Inter-Infrastructure Simulations across Telecom, Power, and Emergency Services

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Abstract – **Critical national infrastructures for power, emergency services, finance, and other basic industries rely heavily on information and telecommunications networks (voice, data, Internet) to provide services and conduct business. While these networks tend to be highly reliable, outages do occur which can have cascading effects to other infrastructures. This paper describes a dynamic simulation model of a power outage which cascades to impact telecom for services without power back-up, which cascades to impact emergency services 911 calling, which causes increased severity of injuries.**

Index Terms – reliability, dynamic simulation, emergency services.

I. Introduction

This paper describes a collaboration across infrastructures and the System Dynamics simulator models to support that collaboration. The simulation models are implemented using Vensim [3], which can be used for dynamic simulation of other industry infrastructures [1]. Previous efforts have included the N-SMART Voice [2] metro area PSTN discrete event, call-by-call, simulation model. This more detailed model drives the aggregated systems dynamics representations presented here in the higher level models across infrastructures.

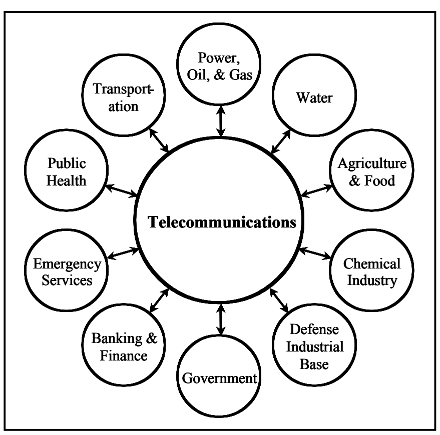

Figure 1 - Pairwise Inter-Infrastructures

The critical national infrastructures are shown on Figure 1. We have telecommunications depicted at the center since it is critical to all the others. Around the circle are critical infrastructures for power, transportation, water, agriculture, emergency services, and the others.

What's new here is that we are no longer taking a smokestack approach to industries, that is, each within their own perview. But rather, we are taking them in pairs to look at the cascading of impacts between industries.

In the next section we make this general discussion more specific. That is, we simulate three infrastructures (Power, Telecom, and Emergency Services) together in relation to a specific problem that might be encountered in the future. In particular, power blackouts may cause loss of telephone service for those without power back-up, which then impacts the ability of people to call 911 in emergency service situations. The resulting impact is that regular injuries become major injuries, and major injuries could become fatal.

II. Power, Telecom and Emergency Services

Figure 2 shows the potential cascading of events across infrastructures.

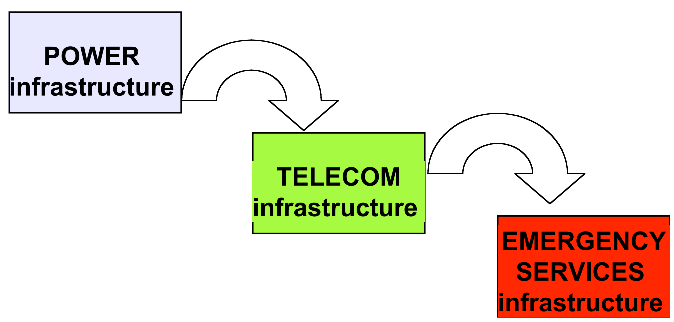

Figure 2 - Cascading of Impacts across infrastructures

A. Inter-Infrastructure Vulnerability: Power and Telecom (Today's situation)

Today, there is very little cascading of impacts due to a power blackout. Most people still have wireline phones that continue to work during a blackout. Why? Central offices have back-up batteries and/or emergency diesel generators to power the telephone lines during a blackout. Hence, people have access to emergency services (police, fire, medical) even during a blackout.

B. Inter-Infrastructure Vulnerability: Power and Telecom (A future situation)

It is a fact that more and more people are moving to situations where their phones won't work in the event of a blackout. These situations include:

1. People with only cordless phones, which need power to operate.
2. People with wireless only service. It is estimated that about 4% of households in 2004 have wireless only service, i.e., no wireline service. This is expected to grow rapidly because of the economic incentive to do so. [4]
3. People with voice over cable telephony service. The cable modems need power to operate.
4. People with other VoIP arrangements where back-up power is not provided.

Where a telephone service has back-up power, we use the terminology "power lifeline". When it does not, we say "no power lifeline." It is possible for each of the above 4 categories to have power lifeline, but it is typically not provided.

As an example, category 2 on wireless only service is affected only after several hours of blackout. Cell towers typically depend on battery back-up (~4 hours). Hence, a power disruption (blackout) lasting longer than 4 hours would eliminate telephone service for all those "wireless only" access arrangements. Figure 3 shows a plot of a potential future for wireless only service. By 2010, as many as 20-25% of households may use services with no power lifeline [4][5].

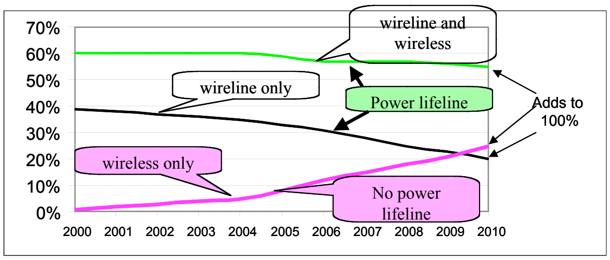

Figure 3 - Forecast of Wireless only Households

III. TELECOM MODEL - EXAMPLE VENSIM MODEL OF AGGREGATE WIRELINE + WIRELESS NETWORK

This section describes a model and uses it as the basis for our aggregate wireline and wireless network of a metropolitan area of 5 million people.

Let's first review the example inputs representing the metropolitan area of size 5 million

Number of people in the area	5,000,000
Average Call Holding Time (Wireline)	300 seconds
Average Call Holding Time (Wireless)	180 seconds
Busy Hour Calls /line (Wireline or Wireless)	2

An example traffic profile for a day is shown in Figure 4. The traffic profile reflects the time-of-day variation of the traffic over a 24 hour period. Communication networks are designed to handle peak busy hours, which corresponds to the part of the profile that is equal to 1. Busy hours on Figure 4 are 10:00 - 12:00, and 16:00 - 20:00. Outside of the busy hour, the traffic rate is scaled by the factor given by the profile. As can be seen from Figure 4, the traffic rate becomes very small during night hours (only 10% of busy hour).

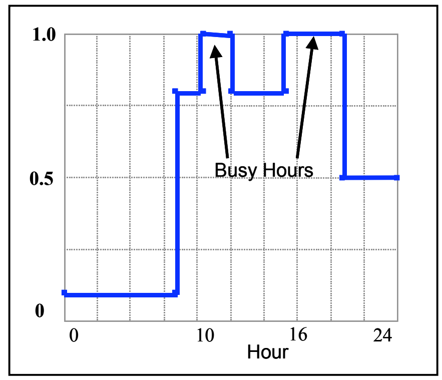

Figure 4 - 24 Hour Example Traffic Profile

The aggregate Vensim Telecom infrastructure model of a metropolitan area is shown on Figure 5. The telecom disrupt indicator variable (a 0 or 1 variable), on the lower right, indicates whether there is a telecom disruption given by the Damage Level variable. The indicator is 0 (no telecom disruption) for this first analysis. A telecom disruption is dealt with later as a sensitivity.

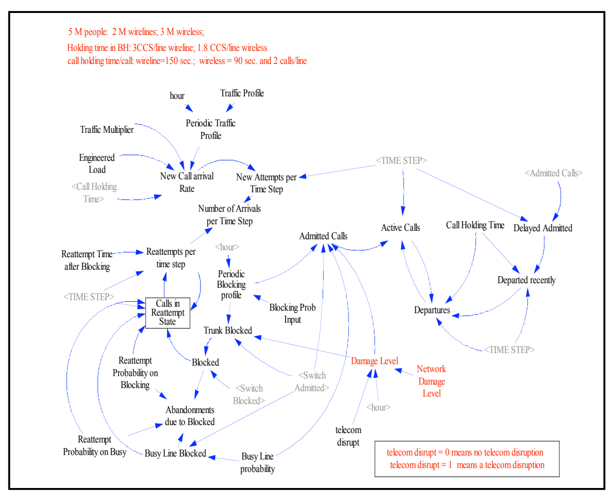

Figure 5 - Network Model

IV. Power Blackout Model

A simple power blackout model is represented in Figure 6. The period under study is 2 days or 48 hours long. Most blackouts last less than this amount of time. There are three parameters:

- start time of blackout (say at hour 4 as in the figure)
- length of blackout (say 34 hours). In our example, this implies recovery starts at hour 38.
- recovery time, that is, length of time after recovery starts that the blackout ends. (4 hours in our example. Hence, the end of the blackout occurs at hour 42.)

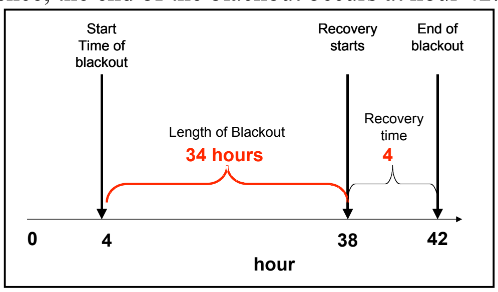

Figure 6 - Timeline model of power blackout

The Vensim model of this blackout model along with the number of wireline and wireless subscribers impacted by the blackout is shown in Figure 7. The left side takes a metropolitan area of say 5 million people, breaks them down in households with wireline and wireless services and eventually ends up with 5 categories of customers

1. wireline only with power lifeline
2. wireline only without power lifeline
3. wireline + wireless with power lifeline
4. wireline + wireless without power lifeline
5. wireless only (assumes without power lifeline)

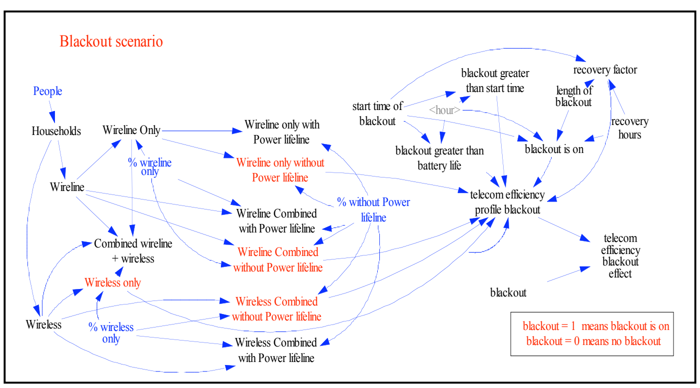

Figure 7 - Vensim Model of Power Blackout

The result of all this is a telecom efficiency function on the right side of Figure 7, explained next.

A. Network Telecom Efficiency under Blackout scenario

Combining the simple blackout model with the forecast of lines throughout the area that are impacted by a power blackout, we get a network telecom efficiency function, which is really a service availability index of customers able to make telephone calls. The blue dashed line on

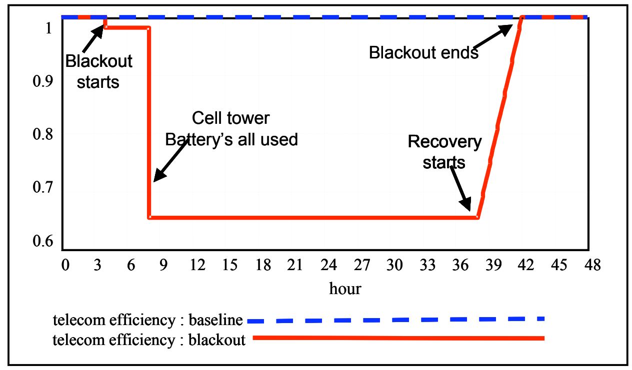

Figure 8 - Network Telecom Efficiency

Figure 8 is the baseline, that is, telecom efficiency = 100% for the whole period. Everyone is able to make telephone calls. The red solid line on Figure 8 is the blackout scenario starting at hour 4 and lasting until hour 42. The blackout starts at hour 4 with a slight dip in telecom efficiency for those wireline only customers without power lifeline. Then it dips significantly at hour 8 after all the cell towers run out of back-up power. We modeled this as an instantaneous drop. In reality, it would be spread out over a few hours as different cell towers blackout because their battery reserves run down. Note that batteries run down as a function of the amount of calling load. So, if there is a spike in demand for cell usage, the cell towers may last significantly less than 4 hours on their battery reserve.

This telecom efficiency function over time will be input into the emergency services model discussed next.

V. Emergency Services Model

Emergency Services consist of police, fire, and medical emergency services. While we could break these down into three buckets and deal with each separately, here we simply bundle them together since they are all accessed by calling 911 in an emergency [6].

Some telecom 911 Facts are included in Table 1. One observes that the number of 911 calls varies widely between areas.

Table 1 - 911 Calling by City

City	Calls per year	Population	calls/person
Washington	1.8 million	563,000	3.2
LosAngeles	5 million	3,694,000	1.4
Baltimore	1.7 million	651,000	2.6

For our generic metropolitan area of 5 million people, we will assume and average 2.5 calls per person per year. This leads to an average of approximately 34,000 calls per day assuming that the calls are uniformly distributed over the 365 days of the year.

Now, two-thirds or 66.6% of 911 calls are non-emergencies. A non-emergency is one in which there is no dispatch of police, fire, or medical services. So, in the end, with our blackout, many of these non-emergency calls won't get through but they have little impact since there was no emergency in the first place.

A. *Injury facts*

In 2003, over 20 million people (~55,000/day) suffered disabling injuries at home, work, in their community, or in transportation [7]. In addition, about 2.4 million people (~6,000 per day) die each year. Deaths by cause and death rates are shown in Table 2. These statistics represent our baseline conditions when the telecom efficiency index is at 100%. All of the following tables are from [7].

Table 2 -DEATHS AND DEATH RATES 2001

Cause	Number of Deaths	Death Rate per 100k population
All Causes	**2,416,425**	**847.6**
Heart disease	700,142	245.6
Cancer (malignant neoplasms)	553,768	194.2
Stroke (cerebrovascular disease)	163,538	57.4
Chronic lower respiratory diseases	123,013	43.1
Unintentional injuries(i.e. accidents)	**101,537**	**35.6**
- Motor-vehicle	43,788	15.4
- Falls	15,019	5.3
- Poisoning	14,078	4.9
- Choking c	4,185	1.5
- Drowning	3,281	1.2
- All other injuries	21,186	7.4
Diabetes mellitus	71,372	25.0
Influenza/pneumonia	62,034	21.8
Alzheimer's disease	53,852	18.9
Nephritis/nephrosis	39,480	13.8
Septicemia	32,238	11.3

Unintentional injury is the preferred term for accidental injury in the public health community.

A disabling injury is defined as one that results in death, some degree of permanent impairment, or renders the injured person unable to effectively perform their regular duties or activities for a full day beyond the day of the injury.

B. *Costs of Unintentional Injuries*

There are two methods commonly used to measure costs. One is the economic cost framework and the other is the comprehensive cost framework.

Economic costs are a measure of the productivity lost and expenses incurred because of injuries. There are five economic cost components: (a) wage and productivity losses, which include wages, fringe benefits, household production, and travel delay; (b) medical expenses, including emergency service costs; (c) administrative expenses, which include the administrative cost of private and public insurance plus police and legal costs; (d) motor-vehicle damage, including the value of damage to property; and (e) uninsured employer costs for crashes involving workers.

The total cost of unintentional injuries in 2003 in the USA was $607.7 billion.
The information below shows the average economic costs in 2003 per death and per injury.

Table 3 -ECONOMIC COSTS per Death or Non-fatal injury, 2003

Death	$1,120,000
Nonfatal Disabling Injury	$45,500
- Incapacitating injury [8] .	$55,500
- Non-incapacitating evident injury	$18,200
- Possible injury .	$10,300

Economic costs, however, should not be used for cost-benefit analysis because they do not reflect what society is willing to pay to prevent a fatality or injury.

Comprehensive costs include not only the economic cost components, but also a measure of the value of lost quality of life associated with the deaths and injuries, that is, what society is willing to pay to prevent them. The values of lost quality of life were obtained through empirical studies of what people actually pay to reduce their safety and health risks, such as through the purchase of air bags or smoke detectors. Comprehensive costs should be used for cost-benefit analysis. Besides the estimated $607.7 billion in economic losses from unintentional injuries in 2003, lost quality of life from those injuries is valued at an additional $1,366.6 billion, making the comprehensive cost $1,974.3 billion in 2003.

C. Assumed Costs for injuries and non-injury related illnesses

The information in Table 4 are the assumed Economic costs we use in our study developed from information in the previous tables. The injury related cost come from Table 3 with the cost per regular injury the average of non-incapacitating evident injury and possible injury. The right side of Table 4 represents the assumed costs for all those causes of illness (e.g., heart attacks) that are not injury related (see Table 2). Since there was no data on these costs, we assumed they were 25% of the injury related costs.

Table 4 - Economic Cost per injury

Injury		Non-injury related illness	
Cost per no injury:	0	Cost per non-injury illness	0
Cost per regular injury:	$14,250	Cost per regular non-injury	$3,562
Cost per major injury:	$55,500	Cost per major non-injury:	$13,875
Cost per fatal injury: (Death)	$1,120,000	Cost per fatal non-injury (Death)	$280,000

VI. VENSIM MODEL OF EMERGENCY SERVICES - 911 CALLS

Figure 9 represents the emergency services Vensim model starting on the left with the telecom efficiency function developed previously in Figure 7 and Figure 8. It starts on the left with the level of 911 calls (i.e., 0.4 calls per second or 120 calls every 5 minutes). This is approximately consistent with the 34,000 calls per day to 911 assumed to be evenly distributed over the 24 hours in a day.

We then divide the calls up into those that get through and those that don't as a function of the telecom efficiency. We next separate out the non-emergencies (66.67%), and then divide the calls into 7 buckets as follows:

- no injuries
- regular injury and regular non-injury illnesses
- major injury and major non-injury illnesses
- fatal injury and fatal non-injury illnesses (death)

The split between injuries and non-injury illnesses (heart attacks, asthma attacks, etc.) is represented by the factor "injury related %". This factor is estimated at 35.5% [7] because

- In 2002 in the USA, there were 38.9 emergency room visits per 100 persons
- Of those 13.8 or 35.5% of those visits were injury related.

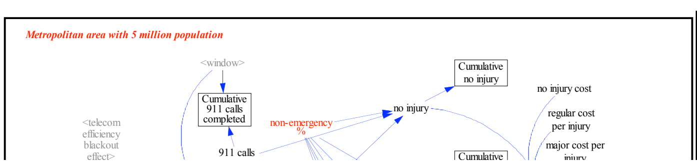

Figure 9 - Emergency Services model

A. Response time for 911 (measured in minutes)

The response time to 911 calls in the USA is amazingly fast for those emergency calls that require dispatch. Note that the non-emergency calls don't require dispatch. The response time is tracked for every call, and a measure of effectiveness is the average response time. A typical example is given by Pinellas County, Florida where it is approximately 5 minutes which is the time from receipt of call to dispatch plus the time to arrive at the scene of the emergency [9]. This is the baseline scenario where all 911 calls are completed through the telecom network. Now all these calls result in either no injury or non-injury illness, regular injury or regular non-injury illness, major injury or major non-injury illness or fatal injury or fatal non-injury illness. The no injury or non-injury illness category is assumed to include all the non-emergency calls (66.6% of all calls). Regular injuries or regular non-injury illness occurs in 70% of the calls, major injuries or major non-injury illness occurs in 29.8% of the calls, and fatal injuries or fatal non-injury illnesses occur in 0.2% of the calls. The major injuries and major non-injury illness (29.8%) and the fatal injury and fatal non-injury illness (0.2%) are approximately consistent with the injury and death facts presently previously.

The blackout scenario forces us to ask the question: What if the potential 911 caller can't get through because their phone is dead? Hence, there can be no emergency service response. We postulate what would happen in Figure 10. We would have changes in the level of injury.

- No injuries category would remain the same
- Most regular injuries remain regular injuries, but some regular injuries would become major injuries
- Most major injuries remain major injuries but some major injuries become worse and even fatal (death)

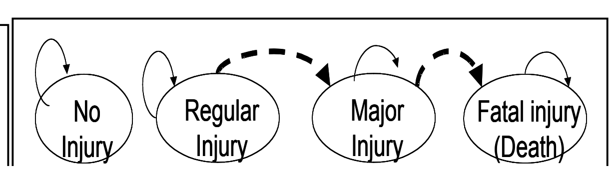

Figure 10 - Changes in injury levels if 911 wasn't available

B. Key Assumptions for our study:

The level of changes to these categories is subject to speculation. In what follows, we have assumed that the fraction of overall regular injuries would go down (to say 44% from 70% in the baseline), since many of those injuries would become major injuries. Major injuries would increase (to 55.6% from 29.8% in the baseline) of the total, and fatal injuries would increase as well (to 0.4% from 0.2% in the baseline) since some of those major injuries would result in fatality. These transition levels require further investigation and drive the results presented next.

We further assume that the same process would work for non-injury related illnesses. They would become more serious or fatal if there was no 911 response.

VII. Summary Results – Injuries and Cost

Combining all of the previous models, the results below show a comparison between the baseline model where telecom and 911 calling is working fine, and the blackout scenario where a significant fraction of the population can't call 911. Figure 11 and Figure 12 show the changes in injury levels and non-injury levels.

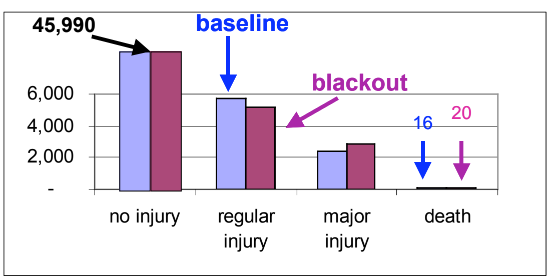

Figure 11 - Number of injuries

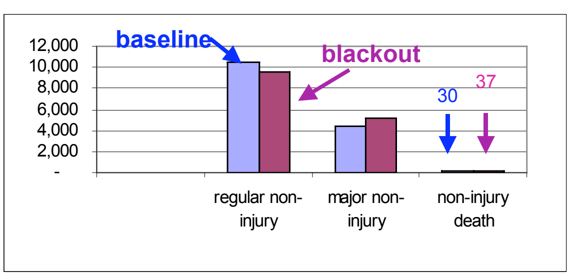

Figure 12 -Number of non-injuries

Figure 13 shows the overall cost results by multiplying the injuries and non-injuries by the cost per injury and cost per non-injury. While the regular injury and non-injury cost goes down somewhat because there are less regular injuries and non-injuries, the major injury and non-injury costs goes up since there is many more of them. In addition, the fatal injury and non-injury (death) category also shows an increase.

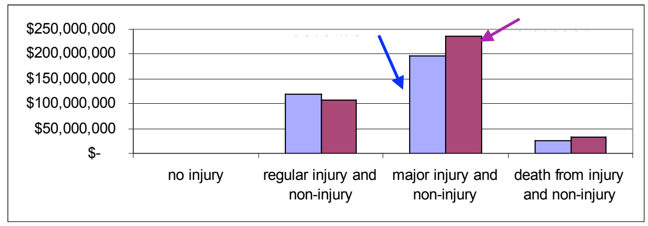

Figure 13 - Cost by level of injury and non-injury

The summary costs for each of the scenarios are shown in

Table 5 - Summary Costs

Baseline Total =	**$342 M**
Blackout Total =	**$378 M**
Incremental Cost =	$ 36 M

The bottom line is that there is a substantial increase in injuries and non-injuries and death with those resulting economic costs. For a blackout lasting approximately 30 hours, for metropolitan area of 5 million people, the incremental economic cost is estimated at $36M. Note that the comprehensive costs to society will be greater, probably by a factor of 3

VIII. Sensitivity Study - Blackout + Telecom Disruption

So far, we have investigated two scenarios:

1. Baseline scenario: no blackout
2. Blackout scenario.

In both of these we assumed there was no simultaneous infrastructure disruption to the telecom network, except for that caused by lack of power. In this sensitivity study, we add a telecom disruption to the whole network lasting from 8 AM to 10 PM of day 1 of our two day period, knocking out 75% of the network capacity.

The additional scenario with both blackout and telecom disruption reduces the overall telecom efficiency to very low levels during the periods of blackout and telecom disruption. Hence very few 911 calls get through during this period. This results in more major injuries and major non-injury and more fatal injury and non-injuries. Table 6 shows the summary costs. The costs are increased to $63M over baseline, almost double that of the blackout only scenario.

Table 6 - Summary Costs

Baseline Total =	**$342 M**
Blackout and Telecom Disruption Total =	**$405 M**
Incremental Cost =	$ 63 M

IX. Possible Future Work

There are a number of important areas to continue this research:

- Investigate additional reference sources for both economic costs and comprehensive costs of injuries and non-injuries.
- Investigate the rate of change in injuries as a function of 911 response time due to all sources of emergency: police/fire/emergency medical services.
- Investigate new power blackout scenarios, and additional simultaneous disruption scenarios, coupling power blackouts with major telecom disruptions.
- Investigate the total cost as a function of the length of the power blackout.
- Investigate the general business costs of a power blackout resulting in loss of telecommunications services. In some industries, for example, airline reservations, this has been estimated at $1M per hour. The general business costs should be much larger in our example than for the emergency services infrastructure. For example, the August 14, 2003 blackout affected 50 million people. It lasted up to 4 days in various parts of USA and Canada. Its estimated costs were between $4B and $10B [10]. Using our 38 hour blackout, effecting 5 million people, this would translate to an impact of between $160M and $400M.
- Investigate possible access to 911 during a blackout. It depends on several factors. Wireline phones (with power lifeline) will still work. A wireless only person (whose phone is out) may have access to someone else's wireline phone if available. What's the probability of availability of a wireline phone in an emergency? There will be some delay in getting access to that working wireline phone (i.e. run to a neighbors house, or use a business line nearby).
- What mitigation is possible to guarantee access to 911? Battery backup for 24 hours at cell sites at high load, or diesel generators installed at all cell sites. (But cell phones will still lose their charge after some time and usage.) Very inexpensive wireline lifeline service (i.e., stays up during a blackout), so people would opt to keep it. What is the cost of mitigation?

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