Simulation of effective response to earthquake disasters taking infrastructures interdependencies in account

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SUMMARY:

Inadequate coordination among infrastructure systems and among hierarchical decision levels has been a major cause of failures in the response of the systems in emergency situations and it has been responsible for unnecessary losses in human lives, property, and economic activity. This paper presents a general description of recent advances at the University of British Columbia (UBC) in Canada on the development and implementation of an integrated hazard analysis methodology to study interdependencies among critical infrastructures. The UBC group has developed a “system of systems” simulator I2SIM that can model the interactions among infrastructure systems and show how the loss of functionality in each system affects all other infrastructure systems and the overall wellness of the global system. The most recent development is the implementation of a Disaster Response Network Enabled Platform (DRNEP) to enable linkage between organizations with simulation expertise in order to better prepare and respond to large disasters, e.g., earthquakes, flooding anywhere in the world.

Keywords: Infrastructure, Interdependency, Hazard, Networks, Disasters

1. INTRODUCTION

Natural disasters such as earthquakes, tsunamis, forest fires, terrorist attacks and global disease outbreaks can dramatically impact the socio-economic well-being of countries, and in a more serious context, our basic survivability. Recent events have demonstrated the need of fast, dynamic and coordinated action plans to increase the chances of survivability for society. Examples of these include the ice storm in eastern Canada in the winter of 2000; the September 11, 2001 attacks in New York city; the August 14, 2003 power blackout; the catastrophic tsunamis in south Asia in 2004, Chile in 2010 and Japan in 2011, and the 2005 hurricane Katrina in the United States with an estimated 125 billion dollars of economic impact. These events have clearly demonstrated that disaster management and preparedness is a dynamic process that requires a holistic analysis of critical interdependencies among core infrastructures in order to mitigate the impact of extreme events and improve survivability of our society.

Public Safety Canada identifies the following infrastructures as being critical to the nation's safety, security and well-being: Energy and utilities, Finance, Food, Transportation, Government, Communications and information technology, Health care, Water, Safety, and Manufacturing. As the rate and severity of natural and man-made disasters’ have increased, so has the possibility that disruption of Critical Infrastructure (CI) could result in prolonged loss of essential services. The complex system of interdependencies among critical infrastructure has heightened the risks and vulnerabilities for Canada, and for other countries. And hence, the consequences can lead to cascading effects expanding across sectors and borders, (Public Safety Canada, 2008).

The task for Canada and other countries is to establish action plans to guide the identification of risks, the implementation of protective safety measures, and the proper and effective response to disruptions of critical infrastructure. The lessons learned from the Canadian point of view have been compiled in OCIPEP (2002) and some of them are summarized here:

- *Communications*: Predetermined emergency phone lines should have call priority and immediate service attention. This will assist emergency response in crisis. During a crisis, a deployable emergency information management capacity will assist first responders and victims; it will also help mitigate the affliction on government and health infrastructure following a disaster.
- *Transportation*: The ability of transportation infrastructure to sustain normal functions will be jeopardized if sufficient planning and resources are not dedicated to cope with disasters. The interruption of one transportation channel (air) will result in mass usage and delays of alternative transportation channels (marine, rail, roads, etc) and will affect operations involving critical personnel and sensitive materials.
- *Energy*: Communications and business continuity will collapse after the initial impact of a disaster if backup power generation is not provided with guaranteed access to fuel and maintenance. The rapid restoration of power to critical sites will depend on a list identifying and prioritizing sites which are particularly vulnerable to prolonged outages.
- *Banking and finance*: Advanced planning and communication among CIs will minimize the impact of interdependencies on business continuity plans.
- *Government*: The development of a wide alert system with high levels of security and infrastructure redundancy will improve the government's ability to coordinate its response to CI threats. Web portals that post emergency response information will help governments to convey important information to citizens during times of crisis; also emergency communications will assist in dealing with the difficult situations. Rescue services and law enforcement should reach agreements on how to manage the rescue of survivors and restoration of normal city functioning while preserving evidence for criminal investigations.

Infrastructure systems have been in operations since the beginning of the human history without computational simulation. During the last 50 years, some organizations have started to rely on simulation in order to analyze problems and elicit strategies on how to approach situations or how to improve normal operation performance and modeling has been done in disaster simulation. When a disaster occurs, organizations respond according to their own beliefs intentions and desires. And different organizations have different intentions and/or set of goals. An organization that owns or controls an infrastructure (for example, the electrical grid) might want to optimize a set of goals, such as: public safety, or economic objectives, but without knowledge about the propagation of decisions to the rest of the interdependent infrastructures or other infrastructures. For instance, when considering the uncoordinated disaster responses from a) the organization controlling the electrical grid and the response from b) the organization controlling the water distribution systems, it is hard to tell whether the objectives could be best achieved by having a coordinated response. The objectives could be the same, or different with no conflict, e.g. public safety, having a model that allows integrating the effects can help to visualize the effects of the decisions on one infrastructure to the other. The impact on one infrastructure, e.g. oil refining, could conceivably affect the rest of the basic infrastructures since all of them are connected and are dependent on one or another.

2. RESEARCH AT UBC ON INTERDEPENDENCIES OF CRITICAL INFRASTRUCTURE

The ultimate goal of this research is to develop a methodology that helps strengthening the resiliency of critical infrastructure. For the seismic hazard, a Seismic Risk Assessment methodology has been used as a benchmark. This methodology is being used for the identification of interdependencies among critical infrastructure. In this research a "system of systems" would be disassembled in a finite number of physical layers (critical infrastructures), that contain both the Building infrastructure and the Lifeline systems, Figure 1. Risks are estimated separately, and interdependencies are assessed superimposing the layers one by one.

The general objectives of the research are to: 1) improve knowledge on multi hazard risk assessment and apply it to the multi hazard setting and construction practices of British Columbia; 2) improve the methodology by evaluating Lifeline Systems; 3) obtain Interdependency Indices for Critical Infrastructure systems; 4) assess the validity of the methodology through case studies; 5) develop multi hazard scenario cases for a case study in BC; 6) provide documentation on how the risk estimates should be implemented; and 7) implementation of results, assessments, outcomes for the simulator I2SIM.

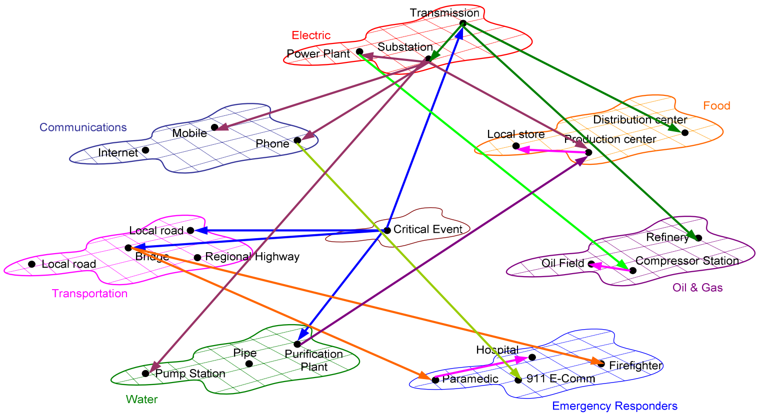


Figure 1. “System of Systems” disassembled in several Physical and Human Layers.

3. THE JOINT INFRASTRUCTURE INTERDEPENDENCIES RESEARCH PROGRAM (JIIRP)

JIIRP was part of an effort by the Government of Canada, through the Natural Sciences and Engineering Research Council (NSERC) and former Public Safety and Emergency Preparedness Canada (PSEPC), now Public Safety Canada, to fund research to develop innovative ways to mitigate large disaster situations. Six universities across Canada were involved. The University of British Columbia (UBC) studied decision making for critical linkage in infrastructure networks. The stated objectives of the JIIRP initiative were to develop knowledge, tools and recommendations to support coordinated decision making among interdependent critical infrastructures. The UBC-JIIRP project was successfully able to assemble a multidisciplinary team of over 24 researchers. Additional information about this project is available at http://www.i2sim.ca and at Ventura, et. Al (2010). The doctoral dissertation by Juarez-Garcia (2010) provides further insight on the methodology developed as part of this project.

The UBC-JIIRP project proceeded on two parallel interlinked investigations. First, an actual local area of study comprising several infrastructures, for example, energy, water, transportation and health services, etc. was modelled. The various vulnerabilities and interdependencies, during emergencies, were identified after discussions with the respective infrastructure operators. Second, in parallel, the UBC-JIIRP team investigated possible metamodels of mutual interdependencies and appropriate simulation methodologies. The teams kept in focus the necessity of ensuring that the modelling/simulation tools should be able to operate seamlessly from the pre-emergency to the recovery phases. The work plan for the entire project was, therefore, divided into four layered sub-investigations, each with an associated set of tasks.

Layer 1: Conceptual Framework for Modelling of Critical Infrastructure Interdependencies
Layer 2: Investigation of Specific Infrastructures
Layer 3: Development of Scientific and Engineering Solutions
Layer 4: Development of Human Resources and Organizational Solutions

Emergency management is a multidisciplinary field and faces many technical challenges, such as lack of a high-level conceptual framework that defines a common context for utilizing decision support methodology and tools, lack of a common technical terminology or vocabulary and lack of semantic coherence. It is, therefore, essential to adopt and develop a common ontological approach, when modelling and simulating complex and diverse systems.

A comprehensive modelling and simulation framework was defined where the main system objective is human survival during the disaster and accelerated business recovery. Human survival is characterized in terms of the system being able to deliver, as fast as possible, the first two levels and part of the third level of Maslow's hierarchy of needs: (1) physiological, (2) safety, and (3) belonging. These needs are characterized in terms of survival tokens that need to be delivered from the places where they are produced or stored (sources) to where they are used by the victims (loads).

It is envisioned that during the emergency management period, infrastructure managers will come together in a disaster-room scenario (virtual or physical room) to coordinate the decisions that affect infrastructure interdependencies. Each manager should be able to visualize his/her own system (which he/she is able to understand in detail) and he/she should be able to have a simplified but meaningful visualization (at a level he/she can understand) of the other infrastructures at the interdependency points. An important tool for this visualization is the availability of Geographical Information Systems (GIS) with feature extraction and simplification. The other tool that should be available in the disaster room is a real-time version of the infrastructures interdependencies simulator (I2Sim). The simulator uses information continuously updated from the developments in the field to resolve the interdependencies. It also allows the disaster-room managers to play "what-if" scenarios in faster-than-real time, so that possible actions can be tested out in the simulator before applying them to the physical system.

Figure 2 shows the case of an Emergency Operations Centre coordinating the management of an emergency in real time. The participating infrastructures (power grid, water grid, and roads) have a human representative (agent) which is in direct contact with the infrastructure's control centre. The infrastructure representatives monitor the developing global situation through visual facilities at the EOC and their own system situation through their interface with their system control centre. Decisions affecting the global system are coordinated among the agents at the EOC and help for these decisions is provided by two modules of I2sim: the intelligent database module (I2DB) for past experiences in dealing with similar situations and by the simulation module I2Sim to "predict" the consequences of suggested actions.

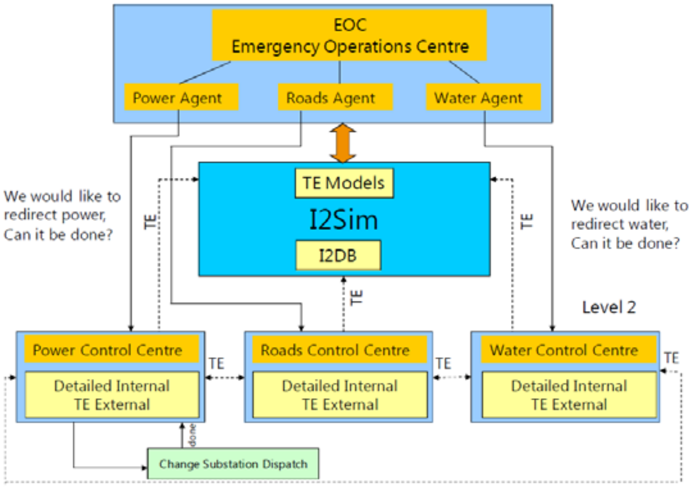


Figure 2. Decision coordination across multiple infrastructures

Different infrastructures use different terminology to model their operations because of their different characteristics. I2SIM uses a common terminology to describe the same types of functions in different environments. There are four key parameters used in I2SIM to model operations of all kinds: cells, channels, tokens and controls. Cells represent functional units and are modeled as input –output units. A hospital is a cell (a production unit) that requires such inputs (tokens) as doctors, nurses, medicines, water and electricity to perform its function of treating patients at an acceptable rate in an emergency. Channels are transportation units for transporting tokens from a source cell to a consumption cell; cables for conducting electricity, pipes for water and transportation links for delivering medical personnel, food and medical supplies. Tokens are the input and outputs of cells such as water, electricity, doctors or phone calls. Controls are distributor or aggregator units. These interface the physical layers of the simulator with the decision making layer to formulate effective response. Damage to the infrastructures during the disaster and greater demand for resources creates a situation where decisions need to be made as to the optimum allocation of the available resources. The simulator supports look-ahead and rewind functions to predict the evolution of the system dynamics in order to assess in real time the effect of suggested decisions before they are actually applied to the real system.

The simulator was initially tested by applying it to the Point Grey Campus of the University of British Columbia. A critical infrastructure on the campus is the University Hospital and the test of I2SIM was to predict the functionality of this hospital after various intensities of earthquake shaking from low to high. For this study, the functionality of the hospital was considered to be controlled by damage to the hospital itself and its contents, and damage to the power and water systems supplying the hospital. Figure 3 shows the loss of functionality of the water system supplying the hospital, due to losses in the four components of the water supply system; reservoir, transmission line, pumping station and distribution line. It is interesting to note that for this case the losses in the reservoir and the pumping station have the greatest effect on the overall loss of water. The pumping station is the most critical asset in this system functionality of the hospital. The effects of damage to the structure of the hospital, the non-structural items and contents on functionality are shown by the dotted red line in Figure 3. Then the integrated effect of the interdependencies between the different infrastructure components is evaluated. The cumulative effects of all contributions to loss of functionality of the hospital are shown by the solid red line in Figure 3. The difference between the solid and dotted red lines shows the cumulative impact of the infrastructure system on the post-earthquake functionality of the hospital.

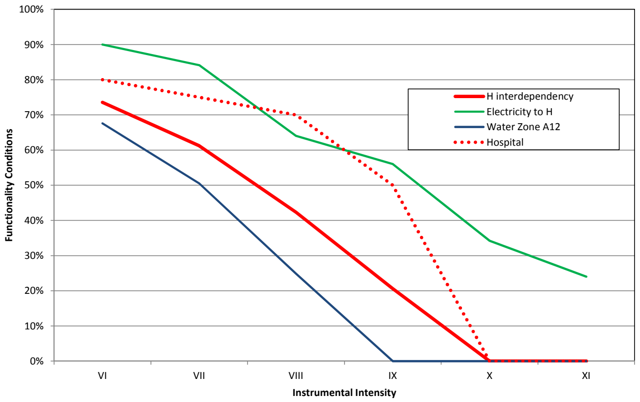


Figure 3. Global Interdependency of the UBC Hospital with water and electrical systems during an earthquake

I2SIM has been used to simulate response to potential disaster events during the 2010 Olympic Games in Vancouver. The scenario was developed in 2009 as follows. The scenario takes place in Downtown Vancouver during the Vancouver Winter Olympic games of 2010. Evolution of events in time:

1. [Time: 00 minutes] An explosion occurs in downtown Murrin Electrical Substation.
2. [Time: 00 minutes] BC Place Emergency Power generator malfunctions. Resulting lack of internal pressure control renders Emergency Exits inoperable.
3. [Time: 05 minutes] A stage collapses on top of spectators in BC Place.
4. [Time: 06 minutes] A multitude starts an uncontrolled egress from BC Place.
5. [Time: 10 minutes] Trapped people and casualties are reported in BC Place after the collapse of the stage.
6. [Time: 19 minutes] Further casualties are reported in BC Place due to egress of spectators.

Objective: Evaluation of the time to assess and stabilize casualties at ERs in different Hospitals of Metro Vancouver, and an estimation of the fatalities due to the delay in treatment of those casualties.

One such event and its aftermath are described below. Only the simulated response to treating casualties is considered here. A controlling factor in formulating response to casualties is the speed of response. Serious injuries must be treated within rather short frame to minimize deaths as illustrated by the mortality chart in Figure 4.

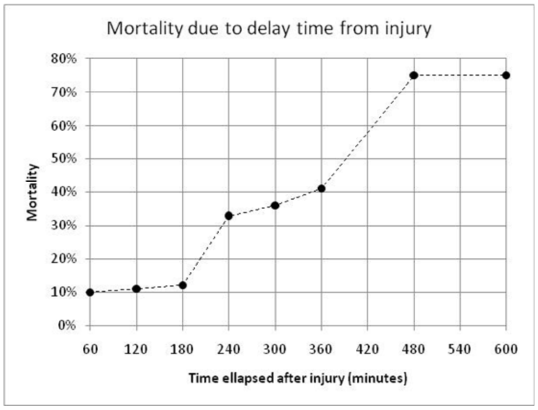


Figure 4. Mortality rates as a function of time to treatment

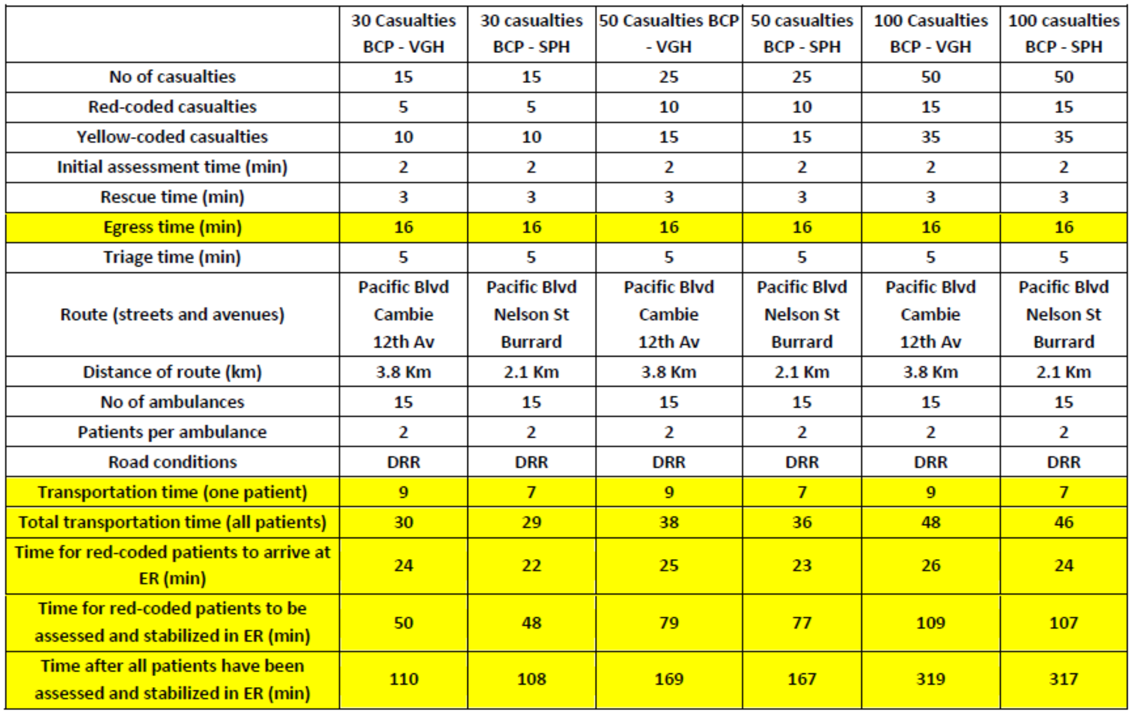
The simulator knows the resources available to move casualties, hospital locations and capacities and can examine travel times by various routes taking into account best current information on conditions along these routes by means of an embedded traffic model. Table 1 shows the results of the simulation for a low number of casualties (<30), while Table 2 shows the corresponding results for a large number of casualties (<864). DRR in the tables designates special reserved Olympic routes.

Table 1. Statistics on handling a small number of casualties (<30)

	Road conditions BCP - VGH (1)	Road conditions BCP - SPH (1)	Road conditions BCP - VGH (2)	Road conditions BCP - SPH (2)	Road conditions BCP - VGH (3)	Road conditions BCP - SPH (3)
No of casualties	15	15	15	15	15	15
Red-coded casualties	5	5	5	5	5	5
Yellow-coded casualties	10	10	10	10	10	10
Initial assessment time (min)	2	2	2	2	2	2
Rescue time (min)	3	3	3	3	3	3
Egress time (min)	16	16	16	16	16	16
Triage time (min)	5	5	5	5	5	5
Route (streets and avenues)	Pacific Blvd Quebec St 2nd Av Laurel St	Smithe St Burrard St	Pacific Blvd Cambie St 12th Av	Pacific Blvd Nelson St	Pacific Blvd Quebec St 2nd Av Laurel St	Smithe St Burrard St
Distance of route (km)	4.4	2.2	3.8	2.1	4.4	2.2
No of ambulances	15	15	15	15	15	15
Patients per ambulance	2	2	2	2	2	2
Road conditions	Normal roads	Normal roads	DRR	DRR	Normal roads No pedestrians	Normal roads No pedestrians
Transportation time (one patient)	21	9	9	7	15	7
Total transportation time (all patients)	42	34	31	31	36	30
Time for red-coded patients to arrive at ER	37	21	24	22	28	21
Time for red-coded patients to be assessed and stabilized in ER	61	49	50	48	56	48
Time after all patients have been assessed and stabilized in ER	121	109	110	108	116	108

The simulator sends all casualties to the two major hospitals, St. Paul's and Vancouver General, which happen to be reasonably close to the BC Stadium. Nonetheless, the time to stabilize all patients is close to the 2 hour limit where mortality rates begin to climb. The output of I2SIM for a large number of casualties (864) in Table 2 shows that the simulator brings in all available hospitals and the time to stabilization of all casualties is measured in hours, not minutes. When time to stabilization becomes so long that mortality rates become serious, the alternative procedures must be invoked such as field hospitals. Realistic simulations can provide clear pictures of potential occurrences and demands and allows the prior organization and preparation of reasonable responses.

Table 2. Statistics on handling a large number of casualties (<864).



	30 Casualties BCP - VGH	30 casualties BCP - SPH	50 Casualties BCP - VGH	50 casualties BCP - SPH	100 Casualties BCP - VGH	100 casualties BCP - SPH
No of casualties	15	15	25	25	50	50
Red-coded casualties	5	5	10	10	15	15
Yellow-coded casualties	10	10	15	15	35	35
Initial assessment time (min)	2	2	2	2	2	2
Rescue time (min)	3	3	3	3	3	3
Egress time (min)	16	16	16	16	16	16
Triage time (min)	5	5	5	5	5	5
Route (streets and avenues)	Pacific Blvd Cambie 12th Av	Pacific Blvd Nelson St Burrard	Pacific Blvd Cambie 12th Av	Pacific Blvd Nelson St Burrard	Pacific Blvd Cambie 12th Av	Pacific Blvd Nelson St Burrard
Distance of route (km)	3.8 Km	2.1 Km	3.8 Km	2.1 Km	3.8 Km	2.1 Km
No of ambulances	15	15	15	15	15	15
Patients per ambulance	2	2	2	2	2	2
Road conditions	DRR	DRR	DRR	DRR	DRR	DRR
Transportation time (one patient)	9	7	9	7	9	7
Total transportation time (all patients)	30	29	38	36	48	46
Time for red-coded patients to arrive at ER (min)	24	22	25	23	26	24
Time for red-coded patients to be assessed and stabilized in ER (min)	50	48	79	77	109	107
Time after all patients have been assessed and stabilized in ER (min)	110	108	169	167	319	317

4. MODELING INFRASTRUCTURE INTERDEPENDENCIES

There are four objects of study when dealing with CI interdependencies:

- The infrastructure network and its internal structure and state
- The relationship between one infrastructure and another (the interdependency)
- An internal event that triggers an abnormal state in one infrastructure network
- An external event that triggers an abnormal state in one or more infrastructure networks

Given these four elements, the following are some problem instances that can be analyzed:

1. Given infrastructure A’s internal structure, what external events would affect it, and how?
2. Given an internal or external event that triggers a failure in infrastructure A, and given a set of rules that define the relationship between infrastructures A and B, how does this affect infrastructure B?
3. Given a dependency of infrastructure B on infrastructure A, what event affecting A, and what state of A, could cause a given disturbed state of infrastructure B?
4. Given a dependency of infrastructure B on infrastructure A, what is the minimum performance of A that would keep B functioning?
5. Given an internal or external event, and given abnormal states of infrastructures A and B, what are the set of rules that define the relationship (the interdependency)?
6. Given an event, and given the interdependency between infrastructures A and B, what decision in infrastructure A maximizes the functionality of infrastructure B.

According to these six instances of the problem, and the types of interdependencies to be analyzed, a variety of tools and modeling approaches (ranging from simulation models, analysis of risks, decision support systems, etc.) have been developed in the past few years with the purpose of studying the relationships between infrastructure systems (Marti, et. al, 2005, 2008a and 2008b; Juarez-Garcia, 2010).

5. THE DISASTER RESPONSE NETWORK ENABLED PLATFORM

The most recent development is the implementation of a Disaster Response Network Enabled Platform (DRNEP) to enable linkage between organizations with simulation expertise in order to better prepare and respond to large disasters (Marti, et, al, 2012). The main goal of the DRNEP is to enable a linkage between organizations with simulation expertise in order to better prepare and respond to large disasters, e.g., earthquakes, flooding anywhere in the world. This linkage is through the CANARIE Network in Canada. The CANARIE Network is among the world's most advanced national research and education networks. CANARIE is a high performance hybrid network that supports data-intensive research and innovation across a range of private and public sector users (http://canarie.ca/en/network). CANARIE's high speed light path is used to connect the University of British Columbia (UBC), the University of New Brunswick (UNB) and the University of Western Ontario (UWO) to form a federation of Canadian expert centres providing real-time simulation results.

The implementation of DRNEP seeks to gather knowledge on the interoperation of interdependent infrastructures specific to a given area from expert organizations around the world in order to assist local emergency responders. For such a matter, organizations rely on simulators that help them to create disaster scenarios for a geographical zone, e.g., a municipality, a region, a province, etc. and elicit strategies on how to better respond to them.

The aim of DRNEP is to model the infrastructure interdependency in order to assess the achievement of a goal, which is to save lives in the case of a disaster by assisting first responders in the preparation, response, and recovery phases. DRNEP relies on I2Sim as the integrating simulator that models a given geographical area in case of disaster. I2Sim is envisioned to interface with other specialized simulators by exchanging information at a given able to model a given physical entity or a human, or set of humans taking decisions. Having a common data model for the system allows integrating the information from different simulators, and not only to integrate the information in one common repository, but also sharing and distributing this data to the rest of the system.

The DRNEP project goal is to create a tool to help decision makers predict the consequences of their choices in the event of a crisis. The tool considers the interdependencies among infrastructures and has three main objectives:

1. Help responders react to a disaster in real time.
2. Prepare responders for disaster events using customized simulations specific to the responder's location.
3. Provide responders with specialized decision support through a network of national and international expert centres.

The total number of researchers who were involved in the DRNEP including professors, staff, students and consultants was 34. One of the goals of the project is to incorporate CANARIE's private network into an overall security system to safeguard sensitive information associated with emergency response.

The innovative aspects of the DRNEP project are:

- Creation of a repository for disaster information, infrastructure models and decision outcomes which could be accessed by expert centres and emergency responders.
- Allow effective interconnection of expert centres to create a networked system of systems

platform over the CANARIE infrastructure for disaster response research.

- Develop a software service which enables the infrastructure interdependencies software I2Sim to synthesize results from infrastructure specific software located in different expert research centres. This is achieved using service oriented architecture (SOA) and web services. The architecture is flexible allowing any new infrastructure specific software to be easily integrated.
- Enable access to the infrastructure simulators located on the CANARIE network by authorized emergency responders using a secure web portal.
- Provide the means for emergency responders to analyze the impact of their decision as predicted by the DRNEP services. Analysis tools present data using maps, graphs, diagrams and tables. Multiple data formats will allow different emergency responder cultures to obtain the data in a way familiar to them.

The DRNEP research platform is characterized by four key components:

1. Custom data base designed for storing disaster response data and publishing data to simulators and users. For example: a) Geo-coordinates of a building are stored, and published on a Google Earth map; 2) The physical integrity on a scale of 1 – 5 is recorded and used as a parameter for infrastructure simulators; and c) Distribution ratios of limited resources is controlled by either users or intelligent software and shared with all expert centres and disaster simulators

2. Custom webservices designed to manipulate information and control software over the CANARIE network. This includes:
    a. Synchronization and data flow management of data among users and expert centres. For example, the BRAHMS decision simulator located at UNB writes a decision scenario to the data base. The I2Sim software reads this information and predicts the impact on the disaster model.
    b. Selection, configuration and control of software associated with the execution of a simulation scenario. For example, the user can control the I2Sim software indirectly through run, pause, stop and continue webservice commands.
    c. Distribution and rendering of data base information over the CANARIE network. This allows programs such as BRAHMS located at the UNB expert centre to request data using webservices which is needed to simulate a decision.

3. Interface methodology allowing different sources of data to access the research platform: a) Development of a disaster modeling ontology allowing simulators specific to a particular expert centre to be incorporated into the DRNEP. For example, the pipes, valves and pumps associated with the EPAnet water simulator are mapped to channels, distributors and production cells of the disaster model ontology. The EPAnet components can now be handled using the DRNEP data rules. b) Standardization of the software interface making the design of the DRNEP independent of present or future collaborators. For example, UNB was able to design a software adapter for their BRAHMS decision software based on the standardized software interface requirements. It was not necessary for the DRNEP software team to understand the functioning of BRAHMS. The ability to be agnostic of the expert centre software will become critical as the number of DRNEP partners increases.

4. Remote user access through any computer having access to the public internet. The public internet access is connected to the private CANARIE network through a secure gateway. The web interface provides access for selecting, executing, updating and analyzing disaster scenarios residing in the secure DRNEP network.
    a. Selection of a disaster scenario is enabled by choosing a model and a case study. For example, Sendai Japan is a candidate model and Tsunami is a candidate case.
    b. Execution of a simulation is possible through the web interface buttons start, stop, pause and continue buttons. The control interface reduces the software complexity that the

emergency responder is required to navigate.

c. Update of the DRNEP data base is enabled through a custom web interface which uses Google Earth. This allows the information update to be associated with a geographic location. The user is presented a satellite image from Google Earth with the model structures super-imposed. The images are created and updated based on the simulation values stored in the data base. For example, the colour of a structure indicates its physical integrity. Structure parameters can be updated in the data base directly from Google Earth.

d. Analysis of all disaster response simulations is available by accessing the DRNEP data base using the web interface. Data associated with model components is presented according to the simulation time resolution in both tabular and graphical format.

6. CLOSING REMARKS

The mitigation of seismic risk to the well-being of a community and the sustainability of a life style can be achieved by the implementation of effective post-earthquake emergency measures. A post–disaster simulator developed by UBC for the national government has been described. It can be used to direct in real time the deployment of resources after a disaster and to develop pre-disaster scenarios to permit effective pre-event planning.

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