Impacts of Blackouts

The United States has had little experience with blackouts that last more than a few days. The only major blackouts over the past 25 years have been the 1965 Northeast blackout, the 1977 New York City blackout, the August 1988 downtown Seattle blackout, and the 1989 blackout in the Carolinas. Most of what we know is anecdotal evidence, drawn primarily from the well-documented 1965 Northeast and 1977 New York City blackouts. The lessons learned from the recent Hurricane Hugo experience should provide additional information on the impacts of blackouts. This is particularly important in light of the technological changes that have occurred in the last decade-especially the proliferation of computers and automation in all sectors and the advances in telecommunications which require a reliable supply of power.

This chapter provides an overview of costs and reviews the quantitative estimates for both actual and hypothetical outages. The remainder of the chapter discusses the impacts of blackouts on the industrial, commercial, and residential sectors and on essential services and infrastructure.

OVERVIEW OF COSTS OF BLACKOUTS

Blackouts have impacts that are both direct (the interruption of an activity, function, or service that requires electricity) and indirect (due to the interrupted activities or services). Examples of direct impacts include food spoilage, damage to electronic data, and the inoperability of life-support systems in hospitals and homes. Indirect impacts include property losses resulting from arson and looting, overtime payments to police and fire personnel, and potential increases in insurance rates. Direct and indirect impacts can be characterized by whether they are quantifiable in monetary terms (economic impacts); relate to the interruption of leisure or occupational activities (social impacts); or result in organizational, procedural, and other changes in response to blackout conditions (organizational impacts).[1]

Direct impacts can be avoided if the end-user has backup systems, but these have often proved unreliable. Indirect impacts may be partially mitigated through contingency planning, improved communications, customer education, social programs, and other planning approaches.[2]

Estimating the costs of electric power outages is difficult and imprecise because the economic value of electric reliability to different customers is not well-understood. Only recently has much progress been made in developing economic values for reliability, including the development of analytical techniques for measuring or estimating the direct and indirect costs of actual and hypothetical outages.

To estimate costs, utilities and public utility commissions (PUCs) rely on either hypothetical cost analysis or reconstruct the level of economic activity that might have occurred had there been no blackout. Both of these methods have inherent uncertainties, and theoretical models have their own shortcomings. Also, indirect and social costs often cannot be quantified but only enumerated.[3]

Types of Costs

The kinds of costs considered in value of reliability estimations include both short-term outage and long-term coping or adaptive response costs.

The true economic cost of any outage is the opportunity value of profit, earnings, leisure, etc. that would have been produced but for the loss. Therefore, one must ascertain what the lost opportunities were and how they would have been valued by those who suffered the loss. The short-term outage costs are incurred during and shortly afterward, and include product spoilage, lost sales, foregone leisure, and other opportunity costs. Long-term coping costs are incurred when customers invest in equipment to mitigate the effects of a shortfall. Investment in backup generators, for example, is clearly made to mitigate the impact of future outages. Historically, mitigation costs have been relatively insignificant in

[1] William T. Miles, Jane Corwin, and Peter D. Blair, "Cost of power Outages—The 1977 New York City Blackout," paper presented at the IEEE Industrial and Commercial Power System Technical Conference, Seattle, WA, May 14-17, 1979, pp. 65-66.

[2] Ibid.

[3] Ibid., p. 66.

Table 3—Direct and Indirect Costs

Primary electricity user	Direct cost components (costs to household, firm, institution, etc.)	Indirect rests	Remarks
Residential	a. Inconvenience, lost leisure, stress b. Out-of-pocket costs —spoilage -property damage c. Health and safety	a. Costs on other households and firms b. Cancellation of activities c. Looting/vandalism	Indirect costs are a minimal, if not negligible, fraction of total (direct and indirect) costs of a curtailment.
Industrial, commercial, and agricultural firms.	a. Opportunity costs of idle resources —labor —land -capital —profits b. Shutdown and restart costs c. Spoilage and damage d. Health and safety effects	a. Cost on other firms that are supplied by impacted firms (multiplier effect) b. Costs on consumers if impacted firm supplies a final good c. Health and safety-related externalities	Indirect effects are likely to be minimal for most capacity-related interruptions, but can be significant component of total costs for longer duration energy shortfalls.
Infrastructure and public service	a. Opportunity cost of idle resources b. Spoilage and damage	a. Costs to public users of impacted services and institutions b. Health and safety effects c. Potential for social costs stemming from Looting and vandalism	Indirect costs constitute a major portion of total costs of curtailment.

SOURCE: M. Munasinghe and A. Sanghvi, "Reliability of Electricity supply, Outage Costs and Value of Service: An Overview," *The Energy Journal,* vol. 9, 19s8, p. 5.

most parts of the United States due to the high standard of reliability.[4]

Short- and long-term costs may have both direct and indirect elements (see table 3). Direct costs are those suffered by the direct customer, such as spoilage or lost production. Indirect costs include those realized by customers of an impacted firm; they may have to purchase higher cost substitutes, incur additional production costs, or have unrecovered costs. Indirect costs can be several times as large as direct costs because the loss of a single input may retard an entire production process. Other components of indirect costs include the multiplier effect from lost wages and other factors of production[5] and potential social costs stemming from looting and vandalism. Social costs are difficult to quantify and have been generally neglected in estimations. For example, while losses resulting from looting and arson can be identified and assigned dollar values, the secondary or ripple effects often cannot be enumerated. These secondary effects, such as a potential increase in insurance rates, represent long-term and far-reaching economic implications.[6]

Hypothetical Outage Cost Estimates

Numerous analyses have estimated the costs of unserved electricity for various consumer sectors. Most of these are based on survey data from particular utility service areas. They vary substantially among classes of customers and among customers within each class.

Table 4 shows some estimates of the costs of power outages. The more recent estimates, based on survey data, reflect the value of service reliability in terms of the average dollar change in a consumer's monthly bill that would offset a change in service reliability. These estimates cannot be compared directly because of differing methodologies, as-

[4]Frank J. Alessio, Peter Lewin, and Steve G. Parsons, "The Layman's Guide to the Value of Service Reliability to Consurners," in Criterion, Inc., *The Value of Service Reliability to Consumers* (Palo Alto, CA: Electric Power Research Institute, EPRI-EA-4494, May 1986).

[5]Ibid.

[6]Arun P. Sanghvi, ''Economic Costa of Electricity Supply Interruptions: U.S. and Foreign Experience,"in Criterion, Inc., op. cit., footnote4, p. 8-45.

sumptions, economic and demographic mixes, and other conditions.

In general, the consensus among utility analysts is that system outage costs can be valued at something between $1 and $5 per kilowatt-hour (kWh) for the types of outages commonly experienced. However, they vary considerably by type of customer, the condition of the outage, the length of the outage, etc.[7]

Actual Outage Cost Estimates

***The* costs** of the 1977 New York City blackout have been studied more extensively than other outages. (Box C provides a description of the sequence of events that led to the blackout.)

Table 5 summarizes the estimated costs of the blackout. Based on these figures, the direct cost of unserved energy was $0.66/kWh and the indirect cost was $3.45/kWh. For the most part, the costs in table 5 are based on secondary data sources provided by numerous public and private organizations. Significant impacts include losses in securities and banking, restoration costs, and capital equipment for Con Ed,[8] and losses to the small business community. Levels of inconvenience appear to have been substantial. These figures should be considered as lower bounds for the total costs.[9]

Damages from looting and arson totaled around $155 million, or about 50 percent of the total economic costs associated with the blackout. The social impacts were sensitive to the unique circumstances of the event and the socioeconomic conditions, including weather, time-of-day, duration, local income distribution and employment, political climate, and availability of contingency plans.[10]

Economic impacts of the 4-day 1988 Seattle blackout were very sensitive to its timing and duration. For restaurants and stores, the timing of the blackout was particularly bad, covering a regular downtown event—the First Thursday Gallery Walk-and the beginning of the Labor Day weekend. Department and clothing stores also missed out on last-minute school shopping. The Bon Marché ` department store estimated its unrecoverable losses at about $500,000. Restaurants in the area estimated lost business at $10,000 to $45,000 for the 4 days. The costs at one hotel included lost revenues from the 75 percent of reserved guests who went to other

Table 4—Comparison of Cost Estimates for Power Outagesl

Date	Geographic scope	Estimated cost
1971	New York State	$2.17 million/hr[a]
1971	New York City	$2.5 million/hr[a]
1971	United States	$0.60/kWh[b]
1973	New York State	$0.33/kWh[c]
1976	United States	$1lkwhd
1976	United States	$2.68/kWh (industrial) $7.21/ kwh (commercial)
1977	Canada	$15/kW (15-minute outage) $91/kW (1 -hour outage)
1978	New York City	$4.1 Ilkwh
1983[2]	PG&E service area	$14.87 to reduce outages to a minimum[e] -$26.41 to tolerate 1,400 hours additional outages
1983[3]	PG&E service area	$6.72/kWh (one 1-hr outage, summer afternoon)[f] $2,126/kWh (eight 48-hr outages, summerafternoon)
1986[4]	PG&E service area	$1.35/outage/year (momentary)[g] $39/outage/year (12 hrs, winter morning)
1986[5]	PG&E service area	$2.93/kWh (4hrs, winter morning, 3.15 kWh unserved)[h] $14.61/kWh (1 hr, winter evening. 0.75 kwh unserved)

[a]Based on wages paid.
[b]Based on GNP/kWh ratio.
[c]Based on GRP/kWh ratio.
[d]Based on cost-benefit analysis.
presidential, based on market research data.
[f]Commercial, based on survey data. Reflects total direct cost range of $3.51 5to$1,112,092.
[g]Residential, based on customer survey data.
presidential, based on contingent valuation data.

SOURCES:
1 Unless otherwise noted, the material in this table is from William T. Miles, Jane Corwin, and Peter D. Blair, "Cost of Power Outages-The 1977 New York City Blackout," paper presented at the IEEE 1979 Annual Meeting, Seattle, WA, May 14-17, 1979, and sources cited therein.
2Andrew A. Goett, Daniel L. McFadden, and Chi-Keung Woo, "Estimating Household Value of Electrical Service Reliability With Market Research Data." The *Energy Journal*, vol. 9, 1988, p. 105.
3Chi-Keung Woo and Kenneth Train, "The Cost Of Electric Power Interruptions to Commercial Firms," *The Energy Journal*, vol. 9, 1988, p. 161.
4Michael J. Deane, Raymond S. Hartman, and Chi-Keung Woo, "Household Preference for Interruptible Rate Options and the Revealed Value of Service Reliability," *The Energy Journal*, vol. 9, 1988, p. 121.
5Michael J. Deane, Raymond S. Hartman, and Chi-Keung Woo, "Households' Perceived Value of Service Reliability: An Analysis of Contingent Valuation Data," *The Energy Journal*, vol. 9, 1988, p. 135.

[7]Rene H. Males, "Reface: Value of Reliability, the Undefined Issues, " in Criterion, Inc., op. cit., footnote 4, p. viii.

[8]In addition to operating revenue losses of $5.7 million reflecting approximately 84,000 MWh of unserved energy, Con ~'S steps to upgrade system reliability will probably cost more than $65 million.

[9]Miles et al., op. cit., footnote 1,p. 66.

[10]Ibid.

Box C—New York City Blackout

On July 13, 1977, at approximately 9:41 p.m., New York City plunged into total darkness. The blackout was caused by a series of lightning strokes compounded by improperly operating protective devices, **inadequate presentation** of data to system dispatcher, and communication difficulties. These combined factors created conditions that cascaded to the point of total collapse of the Consolidated Edison (Con Ed) system.[1]

On this day, Con Ed was providing approximately 5,860 MW of electricity to its New York City customers over 345- and 138-kV transmission lines and cables. Approximately half of the electricity was being generated by plants located in Brooklyn, Manhattan, Queens, and Staten Island; the remaining load was supplied by Con Ed generators outside the city, and purchased from utilities in upper New York State and Canada. Con Ed also was wheeling 240 MW to the Long Island Lighting Co. (LILCO) and approximately 200 MW of emergency power to the Pennsylvania-Jersey-Maryland Pool.

At 8:37 p.m. lightning hit two 345-kV lines supplying 1,200 MW of electricity from the Indian Point No. 3 and the Bowline and Roseton generating units to the City. The resulting short circuit caused the protective relays, located at the Millwood West and Buchanan South substations, to open the circuit breakers and disconnect the lines. This interrupted the supply (870 MW) from Indian Point No. 3, which then shut down automatically. Isolating the generator at Indian Point No. 3 caused one of the 345-kV transmission lines between Pleasant Valley and Millwood West to increase load above its normal capacity rating (825 MW), although it remained within its long-term emergency rating (860 MW). This caused operators to reduce voltage by 8 percent. The Con Ed system operator requested all generators within the city to increase power production to replace the loss and relieve loading on the 345-kV line. However, by 8:55 p.m. the in-city generation had increased (550 MW) only enough to compensate for the two-thirds of the power lost.

Nineteen minutes later, another bolt of lightning hit with a devastating effect. This bolt hit one of the remaining large, heavily loaded 345-kV lines bringing power to the city. Normally, the strike should have caused relays to temporarily isolate the line for mere moments-just long enough to dissipate the lightning's energy. However, one circuit breaker failed to operate properly, causing other relays to isolate the line entirely. This loss of transmission capacity overloaded remaining lines, resulting in their isolation.

With the now inadequate supply of power, Con Ed had no choice but to shed load, blacking out parts of Westchester County. Simultaneously, LILCO's spinning reserves automatically increased output. However, the cables connecting LILCO and Con Ed were overloaded as a result, and LILCO disconnected itself from Con Ed, eliminating a further source of power.

At 9:27 p.m., still another lightning bolt struck a power line. When this happened, the remaining Con Ed generators could not maintain the load and were shut off automatically. At the same time, Public Service Electric & Gas Co. disconnected from the Con Ed system severing Con Ed's remaining ties to the north. At approximately 9:41 p.m. the 1977 New York City blackout began.

Full power was restored in about 25 hours. Many protective circuit breakers had to be individually examined and reset. The city was powered up one section at a time, carefully balancing the added loads with supply, as described in chapter 5.

1Systems Control, Inc., *Impact Assessment of the 1977 New York City Blackout,* prepared for the U.S. Department of Energy, July 1978, p. 13.

hotels, plus expenses for hiring additional security guards.[11]

One industry that profited from the Seattle blackout had electrical generators for rent. One company received 50 to 60 phone calls for 2 generators; another only had 3 available.[12]

Another actual cost analysis was based on a utility-imposed 25 percent curtailment during peak hours for 25 consecutive days in Key West, Florida in July-August 1978. The Key West system experienced a generating equipment breakdown that reduced electric supply to 80 to 90 percent of peak demand. Total electric shortage impact costs in Key

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11Addy Hatch, "Businesses Assessing Losses From the Blackout," *The Seattle Times,* vol. 111, No. 215, sec. C, p. 4, Sept. 7, 1988.

12Ibid.

Table 5-Cost of the New York City Blackout—1977[a]

Impact areas	Direct ($M)		Indirect ($M)	
Businesses	Food spoilage	$1.0	Small businesses	$155.4
	Wages lost	5.0	Emergency aid	
	Securities industry	15.0	(private sector)	5.0
	Banking industry	13.0		
Government (Non-public services)			Federal Assistance Programs	11.5
			New York State Assistance Program	1.0
Consolidated Edison	Restoration costs	10.0	New capital equipment	
	Overtime payments	2.0	(program and installation)	65.0
Insurance[b]			Federal crime insurance	3.5
			Fire insurance	19.5
			Private property insurance	10.5
Public Health Services			Public hospitals-overtime, emergency room charges	1.5
Other public services	Metropolitan Transportation Authority (MTA) revenue:		MTA vandalism	0.2
			MTA new capital	
	Losses	2.6	equipment required	11.0
	MTA overtime and		Red Cross	0.01
	unearned wages	6.5	Fire Department	
			overtime and damaged equipment	0.5
			Police Department overtime	4.4
			State Courts overtime	0.5
			Prosecution and correction	1.1
Westchester County	Food spoilage	0.25[c]		
	Public services: equipment damage, overtime payments	0.19		
Totals		$55.54		$290.16

[a]Based on aggregate data collected as of May 1,1978.
[b]Overlap with business losses might occur sines some are recovered by insurance.
[c]Looting was included in this estimate but reported to be minimal.
NOTE: These data are derivative, and are neither comprehensive nor definitive
SOURCE: Systems Control, Inc., *Impact Assessment of the 1977 New York City Blackout*, prepared for the U.S. Department of Energy, July 1978, p. 3

West were $2.30 kWh average for all non-residential users. The breakdown is $2.00 to producers (e.g., auto repair, stores, schools), $0.10 to employees (wage loss), and $0.20 to consumers. The cost is approximately 50 times the then $0.05/kWh price of electric power in Key West.[13]

In addition, several empirical studies on user loss from power shortages were conducted. These studies examined two electric power shortages of several hours in San Diego, the Key West curtailment, and natural gas shortages in Alabama, Kentucky, Ohio, and Tennessee. The findings concluded that the extra cost to make up interrupted production comprised 60 percent of the loss to both commercial and industrial users. Unrecovered costs totaled 20 and 30 percent for commercial and industrial users, respectively. The inconvenience from postponing appliance use comprised 36 percent of the cost to residential users.[14]

SECTORAL IMPACTS

Industrial

Many industrial processes are highly sensitive to power disruptions. An interruption of less than 1 second can shut plant equipment down for several hours. Outages can spoil raw materials, work-in-

[13]Jack Faucett Associates, *Analytical Framework for Evaluating Energy and Capacity Shortages* (Palo Alto, CA: Electric Power Research Institute, EPRI-EA-1215, April 1980), vol. 2, pp. 1,5-1.7.

[14]Ernest Mosbaek, "Shortage Costs: Results of Empirical Studies, " in Criterion, Inc., op. cit., footnote 4, pp. 3-3, 3-11.

progress, and finished goods. Spoilage is a significant problem in chemical processes, steel manufacture, food products, and other industries.[15] Blackouts also pose opportunity costs from idle factors of production. Human health and safety effects are another major concern in industrial outages. Not only are the workers exposed to possible injury or health hazard from the power interruption, the neighboring population also could be exposed to risk from hazardous spills or releases due to the loss of environmental or safety equipment.[16]

costs

Industrial-sector costs are more directly measurable in terms of equipment damage, loss of materials, cost of idle resources, and human health and safety effects. Lost output is the primary cost. One approach is to take the classic economic factors of production—land, labor, capital, profit, and entrepreneurship-and identify the value of the foregone opportunities for each of them for various industrial processes. Those opportunities can be evaluated using some measure of excess capacity of each of the factors of production. When all resources are idle (have excess capacity), the opportunity cost is estimated at the value of wages. When all resources are fully employed, the loss includes the value that would have been added in production. One may need to add the costs of spoilage and other damage, long-term adaptive costs, indirect costs, and consumer surplus if final demand is left unserved.

For example, in 1965 Dunlop Tire's Buffalo plant lost 1,700 tires (worth $50,000) when power failed during the critical curing process. The Tonawanda, New York Chevrolet plant had to junk 350 engine blocks because high-speed drills froze while boring piston holes. Ford's huge Mahwah, New Jersey assembly plant had to wait for standby power when Orange & Rockland Utilities, Inc. gave West Point priority because "the cadets need to study tonight. ' '17

Commercial

For many commercial customers, any outage of a duration of more than 1 or 2 seconds has a significant cost due to computer problems, equipment jamming, or ruined product. For these firms a l-hour outage is not substantially more costly than a 10-second outage.

With the increasing pervasiveness of computers and communications systems in all economic activity-commercial sales, offices, industrial process control, finance, communications, public works control, government-their performance in a blackout affects all impact sectors. The major consequences include costs associated with the inability of the computer to perform critical functions, loss of data, and possible damage to the computer and peripheral equipment. Degradation of storage media is a major concern if the room temperature strays too far from the norm.[18] Critical systems usually have backup power sources, although most are not designed for an extended blackout, when the operating environment becomes more of a concern.

An entirely new industry has grownup around the need for backup systems and recovery services for heavily computer-dependent activities. Computer security companies take over computer functions, such as payroll, inventory, and records maintenance, when disasters tempera.riiy or permanently disable corporate computers.[19]

costs

The commercial sector is the most difficult of the three sectors to analyze and has been studied the least. Its boundaries and components are ill-defined, and it incorporates a very wide variety of products and services. In many areas, the commercial sector is the most rapidly growing customer class, and the costs of outages may average the highest.[20]

Some utilities define the commercial sector as what is left over after accounting for residential and large industrial customers. Using this definition, large apartment buildings, small grocers, and moder-

[15] M. Munasinghe and A. Sanghvi, "Reliability of Electricity Supply, Outage Costs and Value of Service: An Overview," *The Energy Journal,* vol. 9, 1988.

[16] Mosbaek, op, cit., fOOtnote 14.

[17] "The Disaster That Wasn't,'' *Time,* NOV. 19, 1965, p. 36.

[18] Systems Control, Inc., "Impact Assessment of the 1977 New York City Blackout' prepared for the U.S. Department of Energy, July 1978, p. 46.

[19] Tyson Greer, "Weyerhaeuser Division Waits for Data Disasters," *Puget Sound Business Journal,* vol. 9, No. 21, sec. 2, p. 5A, Oct. 3, 1988.

[20] Sanghvi, op. cit., footnote 6, p. *-26.

ate-sized manufacturing firms would all fall in the commercial class. Another classification is based on SIC (Standards of Industrial Classification) codes. Still others are based on peak demand levels, a kWh rule, or the voltage of service.[21]

For those parts of the commercial sector where the principal activity is production that can be made up after an outage without substantial cost (e.g., laundries, drycleaners, bakeries, etc.), the idle resource cost approach used in the industrial sector probably is most appropriate. At the other extreme, large apartment buildings can be viewed as a concentration of households, and analyzed using one of the residential-sector outage cost methods.[22]

Between these two extremes are commercial establishments that sell products and those that provide services. The potential for product damage and the ability to makeup lost production are critical here. Food stores and warehouses, for example, can have significant spoilage costs. Similarly, fast-food outlets not only can have high spoilage costs, but also service immediate demand and usually cannot make up lost business.[23]

Agriculture

An Ontario Hydro survey conducted between 1976 and 1979 indicates there can be significant hazards to livestock and produce during a blackout. Sensitive processes include incubation, milking, pumping, heating, air-conditioning, and refrigeration. Of the larger-than-average farms included in the survey, 26 percent had standby generation. About 60 percent had facilities to shut off a portion of their load in an emergency.[24] In 1965, farmers deprived of power for their milking machines hooked them up to generators operated by tractor motors.[25]

Residential

Never are Americans more aware of their dependence on electricity and the machines it drives than during a blackout. Without electricity, air-conditioning is off, and many people do not have heat or hot water. In high-rise buildings, people must use stairwells. Senior citizens and the disabled are at an extreme disadvantage in outages. Consumers do not have lights, refrigerators and freezers, stoves and microwave ovens, toasters, dishwashers, intercoms, televisions, clocks, home computers, elevators and escalators, doorbells, hair dryers, heated blankets, can openers, food processors, carving knives, toothbrushes, razors, and garage door openers. With the advent of high-tech electronics, most people have battery-operated radios or TVs, but few keep enough batteries on hand to last more than a few hours.

If a blackout occurs during the winter, as did the 1965 outage, those with yards or balconies can put food outside. In the 1989 summer blackout in Washington, DC, PEPCO distributed dry ice. For those with fireplaces or barbecues, cooking is still possible; others must resort to cold food or restaurants. Illness from food spoilage can be a significant problem.

One of the more sociologically interesting impacts of the 1965 outage was the fact that without access to their normal forms of entertainment, people turned to each other; 9 months after the blackout, the birthrate increased from 50 to 200 percent at New York hospitals.[26]

costs

Electricity permits activities whose value varies with time of day, week, or year. The short-term opportunity cost is the degree of disruption of the household's preferred consumption pattern. Some activities, such as cleaning, can be deferred without significant loss (and in many cases might be considered an emotional benefit). Others can be deferred or relocated (e.g., washing clothes, eating dinner). Still others can only be relocated (e.g., watching a particular TV program). At some times of the day/year and/or for particular groups, there can be health and safety implications (e.g., lack of heat/AC, elevators, life-support systems, hot water, and refrigeration). Costs also vary by household income, type of appliance stock, preferred leisure activities, and other household characteristics.

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21 Ibid.

22 Ibid.

23 Ibid.

24 Len Skott, "Ontario Hydro Surveys on Power System Reliability: Summary of Customer Viewpoints," in Criterion, Inc., op. cit., footnote 4.

25 "The Disaster That Wasn't," op. cit., footnote 17.

26 "Blackout Fallout," *Time*, Aug. 19, 1966, p. 40.

In addition to deferring or relocating activities, households may experience out-of-pocket expenses for mitigating responses such as using block or dry ice to preserve food, firewood for heat or cooking, candles and batteries for lighting, batteries for radio/television, etc.[27]

Two equivalent measures of loss are the dollar amount the household would accept as compensation for the disrupted consumption pattern, and the amount the household would be willing to pay not to have its preferred consumption pattern disrupted.

Transportation

A blackout affects virtually every mode of transportation (box D). Subways, elevators, and escalators stop running, and corridor and stairwell lights usually are out. Street traffic becomes snarled without traffic lights. Gasoline pumps do not work, and the availability of taxis and buses declines over time. Parking lot gates and toll booths will not operate. Pedestrians are perhaps the least affected, although their danger increases without traffic signals and after dark with the loss of street lighting. Trains can still function, but doing so can prove hazardous without signal lights. Airports are powered by auxiliary generators that enable aircraft to land and take off in an emergency. However, considerable delays can be expected. In high-density areas where most people are dependent on public transportation, economic and other impacts are increased by the inability to get to work. Other transportation effects result from the inability to deliver goods.

Telecommunications

There is a growing reliance on telecommunications networks in all sectors of the U.S. economy. Businesses and government depend on reliable communications to perform routine tasks. Also, businesses are using their communications systems and the information stored in them to achieve a competitive advantage and to restructure their organizations on a regional or global basis. Thus, the failure of a communications system can lead not only to market losses but also to the failure of the business itself.[28]

The functioning of all crucial municipal public services, such as police, fire, etc., will also depend on telecommunications. A recent study by the National Research Council noted that our public communications networks are becoming increasingly vulnerable to widespread damage from natural disasters or malicious attacks.[29]

Extended power outages can affect telecommunications networks and lead to economic disruption. The extent of the disruption will depend on whether telecommunications networks, both public and private, have emergency backup power systems and how reliable the backup systems are. Today, many networks have their own dedicated emergency backup system. The importance of backup power systems was evidenced during Hurricane Hugo and the recent San Francisco earthquake. At the height of Hurricane Hugo, 39 central offices and 450 digital loop carrier facilities were operating on backup power. Southern Bell indicated that the facilities could operate on battery power for about 8 to 10 hours before gas or diesel generators take over.[30] With the commercial power turned off in San Francisco because of the risk of free, central offices operated on diesel generators. These diesel generators could operate for up to 7 days, according to PacBell. The earthquake did little damage to the network.[31]

In an emergency, commercial satellites could also be used to augment or restore a public network. Currently, only the American Telephone & Telegraph Co.'s interexchange carrier network is augmented by the Commercial Satellite Interconnectivity program, which uses surviving C-band commercial satellite resources.[32]

The impact of a disruption will depend on how crucial communications equipment is to a particular

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27 Sanghvi, op. cit., footnote 6.

28 U.S. Congress, Office of Technology Assessment, *Critical Connections: Communication for the Future*, OTA-CIT-407 (Washington, DC: U.S. Government Printing Office, January 1990).

29 National Research Council, *Growing Vulnerability of the Public Switched Networks: Implications for National Security Emergency Preparedness* (Washington, DC: National Academy Press, 1989).

30 *Telephony*, "Survival of the Network,'' Oct. 23, 1989, p. 42, and "Hugo No Match for So. Bell," Sept. 25, 1989, p. 3.

31 ''PacBell Network Survives Quake,' *Telephony*, Oct. 23, 1989, p. 14.

32 Ibid., p. 18.

Box D—Transportation Impacts—Northeast and New York City Blackouts

The 1965 Northeast blackout occurred at 5:30 p.m.—a peak period for most modes of transportation-and lasted for up to 13 hours. The worst potential hazard was in the air, where at peak hours between 5:00 and 9:00 p.m. some 200 planes from all over the world were headed to New York's Kennedy Airport. Logan Airport in Boston, as well as numerous smaller airports, also were blacked out. Inbound flights lost visual contact as the ground lights went out. Luckily, it was a clear night, and pilots could seethe other planes over the darkened cities. Planes bound for New York were diverted as close as Newark and as far as Cleveland and Bermuda. Philadelphia received 40 NY-bound airliners carrying some 4,500 passengers. Kennedy was shut down for 12 hours.[1]

In 1965,630 subway trains in transit ground to a halt, trapping 800,000 passengers. Under the East River, 350 passengers had to slog to safety through mud, water, and rats. In the middle of the Williamsburg Bridge, 1,700 passengers were suspended in two trains swaying in the wind. It took police 5 hours to help everyone across a precarious 1 l-inch wide catwalk running 35 feet from the tracks to the bridge's roadway. A total of 2,000 trapped passengers preferred to wait it out, including 60 who spent 14 hours in a stalled train under the East River.[2]

Thousands of people were trapped in stalled elevators. In at least three skyscrapers, rescue workers had to break through walls to get to elevator shafts and release 75 passengers. Elevator failure resulted in the only two deaths attributable to the 1965 blackout: one person fell down a flight of stairs and hit his head, and another died of a heart attack after climbing 10 flights of stairs.[3]

Traffic lights failed and main arteries snarled. At unlighted intersections, countless volunteers took over the job of directing traffic. Hundreds of drivers ran out of gas as they waited for traffic to clear, only to find that service station pumps cannot work without electricity.[4]

In 1977, the New York airports were ordered closed at 9:57 p.m. on July 13, only minutes after the power failure. At Kennedy, 108 airline operations were scheduled between 9:00 p.m. and midnight July 13; 37 operated before the airport was closed. LaGuardia had scheduled a shutdown at midnight July 13 for runway construction, and disruption was much less significant (39 of 60 scheduled operations). Newark Airport handled 32 diverted aircraft from Kennedy and LaGuardia. Auxiliary generators supplied emergency power to the terminals, in which more than 15,000 passengers remained through the night. At Kennedy International Airport, some power returned at 3:30 a.m. on July 14, but the first authorized takeoff was not until 5:34 a.m. At both Kennedy and LaGuardia, parking lot gates and payment systems were out, and parking area employees computed fees manually. This resulted in severe traffic jams and long delays.[5]

The subway system fared a little better in 1977. The blackout occurred around 9:40 p.m., after most commuters were home. Also, the storm activity and brownouts offered some warning. Dispatchers running the subway system noticed power surges on the line before the blackout and radioed motormen to go to the nearest station and remain there.[6] Thus, only seven trains in the entire system were in transit when the power went off. Emergency evacuation problems were most severe for a train stuck on the Manhattan Bridge. Even buses could not run the next day, however, because of the unavailability of fuel from electric pumps. Moreover, Grand Central Terminal was forced to close when drainage pumps lost power. Even after power was restored, flooded converters prevented electrically powered trains from using the station during the morning rush-hour on July 15, thus delaying about 75,000 daily commuters.[7]

The train stations in New York City halted operations during the 1977 blackout. The main inter-urban train line, AMTRAK, stopped service from the south in Newark. Going north, AMTRAK provided buses to New Haven, where trains from Boston turned around. Conrail trains serving Trenton, New Brunswick, and South Amboy experienced delays up to several hours.[8]

After the 1977 blackout, the Metropolitan Transportation Authority initiated an$11 million program to install new equipment to ensure against massive disruption of the transit system in the event of a future blackout.[9]

1 "The Disaster That Wasn't," *Time, Nov.* 19, 1965, p. 36.

2 Ibid.

3 Ibid.

4 Ibid.

5 Systems Control, Inc., *Impact Assessment of the 1977 New York City Blackout,* prepared for DOE, July 1978, pp. 16, 89-$@.

6 Alan McGowan, "The New York Blackout," *Environment, vol.* 19, No. 6, August/September 1977, p. 48.

7 Systems Control, Inc., op. cit., footnote 5.

8 Ibid.

9 Ibid.

industry/business. Medium- and large-size businesses that use integrated information systems to link operational processes—i.e., order entry, scheduling, etc.—will experience economic damage shortly after a power failure. While many business use a number of interconnected networks, supplied by a variety of sources (including local area networks and private and public networks), most private networks depend on public networks for transmission and switching capabilities. The Federal Government, for example, uses a number of private networks to communicate within a particular department or agency, but uses public networks to communicate outside.[33]

OTA has found that, in general, businesses have been slow to prepare for emergencies or adopt security measures, often postponing action until after a problem has occurred. One major reason cited is cost. Moreover, the value of communication security has to be traded off not only against cost, but also against system access and interoperability .[34]

Emergency Services

Emergency services include police and fire and their communications and transport, as well as hospitals. Power outages can also affect these services. All hospitals have emergency power systems to support the most critical activities, such as operating rooms, intensive-care units, emergency services, etc. Depending on the facility, auxiliary power systems may not be able to support some other activities, including x-ray, air-conditioning, refrigeration, elevators, etc. Moreover, technical problems may arise with the auxiliary generators, as evidenced in the 1977 New York blackout. In some instances, hospitals had difficulty bringing generators on-line, and were faced with generators overheating and inoperable transfer switches for connecting loads to emergency circuits.

Fire-fighting and police communications could be severely disrupted by the loss of power. Fire alarm systems may be inoperable and fire-fighting maybe hampered in those areas where some power is required for pumping water.

Moreover, the indirect impacts of a blackout, such as looting and arson, can severely strain fire-fighting and police services. For example, during the New York City blackout, 70,680 calls were made to911, compared with the 17,700 made in a normal 24-hour period. Also, during the 1977 blackout, there were 1,037 fires (primarily arson) with over 6 large-scale frees, requiring 5 companies. More than 80 injuries were reported due to the abnormal fire activity. Exhaustion was common due to the high heat and humidity and the lack of food supplies and rest areas.[35]

Public Utilities and Services

Public utilities include electric, water, gas, sewage, garbage, and related services (e.g., public health inspection).

Water supply systems generally rely on gravity to move water from reservoirs through the mains and to maintain pressure throughout the system. Some power may be required at pumping stations and reservoirs. Loss of pressure in mains hampers free-fighting and hospitals, and may permit contaminants to seep into the water supply. Typical system pressure will supply buildings up to five or six stories tall. High-rise buildings use electric pumps to provide adequate supply on upper stories, or have roof tanks with 24- to 48-hour storage capacity. If electric pumps in high-rise buildings do not work, residents would have to go without water or get it from neighbors below.[36]

Electricity is needed in treatment and pumping of sewage. An outage at a treatment plant causes raw sewage to bypass the treatment process and flow into the waterways. Lack of pumping station power prevents sewage flow and ultimately causes a backup at the lowest points of input (usually basements in low-lying areas). During the 1977 New York City blackout, many of the sewage treatment plants and pumping stations in Westchester County and New York City had standby power supplies, but only for short durations. After the standby power was exhausted, untreated sewage flowed continu-

[33] 1bid., pp. 82-84.

[34] Office of Technology Assessment, op. cit., footnote 28, ch. 10.

[35] Systems Control, Inc., op. cit., footnote 18.

[36] Ibid.

ously into the harbors. Signs were posted on all neighboring beaches prohibiting use.[37]

costs

Outage costs attributable to essential services and infrastructure, including street and traffic lights, public transport, telecommunications, hospitals, airports, sewage and sanitation, fire and police protection, etc., are difficult to measure. For many of the essential functions, backup emergency generation already exists, although it maybe unreliable or only designed to be operated for a few hours at a time. For some infrastructure services, the cost of installing standby generation should provide a reasonable order-of-magnitude estimate of outage costs. However, the costs of public transportation and lighting outages are more difficult to estimate.[38]

In a blackout, electric utilities have revenue losses from unserved energy, expenses for equipment and overtime personnel to restore power, plus any capital investments needed to ensure that particular type of blackout does not occur again.[39]

Consolidated Edison suffered more than bad press in 1977. In addition to operating revenue losses from 84,000 MWh of unserved energy, and the cost of restoring power, Con Ed had to make capital and other investments (e.g., operator training programs) to upgrade system reliability .40 Moreover, Con Ed stock experienced increased trading on July 14, and closed at its lowest value for some time. The stock had a closing loss of 1.25 at the end of a week that had begun with increasing values.[41]

Following the 1965 blackout, utilities across the country changed their operating procedures and made capital investments in relays and circuit breakers to ensure that no single failure would again result in a cascading outage. (See ch. 4.)

[37] Ibid.
[38] Sanghvi, op. cit., footnote 6.
[39] "The Diaster That Wasn't," op. cit., footnote 17.
[40] Miles et al., op. cit., footnote 1.
[41] Systems Control, Inc., op. cit., footnote 18.