Development of a Dynamic Scenario Model for the Interaction of Critical Infrastructures

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By failing to prepare, you are preparing to fail.–Benjamin Franklin

ABSTRACT

This paper summarizes the development of a Cross Impact and Interpretive Structural Model of the interactions of 16 critical infrastructures during disasters. It is based on the estimates of seven professionals in Emergency Management areas and was conducted as an online survey and Delphi Process. We describe the process used and the current results, indicating some of the disagreements in the estimates. The initial results indicate some very interesting impacts of events on one another, resulting in the clustering of events into mini-scenarios.

Keywords

Cross impact Analysis, critical infrastructure, Interpretive Structural Modeling, Collaborative Modeling, Delphi Method, Scenario Planning and Training, Emergency Management

INTRODUCTION AND LITERATURE REVIEW

"Critical infrastructure" (CI) refers to those utilities and processes that are necessary for the normal functioning of a society or organization. They are systems and services, whether physical or virtual, which are vital. In the human body, if vital organs such as the heart or lungs or brain stop functioning, death will follow unless they are restarted (e.g., by administering CPR). Likewise, especially in modern societies, people are no longer self-sufficient when it comes to needs such as energy (few can cut down a tree to provide heat), water (few have wells) or transportation (few have a horse or can travel without open highways). In New Zealand, the term "lifeline utilities" is used instead of CI, embodying the analogy of society to a biological system.

Often, CI is defined by illustration of examples, and there are many different lists of what constitutes CI. For instance the U.S. includes agriculture (food), water, public health facilities such as hospitals, defense industrial base, telecommunications, energy, transportation, banking and finance, chemicals and hazardous materials, and postal-type delivery and shipping (White House, 2003). The European Commission (2005) listed the following sectors: energy, information and communication technologies (ICT), water, food, health, financial, public & legal order and safety, civil administration, transport, chemical and nuclear industry, and space and research (Labaka, 2013). Thus, what exactly constitutes CI will vary from one nation, culture, or time to another.

Egan (2007) suggests that infrastructure elements are critical if they provide functions essential for routine system function; no rapid substitutes exist; sudden stoppage causes widespread and non-trivial harm; and they are embedded in a much larger, integrated system. This latter point is extremely important for studies of CI; they are currently very interdependent. For example, during the Canadian electrical blackout of 2008 caused by an ice storm, the transportation section was severely affected: gas stations were unable to pump fuel, the airports became low on fuel, and railways were shut down because signals did not work (Chang, McDaniels, Mikawoz, and Peterson, 2007). Boin and McConnell (2007) provide the example of Katrina, when, via the CNN news network, much of the world watched "in horror" the breakdown of emergency services, energy, communication, transport, medical facilities, sanitation, water and food networks.

These are examples of "cascading effects," a "system of systems" in which the failure of one CI sooner or later leads to the failure of others. The complexity of these systems and their tight coupling mean that relatively small disturbances at one site may rapidly spread and escalate into large scale catastrophes with long term consequences (Turner, 1978; Perrow, 1999). Rinaldi (2004) specifies four types of interdependencies. Interdependencies may occur because the state of one CI is *physically* dependent upon inputs from another CI; e.g.., water plants need power in order to run the pumps. Secondly, there may be a *cyber* dependence, whereby a CI's state depends on information transmitted through the communications infrastructure. For example, most emergency response organizations depend upon communications systems for gathering information and dispatching responders. *Geographic* dependency relates to co-location whereby a local environmental change affects all other CIs in the region. For example, a flood may disable electricity generation, transport, the ability of hospitals and first responders to help victims, etc. Finally, what Rinaldi (2004) refers to as "logical" interdependence relates to social and political processes. The state of a CI may depend on another CI because of policy, legal, regulatory, or similar mechanisms and procedures. For example, the U.S. power grid is inter-connected with the Canadian power grid through international agreement.

Sarriegi, Sveen, Torres, and Gonzalez (2008, p. 238) presented several key ideas about these interdependencies that were one of the sources used in developing this research project:

- There is a need to understand CIs as interdependent elements of a complex system.
- Ever-increasing interdependencies create new complexity.
- Crises in CIs are dynamically complex due to the existence of significant time delays.
- Knowledge about CIs is fragmented and resides within many different stakeholders that need to be identified and brought together.
- There is a need for modeling techniques that can unite the fragmented CI knowledge.

There is a very comprehensive review of the literature in a recent thesis (Labaka, 2013). It is one of the few attempts to try to model the interaction between different Critical Infrastructures and obtain viewpoints relative to the consequences of time span of interruptions. CIs are controlled by very different organizations, this makes it very difficult to seriously treat or handle their interdependencies in disaster situations let alone mitigation resulting potential problems (Turner, 1976)

DESCRIPTION OF THE PROCESS USED IN THIS STUDY

After our review of the literature on Critical Infrastructures, it was quite clear that there were differences in what are considered to be CIs. We collected what we felt were sixteen separate infrastructures that are critical to both the response period and the near term recovery period in order to bring back services necessary for normal life and property preservation. This did not include such things as research, which is classified as a CI in at least one European Union report (2005).

We decided it would be ideal to build a dynamic scenario model using our recent work in the merger of Cross Impact Analysis (CIA) and Interpretive Structural Modeling (ISM) (Turoff 1972; Bañuls, and Turoff 2011, Bañuls, Turoff, and Hiltz 2013). This is a collaborative modeling process and we decided to use a set of very negative events, where for each CI the event is the worst possible outcome - a complete breakdown in the structure or availability of service. Seven academicians and EM practitioners participated, drawn from professional contacts on several continents, who were identified as having expertise in the area of critical infrastructures and emergency management. In the process of collecting data, the participants were asked to assume that, with certainty, one of the negative event set did not occur (e.g. a service is now available or a negative condition has become positive) and then to estimate the impact of that good outcome on the outcome (probability) of all of the other CI negative events.

So, for example, a negative CI event such as: "water supply is undrinkable" becomes the assumption "there is adequate drinkable water," for the water infrastructure estimates of the impacts on the other negative events. We then asked the expert participants to indicate whether the initial probability of .5 (zero point of probability with no evidence for the outcome) of all the other (negative) events changes (or not) based upon this assumption. This focuses their attention and estimation on how a positive (good) event causes an improvement in any of the negative events by reducing the probability from .5 to a lower value. We are assuming that the positive (good) version of a bad event being true does not make any of the other bad events more probable. The study is an example of a Delphi process (Linstone and Turoff, 2012). It allows a group of professionals to asynchronously develop a collaborative model of a complex situation.

For the 16 infrastructure failure events we presented, this process requires 16 x 15 = 240 estimates by each expert to complete all assessments. For some of the estimates the assessment will be that there will be no change in the initial probability value of .5 if there is no impact of the new assumption on the negative event being considered. In our pilot trials, we estimated that the time to do this for one participant was approximately one and a half hours. We developed a website giving the information and instructions as well as a short explanation of what we are doing. If invited experts then agreed to participate, we gave them access to an online summary of the events and to the estimation instrument, on Survey Monkey®. We gave them a commitment to maintain confidentiality and follow procedures approved by a university IRB. We also have promised them that they may decide after seeing our final report if they want their name and affiliation to be published as contributors to the model. We clarified the descriptions of the events below, without changing the meaning, based upon feedback from the respondents. Due to lack of space, only the modified version is shown. This present paper is based upon these first seven sets of estimates. The initial 16 negative outcomes for each CI are as follows:

1. **Fires underway:** There are major fires out of control.
2. **Water supply undrinkable:** The normal water supply is contaminated.
3. **Electrical Energy cutoff:** Electricity is unavailable except for too few portable generators.
4. **Natural Gas supply unusable:** Natural Gas is unavailable; Leaks exist in the system. Tanks of compressed gas are in very short supply.
5. **Sewage untreated:** The sewage system is not functional and has backed up in places.
6. **No Gasoline:** There is no significant store of gasoline for emergency vehicles or public vehicles.
7. **No Airports:** There are no functional local airports.
8. **Emergency Responders lacking:** Trained Emergency Responders are in short supply; Many have chosen to help their families; this includes local government and utility maintenance personnel.
9. **Problem/Hazardous Materials:** Chemical Plants, locations of hazardous materials, and contaminants are unsecured and could develop further leakages.
10. **No Medical Service:** Hospitals and clinics cannot fully function; Medical supplies and prescriptions are unobtainable; there is no air rescue functioning; Inadequate maintenance and supplies for ambulances.
11. **No Information and Command System (ICS):** The Internet is not functioning. The local emergency center is cut off from most networked sources. There is no single list and map of all critical facilities in the area; the command center is understaffed and key people are missing.
12. **Community Response Lacking:** Community organizations have not been able to organize to aid response. There are few public shelters. Citizen volunteers are very few in number.
13. **Road Network clogged:** A majority of the roads is not serviceable; Solid waste and construction debris is excessive and blocking roads and rescue attempts; Government Public works and construction companies have not been able to respond to the situation nor coordinate their activities; Public transportation has shut down; some roads have become parking lots.
14. **Public Communications in difficulty:** Public Communication is unreliable; Emergency communications are not fully functional; Cell towers are out of backup energy supplies; Incompatible communication equipment in use among many different response organizations
15. **Local Government not functioning:** Local governments in the area of the disaster are not able to fully function and key people cannot be reached. No security (police, firemen, public services).
16. **Private sources not supportive:** Food shortages are occurring; People are raiding stores for supplies; There is no agreement with supermarkets, hardware stores, etc. to provide needed materials and substances; Homes, on the average, have only a few days of food and liquids; Private organizations are not contributing to the response to this disaster.

For each assumption (the 16 positive outcomes that were the reverse of the negative events), we offered the participants to assess the impacts of that assumption on the other 15 negative events or skip that section of the survey and move on to the next assumption. For each positive assumption they chose to assess the impacts of, we gave the following choices:

1. Make "no judgment" if you feel uncertain about the relationship between the two events.
2. Check off keeping the initial value of .5 if you feel there is no real interaction between these two events.
3. If you feel the positive assumption will reduce the probability from .5 to a lower value please choose from .4, .3, .2, .1, or .01 as a new probability value for this condition.

There is in the above set of choices the possibility of a disagreement among the group. If one or more persons chooses number 2 above and one or more persons chooses number 3 above, this is clearly an inconsistent or disagreement choice for that interaction of two CIs. One group is saying there is no interaction between the two CIs and the other is saying there is. Out of the 240 possible relationships there was some degree of disagreement for 185 relationships. Out of those only 73 relationships did not have a clear majority view. This is discussed further after Figure 2 and it is shown they do not affect the major findings.

While we asked the subjects to assess the impact of an adverse event not happening on the probabilities of the other 15 adverse events happening, through our analysis technique we are able to determine the relationships between any two adverse events both happening. We use a Bayesian relationship (Bañuls and Turoff, 2011) to average the probabilities for each relationship, for all the probability choices from .5 down to .01. This makes the result much stronger than the average value so that a large number of respondents are likely to reduce the effect of a disagreement if a general consensus occurs. We will also in the future look at some of the arguments that can be made about the specific disagreements by asking the total group to participate in further qualitative inputs relative to them. The Bayesian relationship was developed by Norm Dalkey (1975).

RESULTS

Analysis of the first seven sets of expert estimations in the cross impact structure results in the basic cross impact matrix of the C(i, j), the cross impact factors (See Table 1) expressing the linear influence of event j (columns in the matrix) upon event i (rows in the matrix). If we look at the first event row, "fires underway" we see that event 8 (the assumption that there is a lack of emergency responders) with C(1, 8)= 1.76 has the strongest influence interaction of any event on "fires underway". Also j = 13 (clogged roads) is the second most important with C(1, 13) = 1.70. These negative events are having a strong influence on raising the probability of the other negative events. In fact, all the C(i, j) in this table are positive because there are no "good" events in our original set.

	Events by Number (i.j)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	P(i)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
1	Fires underway	OVP	0.00	1.04	1.30	0.00	0.41	1.46	1.76	0.88	0.20	1.20	1.60	1.70	0.34	1.04	0.20
2	Water supply undrinkable	0.00	OVP	0.66	0.00	1.72	0.00	0.00	1.38	3.11	0.41	1.20	1.43	1.04	0.00	1.20	0.54
3	Electrical Energy cutoff	2.30	0.00	OVP	2.60	0.90	0.83	2.66	1.20	0.72	0.90	1.53	1.92	1.04	2.55	2.72	0.00
4	Natural Gas supply unusable	1.76	0.00	2.31	OVP	0.20	2.42	1.85	1.20	1.20	1.10	1.20	1.60	1.38	0.00	1.20	0.20
5	Sewage untreated	0.34	4.51	0.66	0.00	OVP	0.72	0.00	1.54	0.85	0.00	1.30	1.60	1.20	0.00	1.20	0.00
6	No gasoline	1.89	0.00	0.50	3.22	0.20	OVP	1.19	1.04	0.72	0.90	1.04	1.43	1.20	0.00	1.20	0.20
7	Airports closed	0.74	2.30	1.93	1.43	0.20	1.39	OVP	1.04	0.32	0.20	1.37	1.43	1.54	0.16	1.54	0.41
8	Emergency Responders lacking	1.60	0.69	1.04	0.16	1.12	0.68	3.99	OVP	1.04	1.71	2.31	2.67	1.54	0.66	2.31	0.90
9	Significant problem materials	2.03	2.92	0.32	0.41	2.48	0.41	0.00	1.37	OVP	0.00	1.30	1.60	1.20	0.34	1.20	0.20
10	Medical Problems	2.01	0.90	0.49	0.41	1.81	0.50	0.27	3.14	0.34	OVP	1.22	1.50	1.20	0.16	1.76	0.83
11	No information and command system	1.44	2.30	1.93	0.16	0.20	0.49	1.46	1.92	0.00	0.69	OVP	1.93	1.20	3.06	1.70	1.10
12	Community Response Lacking	1.15	1.30	0.88	0.41	0.90	0.32	1.74	2.81	1.43	1.52	2.47	OVP	1.53	1.93	2.47	3.19
13	Road Network clogged	1.89	0.90	0.61	1.37	1.10	1.22	1.19	2.24	0.00	0.90	1.38	1.71	OVP	0.00	0.83	0.42
14	Public Communications in difficulty	1.61	0.00	1.54	0.00	0.20	1.20	0.27	2.47	0.16	0.20	2.31	2.42	1.50	OVP	1.93	1.72
15	Local Government not functioning	0.73	1.10	0.88	1.04	0.69	0.32	2.03	2.80	0.00	0.41	2.47	3.35	1.54	1.88	OVP	1.72
16	Private sources not supportive	2.28	2.22	0.32	0.32	0.20	0.32	1.49	2.47	0.88	0.61	1.43	2.15	1.53	0.50	1.54	OVP
	G(i) Sum for each i Total = -140.50	-6.57	-6.35	-10.93	-8.82	-6.96	-7.37	-8.01	-11.21	-7.89	-8.27	-9.80	-12.03	-7.88	-10.76	-12.65	-11.06
	Cjj Sum for each j Total = 281	21.79	19.13	15.13	12.83	11.94	11.23	19.61	28.40	11.65	9.74	23.75	28.33	20.37	11.59	23.87	11.65

Table 1 – Cross Impact Matrix and G vector

"Fires are underway" has a strong impact on “emergency responders lacking” with C(8,1) = 1.60. The two together create a reinforcing cycle where A influences B and B influences A, so that one might as well take those two individual events as one mini-scenario. We also see another cycle where "sewage untreated" influences "water undrinkable" with C(2, 5) = 1.72 and Water undrinkable is influenced by "sewage untreatable" with C(5, 2) = 4.31. This forms another strong mini-scenario. We will see these cycles emerge in the ISM analysis that is shown in Figures 1 and 2 below.

The C values are related to the concept of the "weight of evidence" in probability theory when multiplied by the value of P(j) which is set to an initial value of .5 for all the events. The Gamma variable G(i) represents the impact of the events that have not been specified, which for this problem is probably concerned with the lack of incorporating into the model initial conditions characterizing possible types of disaster also having an initial probability of being true or false. In this model, the sum of the absolute values of Cs is about 2/3 (281) of the total impact factors (421.5) and the absolute value of the Gammas is about 1/3 (140.5). Therefore, the explicit events in this model explain about 2/3 of the impact information and the unspecified events explain about 1/3. We show the sums of Absolute value of the C(i, j) for each j value in the last row. We also show the sum of the Gamma values. The C(i, j) = 0 indicates that no one felt there was an interaction of column event j impacting row event i. Some of the low value C(i, j) might actually result from the disagreement between some of the estimators saying there was not an interaction and some saying there was an interaction.

One can use the equations in (Bañuls & Turoff, 2011) to program a model where users can change one or more initial values of P(i) to see the impacts on the other events. One can scan the row for a particular event and order the events by their absolute value to find the event that has the most impact down to the one that has the lowest. All these C(i, j) factors are positive because we have assumed a negative (bad) event that have an impact to raise the likelihood (higher than .5 probability in this formulation) of any of the other negative events. The C(i, j) factors are leaner measure of influence just as the "weight of evidence" factor are.

The C(i, j)s are the factors that are used in Interpretive Structural Modeling to build a directed graph of influences of the events on one another. For this particular problem the S(i, j) (Table 2) probabilities are of particular interest: S(i, j) = P(i) for C(i, j)= 0. This is then the lowest value possible for P(i) given that another condition is equal to zero. Since these are negative events which we prefer to see have a low probability value, or become zero, we can see the major possible outcome to each different event operation. If we look for the lowest S(i, j) for each i event we find that event 8 going to zero has the greatest impact in reducing six other events: 1, 10, 12, 13, 14, and 15. So "having emergency responders" greatly improves the situation for a significant number of the events. S(i, j) is useful in understanding the power of one event interacting upon another. Note that for event 13 "road network clogged, (column j=13)" this event dropping to zero only reduces the "fires underway, (row i = 1)" to .30 so in this model having the gasoline is less important than roads being unclogged.

	Events by Number (i,j)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	P(i)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
1	Fires underway	OVP	0.50	0.37	0.34	0.50	0.45	0.32	0.29	0.39	0.47	0.35	0.31	0.30	0.46	0.37	0.47
2	Water supply undrinkable	0.50	OVP	0.42	0.50	0.30	0.50	0.50	0.33	0.17	0.45	0.35	0.33	0.37	0.50	0.35	0.43
3	Electrical Energy cutoff	0.24	0.50	OVP	0.21	0.39	0.40	0.21	0.35	0.41	0.39	0.32	0.28	0.37	0.22	0.20	0.50
4	Natural Gas supply unusable	0.29	0.50	0.24	OVP	0.47	0.23	0.28	0.35	0.35	0.37	0.35	0.31	0.33	0.50	0.35	0.47
5	Sewage untreated	0.46	0.09	0.42	0.50	OVP	0.41	0.50	0.32	0.40	0.50	0.34	0.31	0.35	0.50	0.35	0.50
6	No gasoline	0.28	0.50	0.44	0.17	0.47	OVP	0.35	0.37	0.41	0.39	0.37	0.33	0.35	0.50	0.35	0.47
7	Airports closed	0.41	0.24	0.28	0.33	0.47	0.33	OVP	0.37	0.46	0.47	0.34	0.33	0.32	0.48	0.32	0.45
8	Emergency Responders lacking	0.31	0.41	0.37	0.48	0.36	0.42	0.12	OVP	0.37	0.30	0.24	0.21	0.32	0.42	0.24	0.39
9	Significant problem materials	0.27	0.19	0.46	0.45	0.22	0.45	0.50	0.34	OVP	0.50	0.34	0.31	0.35	0.46	0.35	0.47
10	Medical Problems	0.27	0.39	0.44	0.45	0.29	0.44	0.47	0.17	0.46	OVP	0.35	0.32	0.35	0.48	0.29	0.40
11	No information and command system	0.33	0.24	0.28	0.48	0.47	0.44	0.32	0.28	0.50	0.41	OVP	0.28	0.35	0.18	0.30	0.37
12	Community Response Lacking	0.36	0.34	0.39	0.45	0.39	0.46	0.30	0.20	0.33	0.32	0.22	OVP	0.32	0.28	0.22	0.17
13	Road Network clogged	0.28	0.39	0.42	0.34	0.37	0.35	0.35	0.25	0.50	0.39	0.33	0.30	OVP	0.50	0.40	0.45
14	Public Communications in difficulty	0.31	0.50	0.32	0.50	0.47	0.35	0.47	0.22	0.48	0.47	0.24	0.23	0.32	OVP	0.28	0.30
15	Local Government not functioning	0.41	0.37	0.39	0.37	0.41	0.46	0.27	0.20	0.50	0.45	0.22	0.16	0.32	0.28	OVP	0.30
16	Private sources not supportive	0.24	0.25	0.46	0.46	0.47	0.46	0.32	0.22	0.39	0.42	0.33	0.25	0.32	0.44	0.32	OVP

Table 2 – Sij Estimations

Note that for i^{th} event, P(i) = 0 is the positive i^{th} event assumption that we applied to get the original estimates from the participants. So the lower values of S(i, j) are how close the i^{th} event is approaching a good outcome when P(j) is assumed to be 0 or the initial assumption for participants to make their estimations. Our fundamental assumption was that for our set of bad outcome events expressing each of the critical infrastructures, the completely bad outcome of P(i)=1 as an assumption would never improve any of the other bad/negative events.

In the next step we take all absolute values of the C(i, j) and order them from highest to lowest value. We then take the first 10% of them to form a directed graph of the events and use ISM to determine if any internal cycles exist. These represent mini-scenarios and indicate that one can treat the situation by assuming the events in the mini-scenario should be considered to be a single dynamically linked package. Each member event has to occur for the whole set to occur. In Figure 1, we see that there are six events (two physical and four behavioral) in the local area of the disaster that are strongly coupled with the Information and Command System (ICS, event 11). If we want a successful ICS for emergencies than we really need to have success for having Emergency responders (event 8), Community Response (event 12), good Community Communications (event 14) , Functional Local Government (Event 15), and Private Sources being supportive (event 16). If any one of these factors is clearly a failure in a given disaster, then it is likely that all of this set of clustered events will be a failure. All six of these events should be part of a single long term development and mitigation effort before the disaster. Note that at this level of analysis we could find another isolated mini-scenario conformed by three events: water supply undrinkable (event 2), sewage untreated (event 5) and significant problem materials (event 9). Note we are using only 10% of the C(i, j) > 2.31 in Figure 1. We also note other important causal chains; for example having airports can bring in missing emergency responders and aid the government to begin functioning and finally bring electricity back online

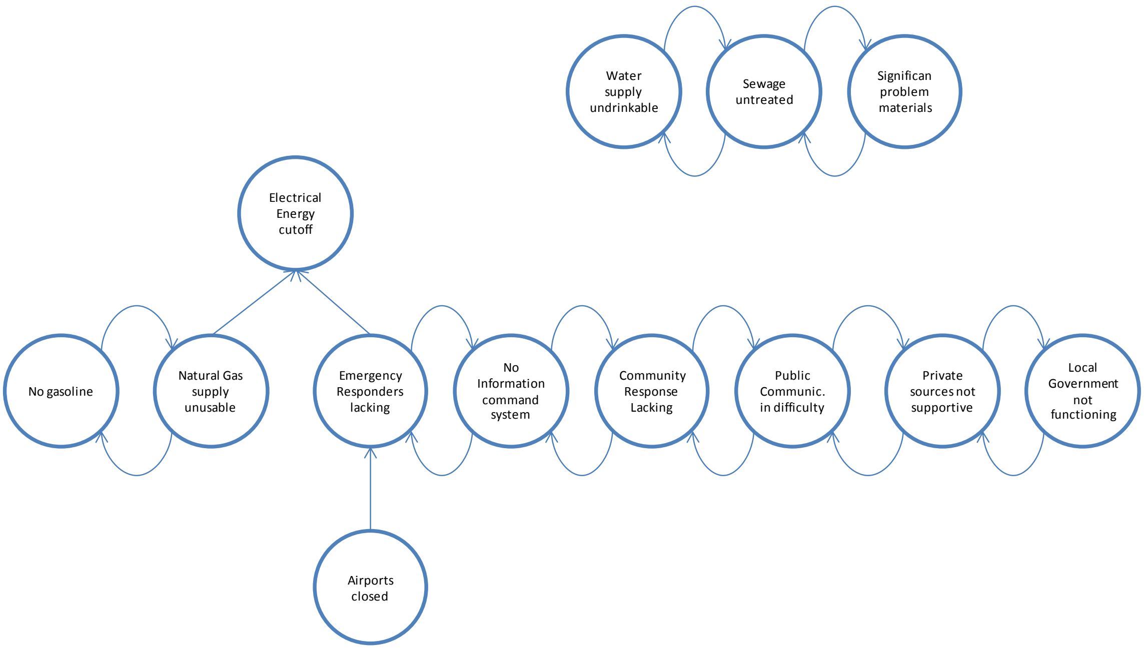

Figure 1 - CIA-ISM Digraph – Cij> 2.31

If we go to adding the cross impact factors to values of C(i, j)>2.0 of the lower value C(i, j)s, we end up with almost everything clustering (Figure 2). We suspect that eliminating some of the disagreements in the estimation process will improve this situation. As we move forward with our series of studies, we will gather more data, including qualitative data, which will refine our understanding of results. We hope to present some of these more in-depth results during our presentation of this paper. We will develop some qualitative information from the participants on the interactions which express current disagreements. It is for that reason that we will stop now at an intermediate value C(i, j)>2. Taking this cutoff value we now have in Figure 2 a third cluster of three events that form another almost intuitive cluster of Critical Infrastructure events: Electrical energy cutoff, No gasoline, and Lack of natural gas. The six event cluster now directly impacts on two events: Road Network Clogged and Medical Delivery Problems. The other causal chain (Significant problem/hazardous materials, water supply undrinkable and untreated sewage) is now connected with the rest of the set of the events.

Turner concluded (1976) that dividing a major problem into smaller "simpler" problems spread among many different organizations is a major cause of poor planning and mitigation, leading to poor response to a major disaster. Figure 2 shows this view is held consciously or unconsciously by a majority of our contributors. There are three clusters of events that should each have a single Emergency Management planning, mitigation, and regulatory organization over all the infrastructures in the cluster.

We will ultimately add to this model initial condition (source) events and outcome events having a probability of being true or false at the beginning and at the end of the response period. These will be integrated into a more complete model with the dynamic set of events we used here (e.g., Banuls, Turoff, & Hiltz, 2013).

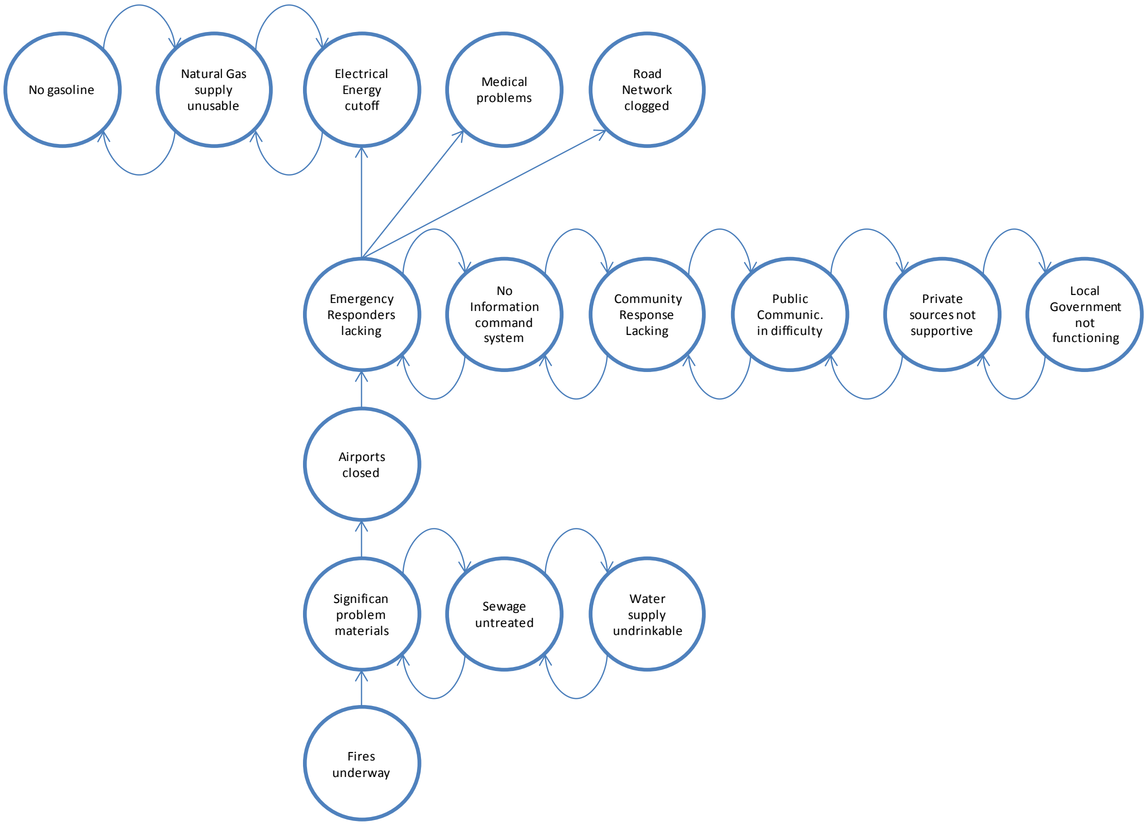

Figure 2 - CIA-ISM Digraph – Cij> 2.

Out of the 240 possible relationships between the 16 critical infrastructure events we found 185 that had some amount of disagreement. Disagreement was obvious when for a given interaction between an assumption of a good outcome interacting with one of the bad assumptions there were some respondents that voted for "no interaction (Probability = .5) and some respondents voted for one or more of the lower values (Probability = .4, .3, .2, .1, or .01). Clearly, it has to be one or the other for there to be no disagreement. For the seven possible responders we consider it a consensus when one of the alternatives received two votes more than the other choice (e.g. 5 to 2 or 4 to 2). There were 112 relationships that satisfied having at least a majority for one of the two choices. There were 73 relationships where there was a tie vote or only a one vote difference between the two options. Table 3 summarizes the distribution of the 240 relationships.

Number of .5 choices	Disagreement (majority/>+1	Conflict (tie/+1)	Consensus	total
0	0	0	29	**29**
1	54	1		**55**
2	21	31		**52**
3	13	40		**53**
4	23	1		**24**
5	1	0		**1**
Unanimous	0	0	26	**26**
total	**112**	**73**	**55**	**240**

Table 3 - Summary of disagreements and conflicts

We consider these serious conflicts (30.4% of 240) which we will be investigating qualitatively with the responders. This left 55 relationships with no disagreement. There were 26 relationships for which all chose no interaction, and 29 interactions without any disagreement. Note that we used only 38 (15.83 of the 240) relationships of the interactions to form the model for figure 2 and they were the largest values in the influence factors. Those 38 were composed of the 29 no disagreements and 9 of the disagreements with the largest majorities. Therefore, Figure 2 is not influenced by any of the real conflicts in the estimation.

In our survey, we also asked the participants to use a comprehensive list of disaster types to indicate to what degree they felt their estimates of the interactions could apply to each disaster type. We were surprised that the participants considered this approach to be appropriate to many disasters. The results are shown in the following table:

Disaster: Very Appropriate Rating (1-1.9)	**Mean**	**Disaster Uncertain (3-3.9)**	**Mean**
Hazardous material incidents	1.83	Wind storms	3.00
		Blizzards	3.00
Disasters Mean Appropriate (2-2.9)	**Mean**	Failure of safety standards in mining	3.00
Failure of technical systems due to complexities	2.00	Railroad accidents	3.00
Collapse of buildings/structures	2.00	State or state-sponsored terrorism	3.00
School shootings	2.00	Explosive weapons of mass destruction	3.00
Human-caused environmental problems	2.17	Biological weapons of mass	3,00
Fires	2.17	Thunderstorm	3.17
Failure of technical systems due to human error	2.20	Tornadoes	3.17
Chemical weapons of mass destruction	2.20	Landslides	3.17
Workplace violence	2.25	Famine	3.20
Nuclear/Radiological weapons of mass	2.25	Medical errors involving nuclear	3.20
Snowstorms	2.33	Highway accidents	3.20
Tropical cyclones	2.40	Maritime accidents	3.20
Nuclear power plant incidents	2.40	Civil disobedience –Labor riots	3.20
Earthquakes	2.50	Hate-crimes	3.25
Floods	2.50	Aviation accidents	3.40
Pandemics	2.60	Heat waves	3.50
Industrial use of nuclear power plant issues	2.60	Civil disobedience – Race riots	3.50
Epidemics	2.67	Civil disobedience—Political riots	3.50
Industrial (factories and refineries) problems	2.67	International non state terrorism	3.50
Volcanoes	2.80	Hailstorms	3.60
Tsunami	2.80	Mining (coal) incidents	3.60
Wildfires	2.80	**Disasters Inappropriate (4.-5.)Very**	**Mean**
Diseases	2.80	Mudflows	4.00
Domestic terrorism	2.80	Sinkholes	4.00
Ice storms	2.83	Overpopulation	4.00
Droughts	2.83	Cold waves	4.20
		Subsidence	4.20
		Avalanches	4.60

Table 4 - Ratings of Appropriateness of different disaster types.

CONCLUSION, LIMITATIONS, AND FUTURE RESEARCH

The results of our effort have provided some significant insights into the interactions among Critical Infrastructures. We have shown that this collaborative modeling methodology is able to allow a group of professionals in Emergency Management to develop a single model exhibiting their collective viewpoints on interactions of Critical Infrastructure conditions. The resulting model of influences appears to be quite rational and able to exhibit significant relationships via scenario clustering among the 16 infrastructure variables treated. It is not surprising to those of us that have worked with collaborative efforts, such as Delphi, that professionals in the same area have different views about relationships in developing complex models. These differences of viewpoint usually do not surface in most reports.

The seven current respondents represented a mix of both academicians and practitioners, with many having experience in both domains. With an average of 11.8 years, the highest average time spent in any practitioner position was that of an EM manager. Our respondents also had an average of 5.71 years of experience as academics (with a minimum of 2 and a maximum of 10). A limitation is the small number of professionals (i.e. 7) who contributed to the collaborative model thus far. We expect to extend this study in the future to explore the reasons for the current disagreements with the current participants and new participants.

In addition, space limitations mean that we could not present the full mathematical and verbal descriptions of our analysis procedures. Those who wish to understand the methodology we are using here should review the following articles: Turoff, 1972; Bañuls, Turoff, and Hiltz 2013, and Bañuls and Turoff, 2011. Most of these papers have qualitative discussions of what is taking place in addition to the underlying mathematical theory. The most recent one presents a more complete disaster scenario model, based on the case of a dirty bomb exploding in urban area. It contains both initial condition events, the dynamic events in a 24 hour period, and the outcome events at the end of the 24 hours.

We will add more participants in the future to be able to get qualitative feedback on the current disagreements from both our current participants and future ones. We will also explore a much larger version that will add initial conditions based upon different types of disasters and add as well outcome variables having to do with potential results such as damages. This would have greatly increased the number of estimates to be made by contributors much above the 240 possible for these 16 events. We can merge these results with disaster types using the data we already have for the overall model.

Another addition that can be made is outcome events which can further refine the situation. This would be a set of events at the end of the response period that would characterize the resulting situation. They would have a probability of being true or false. They are impacted by the initial condition events and the dynamic events but they do not impact each other. One critical consideration is the length of time that a critical infrastructure item is not functioning, and that in turn influences the disaster outcomes like the number of deaths and injuries. One can increase the number of different events. Since the number of estimates needed is proportional to the square of the number of events, one can quickly create a rather large requirement for estimates. That means a growing requirement for participants. We did, and do, encourage participants not to enter estimates for interactions they are not comfortable with or feel they do not adequately understand. This is a standard Delphi practice based upon very early experiments where more accurate results were obtained when only using estimates of those that felt confidence in their answer.

As can be seen from our prior research on collaborative modeling in Emergency Management, we have been engaged in evolving and refining the merger of Cross Impact Analysis and Interpretive Structural modeling. We believe it makes the building of meaningful scenarios in Emergency Management something professionals in the field can use to create dynamic scenarios that apply very well to the particular locations with which they are concerned. The resulting model can be set up as decision aid and allow individuals to adjust the initial .5 probabilities for any of the events to reflect what they believe are the true probabilities of certainty of the events in a particular situation.

Such collaborative modeling exercises can provide for both planning and training of others in the potential consequences of mitigation and investment decisions of expected disasters. If meaningful models are made available to the public, to see the consequences of changing key probabilities, it may well lead to more public support for preparation and mitigation. Having a library of dynamic scenarios that that can be evolved continuously and refined over time becomes the potential core of a continuous planning process for the handling of all potential emergencies in a given area.

Traditionally scenarios have been the basic approach to examine the plans for major and complex strategic organizational decisions such as the acquisition of a company or the launch of a completely new type of product or service. These situations create new uncertainties and therefore it is very difficult to create formal models in a timely fashion (Van Der Heijden, 1996). A scenario for such a process represents the collective wisdom of managers and professionals who have relevant experience and background for arriving at a scenario expressing a consensus about the consequence of the strategic decision. Attempting to assess the consequences of a major disaster on a specific location is another example of the same challenge which also has a similar degree of unpredictable uncertainty.

The problems are amplified because disasters and the behavior of many different organizations and affected social structures are more difficult to model than the interaction in physical situations. Scenarios allow the integration of physical and social behavioral variables. However, our approach allows one to build dynamic scenarios that can allow the exploration of variations in any of the events. Recent work in scenario planning (Marchais-Roubelat and Roubelat, 2011) points out that the usefulness of scenarios is a function of the improvement and usefulness of the scenario and depends on treating scenario planning as a continuous process to improve and enhance the scenario. We have to put scenarios into an "If then" framework to look meaningfully at the future and this is exactly what the methodology we have developed allows.

We will be expanding this model by incorporating the data of the over 20 contributors which we have obtained to date (2/1/14). We will be asking all our contributors, after the analysis, to provide qualitative insights on the reasons for any remaining conflicts in the relationships, many of which we expect will disappear, and to propose source events and outcome events which can be true or false at the beginning of the disaster and at the end of the response period. Once we have extended the model to include source and outcome events, the final model can become the core of an investment game to be able to invest in engineering probability changes in mitigation source events and threat intensity source events, to try to improve outcomes (.Bañuls, Turoff, & Hiltz 2013)

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