US-NZ Workshop on Critical Infrastructure Systems

August 2005

Printed August 2005.

Publisher

Centre for Advanced Engineering
University of Canterbury Campus
Private Bag 4800
Christchurch
New Zealand

Contents

Summary

A two-day joint US-NZ Workshop on Critical Infrastructure Systems was held in Taupo 10-11th August 2005. The workshop was organised under the joint sponsorship of the US National Science Foundation (NSF) and the NZ Ministry for Research Science and Technology (MoRST). Organisation of the workshop was co-ordinated by the Centre for Advanced Engineering (CAE), overseen by two co-chairs for the Workshop; Professor John Mander of University of Canterbury and Professor Anne Kiremidjian of Stanford University.

The goal of the workshop was to provide an expert forum to examine the linkages and failure implications between infrastructure vulnerability, economic consequences and human social impacts. Workshop papers examined the current 'state-of-the-art' with discussion focused on identifying knowledge gaps and the implications for future research and professional practise.

The workshop followed a CAE organised two day international conference on Resilient Infrastructure held in Rotorua 8-9th August 2005. Whilst not all of the workshop participants from New Zealand attended the conference, the majority did so, as did the entire overseas contingent to the workshop. The conference was well attended, had a strong international contribution and the presentations given had an important impact on the thinking of the people in the workshop. Workshop participants totalled 26 consisting of seven people from the USA, two people from Europe, one guest from Australia and sixteen persons from New Zealand. The delegates represented a wide cross-section of interests from the engineering profession, academia and government.

This report outlines the background to the Workshop and presents a summary of the discussion highlights. The workshop was a very successful meeting. Twelve high-quality presentations were made on the performance and assessment of critical infrastructure systems. As well, useful exchanges of views and experiences took place during lively break-out and question-and-answer sessions.

The workshop resolved to prepare a monograph on *'Assessing Critical Infrastructure Systems'* to be prepared for publication by CAE and with contributions to be provided by workshop participants. It was also resolved that a follow-up workshop be held in the near future, and that the possibility of meeting at about the same time, or during, the 100th Anniversary Conference of the 1906 San Francisco Earthquake be explored (April 2006).

A small group of key people has been convened to define the process and keep it alive. It is expected that this initiative will be developed as a cross-disciplinary effort focused on ongoing collaboration to better define and co-ordinate our understanding of the rules and principles which govern system interdependence and networks inter-operability.

1 Outline of the Issues

Infrastructure is the linked system of networks and facilities that provide the range of essential services that are generally necessary to support a nation's economy and quality of life. Infrastructure represents a massive capital investment and is of enormous economic significance to modern society. Consequently, it is of the utmost importance to government, business, and the public-at-large that the flow of services provided by the nation's infrastructure continues to operate unimpeded in the face of a broad range of natural and man-made hazards. Whenever these facilities are damaged, disrupted, or simply unable to deliver the required services, the results can have major negative impacts on society.

Natural hazards such as earthquakes, landslides, floods, and extreme winds can all negatively impact on infrastructure as do accidental loss, deliberate acts of destruction, design faults, prolonged service lives, ageing materials, and inadequate maintenance. While hazard mitigation has moved beyond purely life safety issues, the protection of lifeline infrastructures has generally focused on designing systems to resist the loads imparted by extreme natural events. More recently, acts such as sabotage and terrorism have begun to receive greater attention.

Modern infrastructure systems have become tightly coupled, highly sophisticated networks that include transportation, electric power, water supply, and telecommunications systems. As these become increasingly more complex and interconnected it becomes more difficult to determine system boundaries. Consequently, to achieve proper resilience, it has become necessary to look beyond the effects of an event on just a single network system and, instead, seek to understand the disrupted behavioural patterns of a complex, 'systems-of-systems'.

In other words, while the failure modes of even highly complex, independent systems can reasonably be predicted, interdependence or reliance on other systems may lead to unforeseen consequences that can be catastrophic. Cascading failure describes the 'domino' effect that arises when the inoperability or failure of a single link in any piece of infrastructure leads to the failure of another system, and so on.

The National Science Foundation recognised the challenges surrounding Civil Infrastructure Systems in two publications, released in the mid 1990's: *"Civil Infrastructure Systems (CIS) Strategic Issues"* NSF 94-129 and *"Civil Infrastructure Systems: An Integrative Research Program"* NSF 95-52. The goals espoused therein included:

- *Enrich the science and engineering base that can advance the understanding, assessment and intelligent renewal of civil infrastructure systems;*
- *Encourage the integration, transfer, an application of knowledge that will contribute to the intelligent renewal of the infrastructure; and*
- *Integrate research with education and training to produce the next generation of engineers, scientists and others who will design, build, and use civil infrastructure systems of the future.*

The NSF initiatives recognised that system integration at all levels is necessary to achieve these goals. However, in spite of these initiatives, almost 10 years later, it appears that rational and consistent application of the concepts of systems integration to infrastructure management in a multiple risk environment have not been particularly extensive and, for the most part, have yet to reach the mainstream of engineering practice or asset management. It is in this context that this Workshop and the related Resilient Infrastructure Conference were brought together. It also builds upon the earlier US-NZ Workshop on Civil Infrastructure Systems Research, held in Christchurch 10th-12th October 2001.

Modern Infrastructure systems also have a critical human component that needs to be understood and integrated into the management and planning for our future infrastructure needs. The companion conference on Resilient Infrastructure that preceded this workshop reinforced the need to define infrastructure more broadly then in the past. Likewise, the behaviour of complex adaptive systems themselves is an emerging field of study, with much left to discover.

In the future it will not be possible to maintain the stability of services without a common understanding of the rules and principles which govern system interdependence and networks inter-operability. There seems little doubt therefore that this is fertile ground for collaborative research between engineering and the physical and social sciences.

If there is to be that paradigm shift in the way infrastructure is planned, built and managed, we need to rethink vulnerability and sustainability, define risk choices beyond just engineering constructs, find a common language for communicating risk and develop the new science and metrics to explore the limits of system behaviour. Critically such an effort requires that we bring together a diversity of skills and experiences to apply new earning concerned with risks, vulnerabilities, resilience and decision-making.

This workshop, with its mix of participants from NZ, the USA, Europe and Australia, and broad participation, importantly provided a unique opportunity for participants across a number of disciplines to begin to deliver on that objective.

2 Goals and Objectives

The main goal of the workshop was to provide an international expert forum to examine the linkages and failure implications between infrastructure vulnerability, economic consequences and human social impacts. In considering these linkages, the implications of cascading failure, which requires a better understanding of the interactions among different infrastructure components from a systems-based perspective, and the characterisation of infrastructure vulnerability were important considerations.

In achieving this goal, the workshop sort to examine the 'state-of-the-art' in the assessment of critical infrastructure systems and identify the knowledge gaps in the understanding of critical infrastructure interdependencies, and the implications for cascading failure. It was envisioned that broad participation at the workshop would promote the exchange of ideas and thinking across discipline boundaries and thereby act to catalyse co-operative research in these areas.

To accomplish the above goals, the following objectives were defined:

- Capitalise on the relationships and goodwill established with US researchers and practitioners, working in this area, during the US/NZ Workshop on Civil Infrastructure Systems; organised by CAE in October 2001 and jointly funded by the US National Science Foundation and NZ Government sources.
- Provide an expert forum for identifying and comparing common problems and solutions, and for promoting international co-operative research in all areas of critical infrastructure systems.
- Raise the level of understanding amongst practitioners in New Zealand, US and elsewhere of interdependencies and their influence on complex network behaviour.
- Assist in the development of strategies and methods to address issues related to the vulnerability of critical infrastructure systems and avoiding failure.
- Bring together all the relevant disciplines, including engineering, finance, insurance and the social sciences, from central and local government, academia, commerce and business to address these issues.
- Produce a landmark publication on this topic, together with policy and research recommendations, based on the conference, the workshop presentations and workshop discussion, and working session outcomes.

3 Programme and Participants

A participant list and their individual affiliations is provided in Appendix 1. A copy of the workshop programme is attached as Appendix 2.

4 Presentation Highlights and Workshop Notes

This summary is prepared from notes provided by Mary Comerio. Note that abstracts of the papers referred to have been included in this report as Appendix 3.

Workshop Objectives and Directions, - George Hooper, CAE

- Acknowledged the contributions made by the Co-Chairs of the meeting; Anne Kiermedjian and John Mander (note that Anne Kiermedjian was unable to be present because of complications resulting from surgery). Also welcomed visitors and acknowledged the previous contributions arising from the 2001 Workshop on Management of Civil Infrastructure in Multi-Hazard Environment.

  Expressed the goals of the meeting from a CAE perspective as:

  1. bring international learning to New Zealand
  2. use New Zealand to test new ideas for the rest of the world
- This workshop focus was thus to promote collaborative research that can benefit all.
- Two themes emerged from the Resilient Infrastructure Conference in Rotorua:
  1. the ideal image of strong professional collaboration in New Zealand had disappeared somewhat with the lack of interconnection (and lack of leadership) in government, industry, and amongst professional practitioners.
  2. The Social Science presentations reinforced the need for better communication and the need to focus on people as well as systems.
- Goals for this workshop: to create a roadmap to new knowledge and cross-disciplinary approaches, to look for areas of collaborative working, and to find one or two projects CAE can take forward.

Session 1: Technical Vulnerability and Disruption of Complex Systems

Building Resilience — Tom O'Rourke, Cornell University

- Emphasised the interdependence of systems, and the need to characterise system vulnerabilities.
- Lessons from the 7/7/2005 London Terror Attack: the small tube size means that a train car fills the tunnel with no exit-way or ventilation. If exploited, it represents a serious vulnerability and illustrates a key vulnerability in the system.
- Lesson from N.E. U.S. Blackout 2003: cascading failure could have been avoided by load sharing. Inadequate awareness and maintenance issues demonstrate key vulnerabilities and failure of institutions.
- Lessons for the Workshop:
  1. Define infrastructure broadly.
  2. Distinguish between natural/accidental hazards and terrorism.
  3. Emphasize need to integrate institutional and organisational approaches.
  4. Focus on need for information sharing protocols.
  5. Explore quantitative means for characterising vulnerability and risk.
  6. Recognize advanced technologies.

Discussion Issues:

1. M. Comerio added a 7th lesson: Identify (and develop) leadership to bring government institutions and infrastructure organisations to the table for discussion.
2. B. Phillips: Also need to pay attention to understandings that workers have of operations. The Shuttle disaster was a case in point. Clearly there are multiple points of view for communication.
3. A. Gheorghe: Reflected that in Europe there are also cultural and language issues that influence cross-border arrangements. A different context from the USA.
4. A. Rose asked: Are there trade-offs between mitigation and resilience? And to what extent can industry self-regulate; is government regulation (by policy) more effective?
5. P. May: Commented that system efficiency driven by economic rationalisation. Does increased resilience result in reduced 'cost effectiveness'?

Modelling Infrastructure Security Issues — Linda Nozick, Cornell University

- Security has become a key concern in network control systems.
- Motivation is the need for a system perspective (not component only) and to look at who pays for security. There is always the trade-off between false positives versus probability of detection.
- Cyber Attack and Aircraft Security examples: need to keep system effective (functioning) even in attack mode, so use models and probabilities to optimise investments, then modify and re-optimise. Objective function for decision making is the degree of "System Hardening".

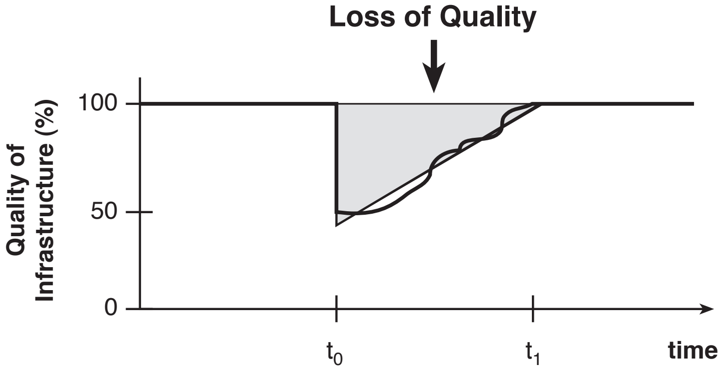
Discussion Issues:

Optimisation, Equity and Human Behaviour

1. How to embed 'Markov System' in decision-maker side to model those who are risk-averse and those who are not.
2. How to optimise in general system-level approaches.
3. How to handle multiple objectives.
4. Equity and fairness: who pays, who gains (public vs private ownership).
5. Industrial espionage is a major contributing cause – loss of collateral value.

Protecting Critical Infrastructure Systems — Ian Buckle, University of Nevada

- The fact that things work at all is magic – understand complexity.
- Resilience needed to save lives and contain escalating costs.



- Quality of system (vertical) time (horizontal) loss in event is vulnerability (what is not lost represents robustness). Recovery time is a measure of resilience. It is possible to reduce vulnerability (using mitigation) or increase rate of recovery (social preparedness)?

Discussion Issues:

1 Are there other effective ways to quantify resilience?

Is $T = Q_o - Q_1/r$ an adequate approach?

Should the "environment" (structures and processes that avoid damage) be included in this definition?

2 Need also to bring in the concepts of business continuity. Resilience is also about market economics and social preparedness, i.e. resilience = f (vulnerability, rate of recovery).

Energy Disruptions and System Availability — George Hooper, CAE

- NZ energy system is small and dependent on hydro for electricity and natural gas for its thermal fuel supply.
- NZ has had 30 years of cheap gas, and that has underpinned NZ export industries such as forestry and dairy. In 2002 redetermination of the gas reserves led to prices for new gas more than doubling in 6 months.
- Low reserves-to-production ratio in natural gas supply affects all sectors, and demonstrates the vulnerability of primary energy supply.
- NZ energy operators (gas, electric) only look at their distribution capacity, not their supply. Because the energy industry is divided, there is no capacity to solve problems.

Discussion Issues:

1 How to transfer risk and minimize vulnerability (and increase resilience)?

2 Who should oversee the system-of-systems?

3 How do we change learning in the current settings (given the liberalisation of energy markets and absence of centralised planning)?

4 How to recoup technical decision making capacity in the current reality of over-reliance on market forces for decisions?

5 Does distributed generation decrease or increase resilience?

Session 2: Modelling Complexity, Uncertainty and Cascading Failures

Critical Infrastructure Issues for Socially Vulnerable Populations — Brenda Phillips, Oklahoma State University

- Social Vulnerabilities Research since 1970's on high risk populations in disasters, but no adequate look at these populations in infrastructure losses.
- Healthy and resilient communities require consideration of intangible, social infrastructure dimensions; such as economic vibrancy, appropriate housing, and equity across groups.
- Research Agenda: need to document what happens to low-wage workers, racial or ethnic groups and special populations (e.g. disabled) in infrastructure losses. Socio-economic status is important.

Discussion Issues:

1 Sharing information across sectors.

2 Getting local solutions/local voices to decision makers (policy makers).

3 Documenting social, contextual, situational realities – how do specific populations respond?

4 Evaluate performance expectations and social needs – what happens, when connections to place, communities and livelihoods are disrupted?

5 Evaluate what structural changes needed to move socially vulnerable populations to the forefront of issues.

6 Evaluate how funding structure for recovery includes or dismisses social recovery issues, i.e. EQC reinstatement of "dwellings".

Resilience of Industrial Infrastructure to Earthquakes — Laura Steinberg, Tulane University

- Resilience is a contextual specific quality and hard to quantify.
- Reference to Natechs: Natural Hazard Induced Technical Disasters (Bophal, Exon Valdez, Cascading events after the 1999 Kocaeli, Turkey Earthquake).
- Industry has many types of systems (components, processes, community, environment) and many types of failures (cascading, escalating, common), but too often facilities do not plan adequately for natural hazards.
- Two way relationships between the Industrial facility, the community, the environment, and emergency response and lifelines. The resilience of the facility impacts the resilience of the community and other systems.

Discussion Issues:

1 UN has done previous work on regional risk assessment, but should be updated to include natural disasters.

2 Resilience of large industrial areas to loss of water, gas and transport is focused on customer's preparedness, but recovery is a dynamic time path dependent on regional capability.

3 Robustness and resilience are words that are used differently in recovery and definitions are needed.

4 How can triggering mechanisms be implemented to incentives improved industry performance?

5 Can the methodology for upgrading of the nuclear industry systems (ref Manual for Classification and Privatisation of Risks from Major Accidents in Process and Related Industries) be used for general infrastructure systems?

6 What are the policy implications for industry – risk assessment and safety management?

Expected Losses in Transportation Infrastructure: Perspectives on Insuring Against Relatively Frequent Events — John Mander, University of Canterbury

- We need to communicate risk –one model is through the equation developed at PEER to describe risk and loss. Dollars are a useful and common currency for discussion.
- Frequency of small events has high level of mean annual loss—and one is not serving users if there is continued spending on minor repairs.
- Example of culvert failures in 100 year floods gives large damages, but should there be investment to upgrade aged infrastructure to improve resilience (consider the impact goes beyond the fixed asset because of co-location of other services).
- What can be done to overcome aggregate losses?

  Is it possible/economic to mitigate against small, frequent losses?

Discussion Issues:

1 What is broad economic (societal) implication of changing design standards from Life-Safety to Improved Performance for frequent events?

2 Beyond modelling of externalities, how would this be implemented in public policy?

3 What opportunities are there for collaboration? Other connected service providers are

generally unaware of their vulnerability.

Managing Resilience of Critical Infrastructure — P Brabhaharan, Opus Consultants

- Consulting project for New Zealand looked at risks to people within both the built and natural environments, layering data in GIS format – where is the resilience in NZ infrastructure?
- The maintenance trap implies not looking at the long-term; focus instead on incremental improvement?
- Multiple issues make decisions seem hard, so nothing gets done. GIS an excellent tool for demonstrating issues to owners.
- Work demonstrates gaps in knowledge and improvements needed in performance levels.

  Discussion Issues:

  1. Need common data protocols and models as well as confidential repository and the capacity to extract data.
  2. Warren Centre, Australia, is establishing a project on shared data sets. Also there is the Australian programme Trusted Information Sharing Network (TISM).

Session 3: Social Economic and Technological Interdependencies

Downtime and Recovery — Mary Comerio, University of California, Berkeley

- Protecting institutional operations is key to resilience of social systems.
- UC Berkeley example: Structural retrofit programme enhanced by loss modelling and business resumption planning—so that retrofit priorities re-set to limit downtime, business and research recovery planning made part of annual preparedness planning, and non-structural retrofits and utility upgrades added to overall programme.
- Performance goal: limit downtime to 30 days.
- How did these decisions get implemented? Culture of involvement of engineering faculty through seismic review committee; Fear on part of new Chancellor; Money from government; Critical data to use in decision making; and Willingness to change behaviour among staff and faculty.
- Lessons for Workshop:
  1. Create new knowledge
     — develop means to illustrate key vulnerabilities
  2. Create dialogue
     — with input from the different sector/stakeholder groups
     — define performance
  3. Create ownership (leadership) to carry forward goals
     — instutionalise risk management planning
     — incentivise improved performance levels.

Making Resilient Organisations — Erica Dalziell, University of Canterbury

- Resilience in organisations means recovery is a process, not an event. Organisations cannot go back to 'what was' but need to re-think new environment. Other opportunities arise in process.
- Analogy: DIY in your house—the last 10% never gets done.
- Resilience is contextual, for organisations, it may not the price or volume of product produced, but instead need to go back to the mission statement of what the organisation is

there for. Resilient for whom?

- Lessons in looking for resilience metrics:
  - — Can we assess resilience independent of hazard?
  - — Actual indicators, or relative quantification?
  - — Reminder not to look too narrowly—disaster provides opportunities to accelerate the speed and ability to change; remove boundaries, reduce likelihood that recoverable limits will be exceeded, increase situation awareness (when environments change, systems response needs to change).

Discussion Issues:

1 Most utility companies have a culture of rapid restoration – the maintenance cycle again. Need to refine thinking. Recovery to what?

2 Can we borrow from concepts of sustainability? Can we use concepts like the 'half-life' of recovery?

Regional Vulnerability of Critical Infrastructure — Adrian Gheorghe, ETH, Switzerland

- European context is established by the values of the European Union; borderless society within a common framework of bilateral co-operation under national responsibility.
- To model vulnerability of Swiss infrastructure, used system-of-systems, with probability, event tree, chaos, cellular automata, and other models. Modelling the full lifecycle of information from 'cradle-to-grave'.
- To view risk-vulnerability nexus, use rule based models instead of integration. Decision Support Systems are developing a new science for critical infrastructure built upon quantitative vulnerability assessment.
- Identify bottlenecks in systems, improved options, clearing-house of ideas, optimal patterns and timing of recovery. Embedded into a GIS computational platform.
- The ubiquity of digilisation is to be considered a new and revolutionary paradigm.

Discussion Issues:

1 Need to apply uncertainty techniques for the analysis of system interdependencies. There is no 'owner' of critical infrastructure interfaces.

2 How to integrate and model system responses?

Tracing Infrastructure Interdependence through Economic Interdependence — Adam Rose, Pennsylvania State University

- Interdependency is at the heart of economics.
- Exploring the use of computational general equilibrium model (CGE) to investigate
- broader interdependencies
- Total resilience extends beyond the physical infrastructure into the customers ability to cope with disruption (Market's ability to ration).
- Resilience differs at the enterprise and market levels. Need to focus on key bottlenecks and our ability to maximise society's adaptive capacity.
- The essence of economic resilience is the innate capacity of an economic system to cushion itself against losses or disruption of services

Discussion Issues:

1 Incorporating economic dimensions of resilience – markets have a certain resilience.

2 How to measure progress in reducing vulnerability?

3 Use of non-structural interventions.

5 Overview of Issues

A summary of the workshop thinking as arose from the various discussion sessions, established a number of key issues as follows:

- There are always trade-offs that need quantification and communication: mitigation vs. resilience, the transfer of risk to minimise system vulnerability and increase resilience, how to optimise resource allocation for multiple objectives?
- Public policy issues included: self-regulation vs. imposed regulation. Does regulation increase resilience? Who should oversee the system-of-systems?
- Metrics: Are there effective ways to quantify resilience?
- How is information shared across sectors?
- What are performance expectations from society?
- What are the policy implications (and costs) of upgrading performance standards (from life safety to a higher standard) for infrastructure?
- What are the economic implications of frequent events?
- How do we measure progress in resilience?
- How do we create modelling and data platforms that are used across systems?
- How do we create new knowledge, dialogue, and leadership in the area of critical infrastructure?

All agreed that there are critical vulnerabilities in our infrastructure: The ultimate question is what can be done, and how do we measure progress?

It was resolved by participants to write a monograph on the topic of Critical Infrastructure Systems. Alternate titles suggested were: *'A New Paradigm for Understanding Critical Infrastructure Reliability Resilience'* and *'Metrics for Critical Infrastructure'*.

As an alternative option to a monograph it was suggested that the papers be combined into a special issue of a journal. Anne Kiremidjian could follow up with NSF on whether a supplement to the workshop grant could be obtained to fund principal authors for each chapter. The Centre for Advanced Engineering would take responsibility for co-ordinating publication.

Basic details for the monograph were agreed as follows:

(a) Working Title: *'Assessing Critical Infrastructure Systems'*.

(b) Audience: Peer groups in risk assessment, researchers, graduate students, sophisticated practitioners and decision makers; not the general public.

(c) Content: four to five sections each written by a team of experts with a lead author; each section to be a state-of-the-art, stand-alone paper, and may or may not refer to other sections; not a text book; all hazards to be addressed.

(d) Sections and authors: Suggested section topics and authors shown in table below. Additional authors need to be assigned in most areas and existing confirmed.

(e) Schedule: Annotated outline of each section by April 2006.

A preliminary list of sections and authors is given overpage.

	Section	**Authors** (draft)
1	Characterising and quantifying resilience	Erica Dalzeill, Adam Rose, Ian Buckle, Bruce Glavovic, Barry Davidson
2	Building and promoting resilience for sustainability (i.e. engineering and organizational issues, policies, incentives…)	Mary Comerio, Brenda Phillips, George Hooper, Eve Coles, Andrew King, Wendy Saunders
3	Avoiding cascading failures	Tom O'Rourke, Laura Steinberg, Dave Brunsdon (ar alternate), Jason Ingham
4	Understanding and modeling system response	Linda Nozik, John Mander, Adrian Gheorghe, P Brabhaharan, Greg MacRae
5	Research needs / action plan	All

* Note: to be formally adopted.

Appendix 1: Participants and Affiliations

Name	Organisation
United States of America	
Professor Tom O'Rourke	Cornell University
Professor Mary Comerio	University of California, Berkeley
Professor Linda Nozick	Cornell University
Laura Steinberg	Tulane University
Professor Brenda Phillips	Oklahoma State University
Professor Adam Rose	Pennsylvania State University
Professor Ian Buckle	University of Nevada
Europe	
Dr Adrian Gheorghe	ETH Zurich
Eve Coles	Coventry University
Australia	
Peter May	Engineers Australia
New Zealand	
Dr George Hooper	CAE
Dr John Mander	University of Canterbury
Dr Gregory MacRae	University of Canterbury
Dr Erica Dalziell	University of Canterbury
Associate Professor Bruce Glavovic	Massey University
Dr Jason Ingham	Auckland University
Dr Michael Pender	Auckland University
Dr Barry Davidson	Auckland University
Dr Daniel Whang	Auckland University
Grant Kaye	University of Canterbury
Andrew King	GNS
John Hannah	Transit New Zealand
Wendy Saunders	GNS
Ruth Berry	FRST
P Brabhaharan	Opus International Consultants
Richard Byfield	Centre for Critical Infrastructure Protection

Appendix 2: Programme

Wednesday August 10, 2005	
1:00 -1:30 pm	Welcome and introductions Workshop objectives: John Mander and Tom O'Rourke Directions for developing outcomes and research recommendations: George Hooper
1:30 – 4:00 pm	**Session One: Technical Vulnerability and Disruption of Complex Systems** 1 "Protecting Critical Infrastructure Systems" by Ian Buckle, University of Nevada, Reno 2 "Modeling Security Issues" by Linda Nozick, Cornell University 3 "Building Resilience into Infrastructure Management" by Tom O'Rourke, Cornell University 4 "Energy disruptions and system availability", George Hooper, CAE
4:00 - 4:15 pm	*Break*
4:15 – 6:00 pm	Discussion and drafting provisional recommendations

Thursday August 11, 2005	
8:30 – 12:30 am	**Session Two: Modeling Complexity, Uncertainty and Cascading Failures**
	1 "Critical Infrastructure Issues for Socially Vulnerable Populations: a research assessment and agenda" by Brenda Phillips, Oklahoma State University. 2 "Resilience of Industrial Infrastructure to Earthquakes: A Study of Structural Damage and Cascading Events resulting from the Kocaeli, Turkey Earthquake of 1999" by Laura Steinberg, Tulane University 3 "Expected losses in transportation infrastructure: perspectives on insuring against relatively frequent events" by John Mander, University of Canterbury.
	4 "Managing the resilience of critical infrastructure – some practical considerations" by P Brabhaharan. Opus International Consultants
10:15-10:30 am	*Break*
10:30-12:30 pm	Discussion and drafting recommendations
1:30 – 3:30 pm	**Session Three: Social, Economic and Technological Interdependencies** 1 "Downtime and Recovery: The Impact of Institutional Closure" by Mary Comerio, University of California, Berkeley 2 "Tracing Infrastructure Interdependence through Economic Interdependence" By Adam Rose, Pennsylvania State University 3 "Regional vulnerability of critical infrastructures and issues of civil defense", by Adrian Gheorghe, ETH, Switzerland. 4 "Making Resilient Organizations," by Erica Dalziell
3:30-4:30 pm	Discussion and drafting recommendations
4:30 -5:29 pm	Working session: Finalising draft workshop recommendations
5.30 pm	Closure

Appendix 3: Abstracts of Papers

Protecting Critical Infrastructure Systems

Ian Buckle

Today, life-safety is no longer the sole requirement of successful design for extreme events but is augmented by other performance criteria such as functionality and minimal economic loss. This realization has led to the concept of *performance-based seismic design* which is a relatively new development in the design and construction of civil infrastructure. Nevertheless substantial progress has already been made in this arena, particularly with respect to the performance of individual components of the built infrastructure, such as buildings and bridges. But the real potential for performance-based design comes when these concepts are applied to systems and subsystems of the infrastructure, such as transportation networks, subject to both service load conditions and extreme events.

This paper describes current efforts to apply performance-based design to the earthquake performance of highway networks in the United States. In recent years, a major review of performance criteria for bridges has been undertaken and a move towards performance-based, multi-level seismic design of bridges has begun. In a parallel exercise, a risk-based methodology has been developed for assessing the performance of highway systems taking into account the seismic fragility of bridges and their interconnectivity, and estimating congestion and delay times. These efforts have opened the door to performance-based seismic design of highway systems, in which system-level performance criteria, such as maximum permissible traffic delay times and minimum restoration times, are targeted for highway systems immediately following earthquakes of different sizes. This paper explores the feasibility of such a design approach and potential applications for resource allocation and emergency planning.

The methodology extends to other critical infrastructure systems, such as mass transit, water supply, telecommunications and to other extreme events, natural or man-made.

Downtime And Recovery: The Impacts Of Institutional Closure

Mary C Comerio

The design choices for new construction and retrofit of existing buildings made by the University of California, Berkeley, which is located in a high-hazard zone near the Hayward fault, demonstrate the application of performance engineering and risk management strategies. The University has invested $250 million in seismic improvements. The investment was justified by the need to protect the safety of students, faculty, and staff, and the preservation of research and the stature of the university. In the 1990's (after the Northridge and Kobe earthquakes) life-safety specific seismic upgrading of existing buildings was the first priority, but the focus expanded to include limiting losses among valuable contents and operational continuity. The University used the Disaster Resistant University (DRU) Initiative together with research at the Pacific Earthquake Engineering Research (PEER) Center to evaluate the performance of contents in modern laboratory buildings in order to develop strategies to limit downtime in future seismic events. The research involved detailed surveys of building contents, modelling of structural performance and shake table testing of key equipment to inform the loss models. The process included mapping building contents and equipment vulnerabilities in laboratory building across the campus because the economic impacts from research downtime are more significant than the capital losses. The research outcomes changed retrofit priorities, informed the development of non-structural retrofit strategies and institutionalised business and research recovery planning.

Making Organisations Resilient: Understanding the Reality of the Challenge

Erica Dalziell

Organisations play key roles within our society. They have the responsibility for managing, maintaining and operating our infrastructure, creating our economy, and providing employment and essential goods and services for our communities. An organisation's ability to respond effectively to adverse events depends on their structure, the management and operational systems they have in place, and the collective resilience of these.

New Zealand organisations have been through considerable structural change over the past two decades. This has occurred at all levels from central through to local government and the private sector. Some organisations have in fact been through several cycles of restructuring in the pursuit of different philosophies. This process has seen the evolution into smaller and more independent organisations and business units. Their focus on short-term economic efficiency has however had a detrimental effect in terms of planning to be resilient in the face of major emergency events.

This paper provides a past/ present/ future perspective of New Zealand by presenting reflections on the impacts of corporatisation during the 1980's and 1990's a view of the current situation and suggestions on where future emphasis should be placed. The view is expressed that relatively few organisations (public or private) in New Zealand are currently making appropriate levels of commitment and investment in the vital element of 'readiness' or preparedness to respond to and recover from major emergency events. In addition to highlighting the challenge that this situation represents, some practical strategies for increasing organisational resilience are suggested, along with key areas where greater resource commitment should be made.

Resilience in Infrastructure Management

T D O'Rourke

Extreme events are caused by natural hazards, severe accidents, and pre-meditated human threats. Infrastructure resilience requires that appropriate measures are taken to assess and reduce the potential for problems resulting from the interaction of extreme events and interdependent, critical infrastructure systems. This paper identifies key characteristics of modern infrastructure, and illustrates their influence on complex network operation by means of case history examples associated with the 2001 World Trade Center Disaster, the 1983 New York City Garment District Incident, and the 1989 Loma Prieta earthquake. Conclusions are drawn with respect to the causes of damage, factors affecting the spread and constraint of damage, and factors that contribute to both the resiliency of urban infrastructure and the attendant services necessary to respond effectively to extreme events. Lessons learned for the managers of infrastructure systems are summarized.

Critical Infrastructure Issues for Socially Vulnerable Populations: a research assessment and agenda

Brenda Phillips

Over the last 20 years a steadily growing body of knowledge has accumulated on high-risk populations in disaster situations. Socially vulnerable populations typically include those experiencing higher rates of death and injury: (e.g.) women, children, the elderly, persons with disabilities, poor households, and racial and ethnic minorities. Attempting to assess the situations of such a diverse set of vulnerable persons vis-à-vis critical infrastructure is made difficult by a startling lack of scientific studies. To start, this presentation examines available literature for clues to critical infrastructure issues. The author then outlines ways in which critical infrastructure losses might generate unique issues for high-risk populations.

In particular, the author calls for a hearty multi-disciplinary research agenda to address the needs of the socially vulnerable when faced with critical infrastructure threats and losses. The author will present a number of items including:

- Theoretical advancements necessary for conducting such research.
- Methods appropriate to such work, including those that incorporate the perspectives of those at high-risk.

- Population specific research, e.g., experiences of the deaf during telecommunications losses.
- The ways in which social vulnerabilities overlap and intersect, heightening risk during infrastructure failures.

The paper concludes with a set of practical strategies for addressing critical infrastructure issues among socially vulnerable populations:

- Funders should require multi-disciplinary research that incorporates meaningfully the broader social impacts so crucial to those at higher-risk.
- All national and state task forces or commissions on high-risk populations must include social vulnerability experts and those at high-risk as active members.
- Conferences, workshops and symposia must include sessions, plenaries and published proceedings that address high-risk populations.
- Professional organizations, universities and researchers must involve those at high-risk, and their advocacy organizations, as participants in the research process and as active interpreters of the research findings.

Tracing Infrastructure Interdependence through Economic Interdependence

Adam Rose

Interdependence is at the heart of the economic system. No single producer or consumer is self-sufficient, but rather depends on others. Moreover, this interdependence is not limited to immediate trading partners of a given business enterprise, but also extends to the successive chain of "upstream" suppliers and "downstream" customers. Thus, every sector of the economy is connected directly or indirectly.

Some inputs are more critical than others in terms of their role in the economy. Infrastructure is at the foundation of the economic pyramid, in that it serves all sectors and because ready substitutes do usually not exist. Infrastructure, however, is not monolithic. Various types (electric, gas and water utilities, communication and highway networks) are interdependent as well.

Economists have developed two major types of models to analyse the interconnectedness of economic activity in general and infrastructure in particular. The first is input-output (I-O) analysis, which was devised many years ago by Nobel laureate Wassily Leontief, and which has long been the most frequently used tool of economic impact analysis, capturing not just direct interaction but multiplier effects of indirect interaction among infrastructure components themselves and with respect to the rest of the economy (see, e.g., Rose and Miernyk, 1989; Brookshire et al., 1997). Unfortunately, I-O has many limitations, including linearity and lack of behavioural content.

More recently, computable general equilibrium (CGE) analysis has been developed, incorporating the best features of I-O but allowing for the inclusion of nonlinearities and behavioural responses to market price signals and resource availabilities under normal and crisis situations (see Shoven and Whalley, 1992; Rose, 1995). Many of these responses correspond to several types of resilience adjustments (e.g., input substitution, conservation) (Rose and Liao, 2005). This more flexible approach has enabled researchers to more accurately assess infrastructure interdependence, improve disaster loss estimation, measure resilience, and identify options that can most cost-effectively reduce losses (Rose, 2005).

This paper will summarize how these two economic modelling approaches are applied to infrastructure interdependence and resilience. Examples will be provided of how research by engineers on infrastructure network fragility can be used in conjunction with GIS to provide a spatial dimension to these economic models, in order to sharpen their abilities to address important questions (see, e.g., O'Rourke et al., 2003; Shinozuka and Chang, 2004). It will provide a summary of recent applications and what we have learned from them. The presentation will conclude with a discussion of conceptual and empirical issues confronting economists and engineers to improve this important modelling capability.

References

Brookshire, D., S. Chang, H. Cochrane, R. Olson, A. Rose, and U. Steenson. 1997. "Direct and Indirect Economic Losses from Earthquake Damage," *Earthquake Spectra* 13: 683-701.

O'Rourke, T., Y. Wang, and P. Shi. 2004. "Advances in Lifeline Earthquake Engineering," *Thirteenth World Conference on Earthquake Engineering*, Vancouver, Canada.

Rose, A. 1995. "Input-Output Economics and Computable General Equilibrium Models," *Structural Change and Economic Dynamics* 6: 295-304.

Rose, A. 2005. "Analyzing Terrorist Threats to the Economy: A Computable General Equilibrium Approach," in P. Gordon, J. Moore and H. Richardson (eds.), *Economic Costs and Consequences of a Terrorist Attack*, Cheltenham, UK: Edward Elgar Publishing Company, forthcoming.

Rose, A. and S. Y. Liao. 2005. "Modeling Regional Economic Resiliency to Earthquakes: A Computable General Equilibrium Analysis of Water Service Disruptions," *Journal of Regional Science* 45: 75-112.

Rose, A. and W. Miernyk. 1989. "Input-Output Analysis: The First Fifty Years," *Economic Systems Research* 1: 229-71.

Shinozuka, M. and S. Chang. 2004. "Evaluating the Disaster Resilience of Power Networks and Grids," in Y. Okuyama and S. Chang (eds.), *Modeling Spatial Economic Impacts of Disasters,* Heidelberg: Springer.

Shoven, J. and J. Whalley. 1992. *Applying General Equilibrium,* New York: Cambridge University Press.