SUSTAINING PITTSBURGH'S VITAL SERVICES WHEN THE POWER GOES OUT

EXECUTIVE SUMMARY*

Department of Engineering and Public Policy
Department of Social and Decision Sciences
H. John Heinz III School of Public Policy and Management

Carnegie Mellon University
Pittsburgh, PA 15213-3890

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***This document contains only the executive summary of the full project report. The full report is available to interested parties upon request to Prof. Granger Morgan (granger.morgan@andrew.cmu.edu) or Prof. Jay Apt (apt@cmu.edu).**

Project Participants

This study was sponsored jointly by the Department of Engineering and Public Policy (EPP), the Department of Social and Decision Sciences (SDS), and the H.J. Heinz III School of Public Policy and Management at Carnegie Mellon University. The students and faculty who participated in this project were:

Students

Benjamin Anderson (ChemE/EPP)	David Lagattuta (MCS/HSS)
Erik Andreassen (ECE/EPP)	Emily Lauffer (ECE/EPP)
Michell Birchak (MSE/EPP)	Rachel Lin (MechE/EPP)
Barbara Blackmore (CivE/EPP)	Landon Lochrie (CivE/EPP)
Laura Cerully (CS/SDS)	Nick McCullar (CivE/EPP)
Helen Davis(CivE/EPP)	Ben Mosier (CivE/EPP)
Jonathan Fasson (ChemE/EPP)	Jonathan Ng (ChemE/EPP)
Dominic Fattore (SDS)	Laura Sperduto (CivE/EPP)
Sandra Gani (CS/EPP)	Marena Tiano (Heinz)
Wenyao Ho (ECE/EPP)	Jennifer Wong (CivE/EPP)

Project Managers

Kyle Meisterling (EPP)

Paul Hines (EPP)

Faculty Advisors

Dmitri Perekhodtsev (Tepper School of Business)

Marija Llic (Electrical and Computer Engineering and EPP)

Jay Apt (Tepper School of Business and EPP)

Granger Morgan (EPP)

Review Panel Members

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Joseph G. Belechak	Duquesne Light Company
Don Berman	Pittsburgh Water and Sewer Authority (retired)
Raymond V. DeMichiei	City of Pittsburgh Emergency Management Agency
Edward V. Johnstonbaugh	Allegheny Energy
Sidney Kaikai	Department of City Planning
John B. Kramer	UPMC
Tom Somerville	Pittsburgh International Airport
William Valenta	Pittsburgh Police
Frank Milfeit	Dominion Peoples

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Mark Abriola	Citizens Bank
Cliff Timko	P.E., CEM
Shelly Chandler	PNC Bank
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Roy Cox	City of Pittsburgh EMS
Carolyn Renner	SPC
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Clay K. Fulton	City of Pittsburgh
Beth Ganley	Carnegie Mellon University
Marvin Sirbu	Carnegie Mellon University

Executive Summary

Many public and private vital services depend on electric power. From recent events such as the North-East blackout of August 14, 2003 we know that power systems are vulnerable to disruptions. Most customers in the United States experience one to two blackouts per year with durations of one to eight hours. While the power system alone may not be an ideal target for international or domestic terrorists in today's world, terrorists could attack the power system in coordination with attacks on other infrastructure. The power system is vulnerable, and there is a limit to how robust it can be made.

While all vulnerabilities cannot be avoided, the power system can be made survivable. Survivability is "the ability of a system to fulfill its missions in a timely manner in the presence of attacks, failures, or accidents" (Lispon and Fisher, 1999). The goal of this project is to find ways to reduce the social and economic costs associated with a blackout by assuring that critical missions in the city of Pittsburgh continue even when the power goes out.

For this project, we established a set of potentially critical services and classified them into the following categories: Emergency Services, Private Services, Utilities, and Ground and Air Transportation. We determined three reference blackout events for which the robustness of each service was evaluated. The reference events were designed to vary in duration and size of the affected area. We also assessed the diesel fuel supply available in Pittsburgh and the interactions between the services under different blackout scenarios.

In summary, we found that while some important services, such as hospitals and 911 emergency response, have taken measures to ensure that service will continue during a blackout, there are several vital services, such as police zone stations and traffic control, that are highly sensitive to electricity outages. We recommend that local and state officials work with federal agencies, such as the Department of Homeland Security, to find efficient ways of investing in the survivability of Pittsburgh area vital services.

Overview of Project Findings with Recommendations

1. Three of the five Pittsburgh police zone stations houses do not have backup generation installed on site. We recommend that the city provide funds for the installation of standby generation at these three locations, or ensure that police services will not be compromised during an extended outage.
2. Important private services such as grocery stores, gas stations and cellular phone service are vulnerable. Although the social benefits from keeping these services running during an outage are large, these benefits are dispersed among individuals, whereas the capital costs are

concentrated in the hands of the service provider. Thus, there is little incentive for the private service providers to change. We suggest policy makers investigate efficient means of ensuring that an adequate level of supply is available when needed, through tax incentives, direct investment, etc.

3. Traffic networks are vulnerable, as all traffic lights fail during a blackout. Installing LED lights with backup batteries would reduce congestion in the event of a blackout, and save the city in terms of annual electricity and maintenance costs. In fact, the LED lights would pay for themselves in fewer than two years. If the city can install LED traffic lights, state or federal funds may be available to cover the incremental cost of installing the backup system.
4. Liquid fuel pipelines and storage tanks rely on electricity to pump fuel and have no backup. Some fuel can be released from storage tanks via gravity flow, but the switchover from pump to gravity flow can be time consuming. So while it is likely that there is a large amount of diesel fuel stored in Pittsburgh at any given time, all of this fuel might not be available in the event of a blackout.
5. An outage during extreme hot or cold weather could have significant health and economic impacts. If the outage occurs during very cold weather, forced air heaters and auto-pilot boilers will likely fail; during hot weather, air conditioners will obviously fail. In either event, some people may be at risk and it is important to ensure that emergency shelters are available and that information regarding such emergency services is disseminated through an effective information campaign. In addition to these health effects, an extended outage during the winter could cause pipes in homes to freeze – putting even more stress on emergency management personnel. While some plans do exist for handling such emergencies, it is important that such plans be regularly reviewed and updated to ensure that the region is well prepared for an extended power outage.
6. The natural gas system is highly reliable; possibly more so than the diesel supply chain. Although natural gas generators are typically more expensive than diesel, natural gas powered backup might be an option worth considering for high value services, especially if the generators are used to produce electricity and heat during normal operating conditions.

In the remainder of this summary, we review important aspects of the analyses carried out in the report.

Funding

We are aware that local public funds for providing improved survivability to critical missions are limited. However it is possible to make significant improvements to the system with limited funding. For example a small surcharge of 0.01 cent/kWh on electricity in the Duquesne light territory would raise approximately $500,000 annually. This would cost the average Pittsburgh household less than two dollars per year, and be sufficient to implement most of the recommendations in this report. In addition, funds may be available through the state of Pennsylvania or the Federal Government from the Department of Homeland Security (DHS). For example, a request could be made to DHS to fund the additional amount required to add backup battery systems for LED traffic lights if the city would pay for the lights. Tax incentives for installing backup of private services may also be considered.

Reference Events

We defined three reference events based on the spatial extent, temporal duration, and likely causes of a blackout scenario in order to accurately study the benefits of the policy options proposed in this report. We used data on outage frequency and duration from Allegheny Power Co. to determine the likelihood and the extent of a relatively low-impact outage, which we consider the first reference event.

The extent and duration of the second reference event, as well its frequency in Pittsburgh, was estimated using the data on “major disturbances and unusual occurrences” collected by the Energy Information Agency (EIA).

For completeness in our analysis, we chose the third reference event such that it would affect all of south-western Pennsylvania (about 4 million people) for two weeks. This would be indicative of a severe weather event or planned attack, as it would affect a large area as well as cause delays in restoration. It is extremely difficult to estimate the future likelihood of such a large area, long duration event. One can roughly estimate this frequency to be of the order once in fifty years based on the historic frequency of major events in the North East such as the 1965 blackout that affected New York and parts of Canada and New England, the 1977 New York blackout, the Quebec Ice storm in 1998, and the 2003 blackout that affected New York, parts of eastern US and Canada. Since the frequency of such events is hard to determine, this probability will be treated as a parameter for several of the analyses in this report. For a given policy, we calculate a “probability threshold for cost-effectiveness” that represents the probability required to make the benefits of the policy exceed its costs.

Table 0.1 – Reference Event Definitions

	Temporal Duration	Spatial Extent	Reference frequency	Likely causes
Ref. Event 1	4 hours	1 circuit (about 1,000 people)	1 in 22 months	Load shedding, weather
Ref. Event 2	2.5 days	400,000 people	1 in 6 years	Weather, disruption of transmission or generation
Ref. Event 3	2 weeks	All of south-western PA	1 in 50-100 years	Weather, terrorism

Assumptions and methodology of the cost benefit analyses of services

In the writing of this report, we employ standard cost-benefit analysis methods to evaluate policy options. Most of the policy options studied for this project pertain to installing backup power for a particular service. In this section we present the common cost and value assumptions used throughout this report.

The majority of the benefit of installing backup power comes from the avoided social costs of a reference event. These costs are function of expected time losses, fatalities, and healthcare service delays resulting from a particular reference event. For the social cost of time lost we use the Pittsburgh average hourly wage of $16 per hour. For the value of avoided fatalities (Value of a Statistical Life) we use $2 million. In order to find the net benefit of a policy, we subtract its capital, operation and maintenance costs from the social benefit. For calculations related to reference event 3, we use the annualized cost and annualized net benefit to calculate the break even probability at which the expected benefit from avoiding the social cost in case of a blackout outweighs the cost of the backup. Thus the following formula applies:

Break Even Probability = Annualized cost of generator / benefit for specific reference event.

We conclude that the policy is worth implementation if the Break Even Probability is significantly less than the estimated probability of the corresponding reference event.

Emergency Services

Emergency Services for the City of Pittsburgh are comprised of hospital systems, police and fire, and 911 emergency call centers. These operations are critical to the health and safety of the people of Pittsburgh. Most of these facilities have thought a lot about operations during a power outage, and have plans and equipment in place to sustain service during a blackout.

Hospitals

UPMC is the largest health care system in Western Pennsylvania. The main UPMC facilities currently have enough backup power generation capacity to remain operational indefinitely during a power outage. This ensures protection against any duration of reference event. UPMC has a secure fuel contract to ensure that its generators can run when needed. Generators are tested monthly, on loads, to ensure proper functionality, and the entire system is tested every six months. The backup systems at UPMC consist of diesel generators with battery ride through. This configuration can operate for several days before refueling. There are separate backup systems associated with each critical center at UPMC.

During the Northeast blackout last summer, a hospital in Cleveland, OH lost power, even though it had backup generators installed. As a result of this incident, UPMC officials are developing a plan of action for updating UPMC's backup power subsystem. As of this writing, UPMC is roughly 50% through implementing their emergency response plan, and has since drafted a set of internal white papers detailing their current emergency power systems.

Police

The police department separates the city into five zone areas, each of which has a station house. Currently, only two of the five zone stations have backup power systems in place. One building runs off a 12.5 kW natural gas generator; the other runs off a 20kW natural gas generator. These natural gas generators are likely to be more reliable than similar diesel generators.

All necessary functions within the stations, such as lighting, radio chargers, computer systems, and telephony, can be operated on backup power. It is crucial that the dedicated telephone line in each station has constant power. The batteries for the police radios are always charged and accessible. They can be charged by the generators if necessary, and the radios in cars charge on car batteries. Handheld radios do not charge in vehicles. They must be plugged into an A/C outlet.

In the event of a blackout, the police department is confident of their ability to remain functional. The stations that currently have backup systems in place can remain fully operational. All departments have access to the National Crime Information Center (NCIC) through radio use, and as such this service is not affected by power outages.

Based on our analysis of the generator system, we recommend that the city install backup generation at the three remaining zone stations. The region covered by the Pittsburgh police department is large. It is essential that police functions remain un-inhibited during an emergency situation such as a wide-spread blackout.

Emergency Operations Center (911)

The Emergency Operations Center provides the means by which the police and fire fighters are alerted to potential risks. The Emergency Operations Center has a backup diesel generator and an

Uninterruptible Power Supply (UPS) System. The UPS supplies the center with power immediately after a power disruption while the generator starts. This system is operated once a month on full load. In the event of an outage, the Emergency Operations Center would be able to function 24 hours a day for seven days before requiring additional diesel fuel.

Public Utilities

We study the survivability and electrical dependence of public utilities in the city of Pittsburgh, specifically focusing on drinking water systems, sewage systems, landline telecommunications, natural gas services, and garbage collection.

Water

The Pittsburgh Water and Sewer Authority is responsible for providing the city of Pittsburgh with clean water for household and business use. Most of the electricity required at the Aspinwall Water Treatment Plant (WTP) is consumed pumping water from the river. From the treatment plant, water is pumped to the three primary reservoirs. About half of the water from the primary reservoirs is delivered directly to homes and businesses. The other half is pumped to a series of smaller reservoirs, tanks, towers, and standpipes around the city. In this report the main reservoirs are referred to as 'primary storage' and the smaller storage facilities as 'secondary storage'.

Pumping into storage facilities is usually activated when water levels in the facility drop below a certain level. Storage facilities are normally kept full, but may drop to 80% in the evenings. Electricity is only needed to pump water into storage facilities. Once water is stored at a high point in a reservoir or a tower it can flow by gravity to any customer located below it.

During the course of this study, we found that immediately following a blackout, water supplies will be unaffected. In the absence of any backup generation, after one day of power outage, as many as 15% of customers could expect to lose water as secondary storage is depleted. All secondary storage is likely to be depleted after three days, leaving 50% of the population without water, increasing the load on primary storage and depleting the first of the primary storage reservoirs within about nine days. The last water storage will be depleted after two weeks.

It may be desirable to backup only secondary pumping, which can ensure full water supply for 7 days everywhere in the city assuming conservation measures can cut consumption by 75%. Secondary pumping would require 7.2 MW, 12,800 gallons per day of diesel and $2.57 million in generator and installation costs.

Current emergency plans include distribution of water by tanker trucks (called water buffalos). Emergency response plans at the city and county level include steps to acquire these trucks from local governments and agencies. With a typical capacity of 2,500 gallons, these trucks would only be practical for providing minimal supplies of water. To provide all 370,000 people in Pittsburgh with an emergency one gallon ration of water per day of water would require 15 trucks working 18 hour days. To provide even 10% of normal drinking water supply would require 240 trucks.

Based on standard fuel consumption and price assumptions for this project, running the treatment plant and Ross Pumping station at normal levels on diesel generator backup would cost about $7,200 per day, with estimated installed generator costs of about $1 million dollars.

Sewage Systems

ALCOSAN is the sewage treatment plant for the City of Pittsburgh and 82 surrounding municipalities, serving 896,500 people in Allegheny County and parts of communities in Washington and Westmoreland Counties. Sewage from residential and commercial buildings flows by gravity through municipal owned pipes to larger pipes owned by the Pittsburgh Sewage and Water Authority, and eventually into the interceptors. The interceptor sewers carry sewage and storm water to the treatment plant where it is pumped into treatment facilities. Finally the treated water is discharged into the Ohio River. The bio-solids resulting from treatment are combusted in an energy recovery facility.

ALCOSAN's average electrical load is 10 MW. There are four on-site generating systems with total energy output of 2.7MW servicing a portion of overall plant electricity requirements.

There are five main pump stations to assist in the delivery of wastewater to the treatment plant. Four are on the Allegheny River and is on the Ohio River. The stations along the Allegheny River are backed up by diesel generator units, while the pump on the Ohio River is not backed up, so it will not operate during an outage, and sewage will be discharged in the river.

We have considered expanding the backup of the sewer treatment plant and of the Corliss pump station on Ohio River. The backup at ALCOSAN would enable the utilization of the sludge cake incinerator, thus reducing sewage discharge during a power outage. The capital costs of such expansion are high. One of the benefits from such backup is expected to be improved human health from reduced sewage discharge. National studies show medical cost associated with the exposure to the sewage-contaminated environment to achieve $4.1 billion per year. It is possible that the benefits of reduced discharge would outweigh the cost of the proposed backup, however this proposal warrants further study.

Telecommunications

Communication is a key service that needs to be provided during an emergency situation. It is important to keep land line communications up and running during a blackout, because many emergency services, like 911 and the hospitals, rely largely on fixed line telephones for communications.

Normal land line telephones are powered at 48V, via multiple-redundant backup power systems at the End Office – thus most phones will continue to operate in a power-failure, although those with newer features that require local power may not operate. The Oakland Verizon Central Office is connected to at least two electricity substations. All equipment in the office and consumer telephones are powered by DC batteries located in the central office. These batteries are continually charged with utility power, so there is no switch-over time or interruptions when the power goes out. The batteries are powered simultaneously by both substations so if one link goes out, the other takes over.

The Central Office has at least 8 hours of battery power. In addition, the Central Office must have at least one backup generator on site. The Oakland Verizon office has two 2500kW generators. On a weekly basis, the Central Office tests the backup system by cutting the utility power and firing up the generators.

Due to the backup systems in place, the land-line phone system survived the 29-hour large-scale Northeast blackout during August 2003. From this, we conclude that land line telecommunications are sufficiently prepared for a power outage of moderate duration.

Natural Gas

Natural gas comprises over 90% of the fuel source used in industrial, commercial, and residential heating in the Pittsburgh metropolitan area, Its survivability during a power outage is therefore critical, especially during the colder winter months. The city of Pittsburgh relies on three major natural gas suppliers for its fuel needs: Equitable, Dominion Peoples, and Columbia. The natural gas is shipped through the pipe system primarily by fluid flow, with pumps powered by natural gas.

The gas infrastructure relies on electricity to power a few gas pumps, and the monitoring equipment at stations. These monitoring stations have natural gas generators on-site. Thus, we feel the natural gas system is well-prepared to deal with any of the reference outages.

Garbage Collection

The city of Pittsburgh uses private contractors to collect garbage from its municipalities, and delivers this refuse to four landfill locations. These landfills are situated to the east, west, and south of the city limits, and are located in the cities of Library, Imperial, Monroeville, and Elizabeth, Pennsylvania. The garbage itself is collected via truck, powered by diesel fuel, and shipped directly to one of these locations. Since garbage collection is undertaken completely on land, this utility requires no direct sources of electricity, and thus is only indirectly dependant on electricity. This service may be indirectly affected by a power loss due to the potential shortage of diesel fuel over the course of a long term blackout; however lack of garbage collection for 2 weeks is unlikely to have large social consequences.

Ground Transportation

In this report we consider the following components of the ground transportation system: traffic lights, public transportation, gas stations, tunnels, river barge travel and rail transport.

Traffic Lights

Traffic lights facilitate the (relatively) efficient movement of vehicles throughout the city. In the event of a power outage, all of the traffic lights in Pittsburgh would go down, causing long delays for motorists and emergency vehicles. In addition, police officers would have to direct traffic at some intersections, diverting a much-needed resource in a time of need.

The extents of delays encountered at intersections depend on when the outage occurs during the day. If the power went out in the late afternoon, when many people are getting ready to leave work, delays would likely be much higher than normal. However, if the power went out in the late evening, when most are home, traffic delays would not be minimal.

We perform a cost-benefit analysis on backing up traffic lights on the Forbes and Fifth Avenues corridor from Squirrel Hill to the Downtown area assuming that the outage occurs during a high-traffic period. This analysis takes into account replacement of halogen traffic lights with LEDs replacements, and installation of Uninterruptible Power Sources (UPS) to power the lights during an outage. Standard UPS backup systems can power traffic lights for approximately eight hours.

Considering the cost of delay to motorists and to emergency vehicles, and the electricity and maintenance savings with LED lights, we find that the benefits of installing LED traffic signals with battery backup systems outweigh the costs.

Public Transportation

Since many will not have access to gasoline to fuel private vehicles during a blackout, we consider buses to be critical infrastructure in the city of Pittsburgh. The main electricity dependence of this service is expected to be diesel pumping. To operate at full capacity, the buses require approximately 9,400 gallons of diesel every day. In the event of an outage, demand for bus service will likely drop, as people might stay home from work or school. However, if the outage persists, the demand might rise again as people begin to need supplies (groceries, pharmaceuticals, etc.).

For security reasons, we were not able to determine the extent to which fuel supply is dependent on electricity, nor were we able to determine the state of backup at Port Authority depots.

Tunnels

A lot of traffic flows through tunnels in Pittsburgh each day. When the electricity goes down, lights in the tunnel go out, as do traffic signals just outside the tunnels. Also, large ventilation fans that prevent carbon monoxide build-up would not function. The movement of cars through the tunnel normally provides ventilation for the tunnel, but if traffic slows, and the fans are not working, traffic must be prevented from traveling through the tunnel. The loss of lights (outside and inside tunnel) would likely cause traffic to slow within the tunnel, exacerbating this effect.

Considering the value of lost time sitting in traffic, and assuming that the loss of tunnel lights would cause delays of approximately 30 minutes/commuter, we found that the benefits of backup generation for the tunnel ventilation systems generally outweigh the costs. This analysis does not include the value of cost of a delay to emergency vehicles traveling into or out of the city. There are alternate routes emergency vehicles can follow, although these routes are considerably longer than traveling through the tunnels.

Gas Stations

Gas stations become more critical to the citizens of Pittsburgh as a blackout endures. Initially, most people can rely on the gas already in the tank. But over time, the demand for gas will grow, as people will want to leave their homes to procure needed items, or to just "get out."

There is little incentive, however, for gas station operators to install generators. The probability of a long outage is sufficiently low that the owner will likely not recover the cost of a back-up generator over its lifetime. Thus, if gas stations were to be made more survivable, the government would likely have to step in. For example, is it feasible to designate a few fueling stations around Pittsburgh as "emergency" gas stations and provide incentive to install backup generators?

Pittsburgh International Airport

Pittsburgh International Airport serves nearly 12 million travelers per year. Currently, the major services that do not get power in the case of a major power outage are as follows:

- People Mover (Tram)
- Jet-ways
- Automated Baggage Equipment
- The Air Mall
- Car Rental Areas
- Baggage X-Ray machines (in some circumstances).

All other services will receive power from two 1.1 MW diesel generators. The airport can function without the services listed above, but delays will occur – estimated at about two hours per flight. These delays result from the increased turnaround time for each flight, due to reduced mobility. Passengers would have to take a bus instead of the tram between the air-side terminal and the land-side building, and would have to walk to the tarmac to board planes via stairs (since the jet-ways would not function). Also, bags which normally travel on automatic conveyors would have to be put on trucks or carts, and check-in time may be reduced due to the X-Ray machine being down.

Our analysis indicates that it would be cost-effective for the airport to install a third back-up generator, especially since there is already a space for it. However, the airport completed an independent cost-benefit analysis and found that installing the generator was not in their economic interest. A major factor in this decision is the fact that since September 11, 2001, the number of air travelers has been reduced.

Private Services

Many socially important services are provided by the private sector. However, unlike the public services discussed above, private services are not funded with public tax money or strictly regulated by government agencies. Normally, decisions regarding electricity outage survivability are made using profit/revenue as the decision criterion, rather than overall social benefit. Intervention from public institutions may be required if this type of service is socially valuable during a blackout, but is not backed up by private service providers. This section will discuss several important private services, and discuss measures to make these missions more survivable.

Grocery Stores

Giant Eagle is the dominant player in the Pittsburgh grocery market, with twelve stores within the city limits. Most have generators to power critical equipment such as emergency lights, but they do not have backup capacity for refrigeration equipment. Pittsburgh has relatively reliable power, and Giant Eagle has decided that large backup is not economically attractive or necessary. On the other hand, Giant Eagle stores in the Cleveland area typically have complete backup capacity, since power there is less reliable.

We estimate that during an extended blackout (reference event 2 or 3), the benefit to consumers of keeping grocery stores is of the order $1.4 million per day. This estimate is based on the valuation of people's willingness to pay for food they otherwise may not be able to purchase during the blackout. This implies that a blackout of two weeks duration would have to occur at least as frequently as once in eighty years in order for the public benefit to outweigh the cost. Policy makers, along with the public, need to determine whether measures should be taken to ensure that grocery stores remain open.

Banking

For security reasons, banks do not provide backup to keep individual branches operating during a blackout. The rationale is such that, for example, if the outage occurred in the winter, the bank would be at risk if people started using the bank as a shelter from the cold. However, both PNC and Citizens report extensive backup capacity at their data and operations centers. This means that customers can continue to do banking, even when there is no power flowing from the grid to the banks' headquarters.

During the two shorter reference events, people can travel to other parts of the city to bank. However, during the third reference event, their access to cash may be limited. All Giant Eagle stores have ATMs in-store. Thus, if the grocery stores are kept running, people will have access to cash via ATMs.

Elevators

Elevators may be considered a critical service, depending on whom or what they are transporting. Clearly, in hospitals elevators are necessary. In retirement homes, where residents may have limited ability to climb stairs, elevators again perform a vital service. The building codes in Pittsburgh stipulate that such buildings must have backup for elevators. Buildings over seven stories high must also provide standby power for elevators. For buildings fewer than seven stories, the decision about whether or not to provide backup is left to the owner of the building. We estimate the cost of installing a small generator to power an elevator to be about $160 per month. Thus, if the building has ten units, rent would increase by about 16 dollars per month, if the costs are spread over all tenants evenly.

Wireless Telecommunications

Unlike land-based phone lines, wireless communications are susceptible to failure in the event of a power outage. During the August 14, 2003 blackout, many people were unable to use their cell phones immediately after the blackout, due to the over-congestion of the wireless network. Also, after about 6 hours time, the battery backups for the cell phone base stations became depleted and the wireless network started breaking down. With the cell phone network dead, calls cannot get through. Of special concern are those calls made by emergency personnel such as police officers, fire-fighters and medical professionals. Since an increasing number of people rely on cell phones as their primary means of communications, we consider wireless communications to be a potentially vital service worthy of study.

We conducted a survey of students at CMU and found that they would be willing to pay, on average $6.00 per minute of calling if the city had been blacked out for four days. If cell stations are to survive an outage longer than six hours, backup generators are required. In a city, cells are very distributed – thus, many generators would be required to back-up cell phone service. This would involve both high capital and maintenance costs. However, the willingness to pay six dollars for a minute of service suggests that cell operators might be able to recover cost through charges levied when a cell station is being powered by the generator.

In addition, there is a possible synergy between elevator-backup and base-station back-up. As we know, cell stations are preferentially installed on tall buildings, and these buildings probably have elevators. If building owners installed generators with a small amount of excess capacity – enough to power a cell station – they may be able to lease part of the generator to a cell phone operator.

Of course, these issues must be reconciled with the fact that many users' cell phones will discharge after about two days. Without power to recharge batteries, base station back-up provides no value. The issue of cell phone survivability deserves to be studied further. How much benefit would consumers get from having the network function for two days instead of four hours after an outage? Perhaps even more importantly, what is the value of calls made by emergency personnel (who may have the means to recharge cell phones) during power outages?

Fuel Supply

As we have seen, the survivability of many critical missions in Pittsburgh depends on a reliable source of diesel fuel. For this reason, we have tried to estimate the Pittsburgh area supply and demand for diesel fuel during an outage.

We expect demand to increase during the second and third reference events. Most services have less than a two-day supply of fuel on-hand. As far as we know, only the land-line telephone service could survive a two-week outage without refueling. Many services have enough fuel on-site to endure an outage of a few hours' duration.

There are two components to the fuel supply. The first is comprised of pipelines that come into the city. Pittsburgh is a hub, where large amount of fuel are stored and distributed by truck and barge. Pumping along this pipeline system is dependant on electricity.

The second component is the distribution within the city to points of need. We are confident that there are enough trucks to supply fuel to all the critical services outlined in this report. However, the pumps that pump fuel from the large storage tanks are vulnerable to electricity outages. We recommend that this issue be studied further to determine if this dependency is acceptable.

Interactions

In order to understand the impact to an individual service of a localized power outage, it is sufficient to study that service in isolation. However, in the case of a sustained blackout, interactions between services become very important. For this section of the project we studied the ways that service failures interact. From our work it is apparent that a coordinated communication system will be essential to the survivability of Pittsburgh services. For example, since blackouts are more likely during extreme weather and most heating, and all cooling requires electricity to operate, there will likely be a high demand for climate controlled emergency shelters during a blackout. Both coordinating and communicating such emergency services will require an intensive effort by public sector employees, such as police officers and emergency personnel, during a blackout.

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