableness of the utility's response to

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emergencies and major outages." CPUC (1998) states the expected priority of restoration as the following:

> The plan shall include guidelines for setting priorities for service restoration. In general, the utility shall set priorities so that service is restored first to critical and essential customers, and so that the largest number of customers receive service in the shortest amount of time (pp. 3 and 6).

To date, a third party has not studied the success of SDG&E's restoration effort. Based on this case study, SDG&E's restoration did not fully meet this standard with respect to either population or critical customers. SDG&E's restoration approach demonstrates either that they were unable or unwilling to follow the state standard.

Similar to the San Diego outage, dissatisfaction has been expressed by customers in relation to other contemporary outages, including those related to Hurricane Irene (August, 2011), the October 2011 snowstorm in the Northeast U.S., the hurricane-force windstorm in Southern California (November, 2011), and the June 2012 derecho in the Mid-Atlantic U.S. Third parties have studied the 2011 restoration efforts of Southern California Edison (SCE) and Connecticut Light and Power (CL&P). Both a SCE and a third party study concluded that SCE did not meet its typical restoration target because the scale of the event was unexpected and unplanned for (SCE, 2012; Davies Consulting, 2012). Both investigations noted that customers were frustrated with actual restoration times, predicted restoration times, and most of all, how SCE's restoration protocol and pre-event planning was communicated. SCE's study states that it needs to improve its ability to predict restoration times, refrain from communicating predictions to individual customers, provide conservative restoration time estimates for only general areas, and expand its use of social media for communicating restoration progress. Davies Consulting (2012) is more direct in saying that SCE needs to explicitly define a restoration protocol, create different protocols for different sized events, and, most pointedly, develop and implement a "prioritized weighting mechanism … in collaboration with communities" to improve the effectiveness of restoration planning. The investigation of CL&P by Witt Associates (2011) resulted in much more critical and detailed conclusions, including the following recommendation.

> CL&P and municipal governments should establish a regular schedule and process for municipalities to provide and update their pre-identified restoration priority lists. CL&P should update and validate municipal priorities on a regular basis … CL&P should also be prepared to explain to municipalities why their priorities may not be addressed exactly as submitted because of the geography of power circuits and utility grid architecture. (p. 19)

In response to the restoration controversy and Witt Associates (2011), the State of Connecticut adopted Public Act No. 12-148, which establishes a national precedent for state policies regulating power (and other utilities) outage mitigation, restoration planning, restoration timeframes, and performance penalties. At this point, no formal analysis of the effectiveness of this legislation has been done. Further, it is not clear how feasible or reasonable Connecticut's legislation is for improving restoration. It is important to critically evaluate this as more states consider adopting such policies.

Conclusion

As illustrated in this case study, widespread loss of electricity results in several types of significant impacts that can be reduced through preparedness efforts, such as infrastructure-centric disaster simulations and mitigation measures, such as backup generators and insurance. Electricity is generated and delivered using what is arguably the most technically complex system in existence. Unfortunately, the restoration of electric and other infrastructure service is not just a technical issue. The complexity of restoration increases several magnitudes in the context of organizational culture, government regulations, public-private relationships, communication difficulties, and resource constraints. As a result, depending on the context of particular cases such as this one, customer needs or expectations for restoration may not be met for various controllable and uncontrollable reasons. Power restoration protocols and planning cannot be fully optimized without understanding such non-technical contextual issues, such as relevant state regulatory frameworks as seen in Connecticut. Understanding how optimal and reasonable restoration can be achieved – what can and cannot be accomplished, and why – should be a focus of inter-disciplinary research by engineers, social scientists and urban planners in order to develop formal best practices.

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References

Butts, C.T., Sutton, J., Spiro, E.S., Greczek, M., Fitzhugh, S. and Pierski, N. (2011) Hazards, Emergency Response, and Online Informal Communication Project Data. University of California Irvine and University of Colorado Colorado Springs.

California Legislature (2011) California Assembly Utilities and Commerce Committee & Joint Legislative Committee on Emergency Management Briefing Paper on September 8, 2011 Southwest Power Outage, *State of California*, Sacramento, CA.

California State Assembly (2011) Testimony of Ron Lane to the California State Assembly Committee on Utilities and Commerce Joint Oversight Hearing October 26, 2011, *State of California*, Sacramento, CA.

City of San Diego (2011) Impacts of the September 8, 2012 Countywide Blackout of the Public Utilities Department, *City of San Diego Executive Summary Sheet*, San Diego, CA.

Journal of Infrastructure Systems. Submitted May 7, 2012; accepted June 20, 2013;
posted ahead of print June 21, 2013. doi:10.1061/(ASCE)IS.1943-555X.0000176

CPUC (2011) San Diego Blackout Sept. 8, 2011, *California Public Utilities Briefing*, San Francisco, CA.

CPUC (1998) Order Instituting Rulemaking for Electric Distribution Facility Standard Setting, *California Public Utilities Commission*, San Francisco, CA.

Davies Consulting (2012) Southern California Edison's Response to the November 30, 2011 Windstorm, *Southern California Edison*, 145 p.

Green, P. (2011) Generators emerge as a status symbol, *New York Times*, November 9, 2011 Issue.

Johnson, S.G. (2001) Insurance coverage for power outage losses, *Journal of Insurance Coverage*, Autumn 2001, pp. 1–25.

Kuwata, Y. and Ohnishi, Y. (2011) Emergency-response capacity of lifelines after wide-area earthquake disasters, *Proceedings of the International Symposium on Engineering Lessons Learned from the Great East Japan Earthquake*, pp. 1475–1486.

Lee, M. (2012) SD targets sewage spills with $12m plan, *U-T San Diego,* January 4, 2012.

Miles, S.B. and Chang, S.E. (2006) Modeling community recovery from earthquakes, *Earthquake Spectra*, 22(2), pp. 439-458.

NUSIPR (2011) Economic Impact of September 9 Power Outage, *National University System Institute For Policy Research*, San Diego, CA.

Ozog, M. and Ratnayake, A. (2010) Orchestrating Duke's 'virtual power plant', *Proceedings of the 2010 Association for Energy Services Professionals National Meeting*, Dallas, TX.

OSHPD (2011) Electrical Requirements for Health Care Facilities. *State of California Office of Statewide Health Planning and Development*.

San Diego Coastkeeper (2011) Sick of Sewage, Accessed February 22, 2012, http://www.sdcoastkeeper.org/blog/sick-of-sewage.html

SDG&E (2012a) SDG&E Dynamic Load Profiles, Accessed February 22, 2012, http://www2.sdge.com/eic/dlp/dynamic.cfm.

SDG&E (2012b) Pacific Southwest Outage, *Business Civic Leadership Center Regional Forum on Thinking About Earthquake Power Outage Challenges and Business Resumption*, March 6, 2012, San Diego, CA.

SCE (2012) December 2011 Outage Report: Restoration and Communications Challenges and Root Cause Evaluation, *Southern California Edison*, 54 p.

Smith, A. (2011) 35% of American Adults Own a Smartphone, *Pew Research Center*, Washington D.C., 24 p.

Torrey, R.S. and Russell, W.J. (2001) Insurance coverage for power interruption-related business losses, costs and damages, *Mealey's Litigation Report: Insurance*, 15(32).

Witt Associates (2011) Connecticut October 2011 Snowstorm Power Restoration Report, *Witt Associates,* 50 p.

Journal of Infrastructure Systems. Submitted May 7, 2012; accepted June 20, 2013;
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Restoration and Impacts From The September 8, 2011 San Diego Power Outage

Figure 1. The fraction of total customers restored over time (black line) and the load profile of the SDG&E service area by economic sector. The load profile data starts at 8pm 9/8/2011 (Hour 20 on the x-axis of the graph) and ends at 6am 9/9/2011 (Hour 48). The load profile data for this period is normalized by the load profile data covering the same two days the week prior such that a value of 1 indicates the load is back to the "normal" load represented by the week prior.

Figure 2. Map of estimated restoration times (a) and total population in 2010 (b) for select communities in San Diego County. (1) Bay Park; (2) Borrego Springs; (3) Carlsbad; (4) Chula Vista; (5) Claremont; (6) Dana Point; (7) El Cajon; (8) Encinitas; (9) Escondido; (10) Fallbrook; (11) Fletcher Hills; (12) Hillcrest; (13) La Jolla; (14) Laguna Niguel; (15) Lake Hodges; (16) Lakeside; (17) Lemon Grove; (18) Mira Mesa; (19) Miramar; (20) Mission Bay; (21) Mission Hills; (22) Mission Valley ; (24) Mission Viejo; (25) National City; (26) North Park; (27) Oceanside; (28) Otay Mesa; (29) Point Loma Heights; (30) Poway; (31) Ramona; (32) Rancho Bernando; (34) Rancho San Diego; (35) San Clemente; (36) Santee; (37) Spring Valley; (38) Torrey Pines; (39) Mt. Helix; (40) Westfield; (42) Centre City; (43) Mission Gorge. Data is from SanGIS, San Diego County OES, and United States Census Bureau.

Figure1

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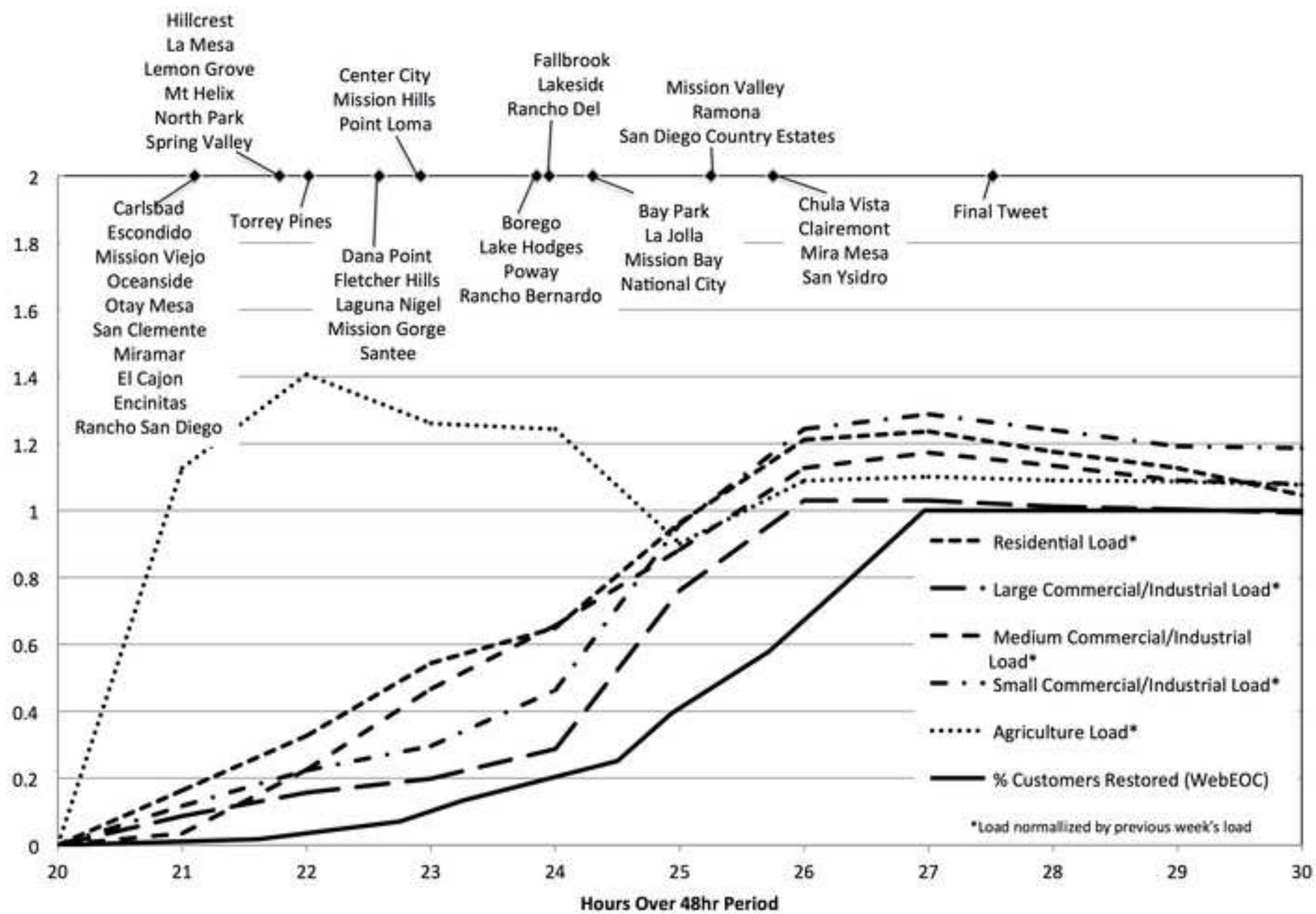

Figure2

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