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Critical Infrastructure Interdependency Modeling: A Survey of U.S. and International Research

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ABSTRACT

"The Nation's health, wealth, and security rely on the production and distribution of certain goods and services. The array of physical assets, processes, and organizations across which these goods and services move are called critical infrastructures."[1] This statement is as true in the U.S. as in any country in the world. Recent world events such as the 9-11 terrorist attacks, London bombings, and gulf coast hurricanes have highlighted the importance of stable electric, gas and oil, water, transportation, banking and finance, and control and communication infrastructure systems.

Be it through direct connectivity, policies and procedures, or geospatial proximity, most critical infrastructure systems interact. These interactions often create complex relationships, dependencies, and interdependencies that cross infrastructure boundaries. The modeling and analysis of interdependencies between critical infrastructure elements is a relatively new and very important field of study.

The U.S. Technical Support Working Group (TSWG) has sponsored this survey to identify and describe this current area of research including the current activities in this field being conducted both in the U.S. and internationally. The main objective of this study is to develop a single source reference of critical infrastructure interdependency modeling tools (CIIMT) that could be applied to allow users to objectively assess the capabilities of CIIMT. This information will provide guidance for directing research and development to address the gaps in development. The results will inform researchers of the TSWG Infrastructure Protection Subgroup of research and development efforts and allow a more focused approach to addressing the needs of CIIMT end-user needs.

This report first presents the field of infrastructure interdependency analysis, describes the survey methodology, and presents the leading research efforts in both a cumulative table and through individual datasheets. Data was collected from open source material and when possible through direct contact with the individuals leading the research.

Table EX-1. Summary of areas surveyed.

	Simulation Name	Developer	Area Model by Infrastructure Sector															Simulation Type		System Model		Hardware Platform Requirements		Software Requirements			User and Maturity Levels	
			Electric Power	Natural Gas	Drinking Water	Sewage Water	Storm Water	Human Activity	Financial Networks	SCADA	Telecom	Computer Networks	Oil Pipeline	Rail System	Highway System	Waterway System	Police/ Regulatory Constraints	Continuous	Discrete	Integrated	Coupled	PC	HPC	Windows	Linux	Solaris	Users	Maturity Level
1	AIMS	UNB														X		X		X							IA	RS
2	Athena	On Target Technologies, Inc.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	A	X	A	X		X			EA	MI
3	CARVER²	National Infrastructure Institute																				X		X			B	MC
4	CI³	ANL	X	X						X	X							X		X							B	MI
5	CIMS	INL	X					X		X									A	X		X	X	X	X	X	B	DV
6	CIP/DSS	LANL, SNL, ANL	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X		X				MI
7	CIPMA	Australia	X	X					X		X		X					X									B	MI
8	CISIA	University Roma Tre	X							X																		
9	COMM-ASPEN	SNL							X		X									X		X					IA	DV
10	DEW	EDD	X							X																	B	MC
11	EMCAS	ANL	X						X							X			A	X		X					IA	MI
12	FAIT	SNL	X	X												X		I		X				X	X		IA	DV
13	FINSIM	LANL							X		X							X			A			X			IA	DV
14	Fort Future	USACE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										B	MC
15	IEISS	LANL	X	X														X			A	X		X	X		IA	MI
16	IIM	UV	X						X		X							I		X							IA	RS
17	Knowledge Management and Visualization	CMU	X											X	X	X											IA	RS
18	MIN	Purdue						X							X													
19	MUNICIPAL	RPI	X								X			X														
20	N-ABLE	SNL	X						X					X					A	X							IA	MI
21	NEMO	SPARTA	X	X	X									X			X	X		X		X						DV
22	Net-Centric GIS	York University												X	X	X											IA	RS
23	NEXUS Fusion Framework	IntePoint, LLC.	X					X			X			X	X												B	MC
24	NGtools	ANL	X	X																							B	MI
25	NSRAM	JMU	X								X								X									RS
26	PFNAM	ANL		X									X															
27	TRAGIS	ORNL												X	X	X	X											MI
28	TRANSIMS	LANL						X											A		A		X		X		B	MC
29	UIS	LANL			X	X	X	X			X				X	X		X	A		A		X		X		IA	MI
30	WISE	LANL			X	X	X											X			A			X			IA	DV

Simulation Type:
I Input-Output Model
A Agent-based

Users:
IA Internal Analyst
EA External Analyst
B Both

Maturity:
RS Research
DV Development
MI Mature Internal
MC Mature Commercial

See Notes.

NOTES:

1	AIMS (Agent-Based Infrastructure Modeling and Simulation) is an agent-based system to simulate and model the (national and cross-border) interdependencies and survivability of Canada's critical infrastructures. Point of Contact (POC): Dr. Stephen Marsh, Adjunct Professor, University of New Brunswick, Canada, Stephen.Marsh@nrc-cnrc.gc.ca
2	Athena is an analysis and modeling tool that is designed to analyze a network of nodes (actors, concepts, and physical) as a "system of systems" by merging various political, military, economic, social, information, and infrastructure (PMESII) models and their associated cross-dependencies. Athena incorporates several reasoning algorithms that allow sophisticated inter- and intra-dependency analysis between and through nodes. POC: Dr. Brian Drabble, On Target Technologies, brain@ontgttech.com
3	CARVER^2 is a simple software program that provides a quick and easy way to prioritizes potential terrorist targets. It compares and rates the critical infrastructure and key assets in jurisdictions by producing a mathematical score for each potential target. It is the first step for conducting more in-depth vulnerability assessments. CARVER^2 helps users make "apples vs. oranges" comparisons such as a water system vs. an energy grid vs. a bridge. POC: Ronald Peimer, National Infrastructure Institute Center for Infrastructure Expertise, rpeimer@ni2.org
4	CI^3 (Critical Infrastructures Interdependencies Integrator) is a software tool for emulating (Monte Carlo simulation) the amount of time or cost (or both) needed for activities that must be completed to restore a given infrastructure component, a specific infrastructure system, or an interdependent set of infrastructures to an operational state. The software tool provides a framework for recognizing interdependencies and incorporating uncertainty into the analysis of critical infrastructures. POC: Dr. James Peerenboom, Argonne National Laboratory, jpeerenboom@anl.com
5	CIMS (Critical Infrastructure Modeling System) is a high level M&S tool that allows visualization in a 3D environment the cascading consequence of infrastructure perturbations. Events can be scripted or assets directly manipulated within the environment during a simulation run to illustrate consequence. POC: Don Dudenhoeffer, Idaho National Laboratory, Donald.Dudenhoeffer@inl.gov
6	CIP/DSS (Critical Infrastructure Protection Decision Support System) simulates the dynamics of individual infrastructures and couples separate infrastructures to each other according to their interdependencies. CIP/DSS models asset information at the aggregate level. For example, a focus area can estimate the number of hospital beds affected by an event, but it cannot directly retrieve information relative to a particular hospital. It utilizes the commercial simulation software Vensim. POC: Randy Michelsen, Los Alamos National Laboratory, rem@lanl.gov POC: Theresa Brown, Sandia National Laboratories, tjbrown@sandia.gov
7	CIPMA (Critical Infrastructure Protection Modeling and Analysis) is a computer based tool to support business and government decision making for critical infrastructure (CI) protection, counter-terrorism, and emergency management, especially with regard to prevention, preparedness, and planning and recovery. POC: Australian Government – Attorney General's Department (AGD), Michael Jerks – Director, Major Projects, Michael.Jerks@ag.gov.au
8	CISIA (Critical Infrastructure Simulation by Interdependent Agents) is described by the authors as a hybrid of the two modeling approaches; interdependency analysis and system analysis. It is a bottom-up complex adaptive systems (CAS) model using interactive agents. The CISIA simulator is designed to analyze short term effects of failures in terms of fault propagation and performance degradation (Panzieri, 2004). POC: Stefano Panzieri Universita Roma Tre, Italy, panzieri@uniroma3.it
9	DEW (Distribution Engineering Workstation) provides over 30 applications for analysis, design, and control of electrical and other physical network systems. DEW allows all of its components (data sets and algorithms) to be reused by a new application, allowing new solutions to build on top of existing work. This provides for cross collaborations among different groups and the emergence of solutions to complex problems. DEW is being used to identify and analyze interdependencies in large scale electrical power systems and fluid systems of aircraft carriers. DEW is open architecture, non-proprietary. POC: Electrical Distribution Design, Inc., Dr. Robert Broadwater, dew@vt.edu
10	EMCAS (Electricity Market Complex Adaptive System) combines engineering techniques with quantitative market analysis: DC load flow models allow you to simulate the actual operation of the physical system configuration as well as regulatory rules imposed on market operations. POC: Guenter Conzelmann, Argonne National Laboratory, guenter@anl.gov
11	FAIT (Fast Analysis Infrastructure Tool) is primarily an economic analysis tool utilizing REMI to conduct economic impact assessment across multiple sectors. It does promote interdependency discovery for first order relationships. The program resides on an SNL server and supports web access. POC: Theresa Brown, Sandia National Laboratories, tjbrown@sandia.gov
12	FINSIM is an agent-based model of cash and barter transactions that are dependant on contractual relationships and a network at the federal reserve level. Agent based models create transactions which rely on telecommunications and electric power. POC: Randy Michelsen, Los Alamos National Laboratory, rem@lanl.gov
13	Fort Future is a collaborative, web-based planning system that uses simulation to test plans for Department of Defense (DoD) installations. It uses an open, service-oriented architecture to allow multiple simulations to be run simultaneously from the same set of alternative, organized into a study. The web-based workbench provides geographic information system (GIS)-based plan editors, controls simulations, and organizes results into a decision matrix. Fort Future assesses the impact of critical infrastructure on mission using a "Virtual Installation" simulation that contains models for transportation, electrical power, water systems, including waterborne chemical/biological/radiological (CBR) agents, airborne CBR plume, facilities, mission tasks and processes, agents, and dynamic plans. POC: U.S. Army Corps of Engineers, Engineer Research and Development Center, Construction Engineering Research Laboratory (CERL), Dr. Michael P. Case, Michael.P.Case@erdc.usace.army.mil
14	IEISS (Interdependent Energy Infrastructure Simulation System) is an actor-based infrastructure modeling, simulation, and analysis tool designed to assist individuals in analyzing and understanding interdependent energy infrastructures. The actor-based infrastructure components were developed in IEISS to realistically simulate the dynamic interactions within each of the infrastructures, as well as, the interconnections between the infrastructures. POC: Randy Michelsen, Los Alamos National Laboratory, rem@lanl.gov
15	IIM (Inoperability input-output model) based on Leontief's input-output model, characterizes interdependencies among sectors in the economy and analyzes initial disruptions to a set of sectors and the resulting ripple effects. POC: Yacov Y. Haimes, University of Virginia, haimes@virginia.edu
16	Knowledge Management and Visualization is a research project to analyze vulnerabilities associated with delivery of fuel. It is designed to help ensure availability of supply and to visualize the impacts for decision support. The project has focused on coal deliveries to power plants because, while vulnerabilities at the power plant level (production) are easier to identify, vulnerabilities and impacts associated with delivery of fuel are more uncertain. Also, data on coal shipments is readily available. POC: Carnegie Mellon University, H. Scott Matthews, hsm@cmu.edu
17	MIN (multilayer infrastructure network) is a preliminary network flow equilibrium model of dynamic multilayer infrastructure networks in the form of a differential game involving two essential time scales. In particular, three coupled network layers—automobiles, urban freight, and data—are modeled as being comprised of Cournot-Nash dynamic agents. An agent-based simulation solution structure is introduced to solve the flow equilibrium and optimal budget allocation problem for these three layers under the assumption of a super authority that oversees investments in the infrastructure of all three technologies and thereby creates a dynamic Stackelberg leader-follower game. POC: Purdue School of Civil Engineering, Dr. Srinivas Peeta, peeta@purdue.edu

18	MUNICIPAL (Multi-Network Interdependent Critical Infrastructure Program for Analysis of Lifelines) is a GIS user interface, built on a formal, mathematical representation of a set of civil infrastructure systems that explicitly incorporates the interdependencies among them. The mathematical foundation or decision support system is called the interdependent layered network (ILN) model. ILN is a mixed-integer, network-flow based model implemented in software drawing on a database containing infrastructure attributes. MUNICIPAL provides the capability to understand how a disruptive event affects the interdependent set of civil infrastructures. POC: Rensselaer Polytechnic Institute (RPI), Earl E. Lee II, Leee7@rpi.edu
19	N-ABLE (Next-generation agent-based economic laboratory) simulates the economy using an agent-based discrete-event model. Agents make economic decisions including purchasing products, hiring workers, selling bonds, collecting welfare payments, conducting open market operations, and others. N-ABLE has been used to evaluate electric power and rail transportation disruptions on commodity production. POC: Theresa Brown, Sandia National Laboratories, tjbrown@sandia.gov
20	NEMO (Net-Centric Effects-based operations MOdel) relies on the following domain specific legacy simulations: CitiLabs' Voyager simulation provides road and rail network analysis. Advantica provides the solver tools for electrical power networks, water and gas pipelines. Users define relationships between components. POC: Brent L. Goodwin, SPARTA Corporation, brent.goodwin@sparta.com
21	Net-Centric GIS is a framework for using GIS interoperability for supporting emergency management decision makers by providing effective data sharing and timely access to infrastructure interdependency information. POC: York University, Toronto, Ontario, Canada, Rifaat Abdalla, abdalla@yorku.ca
22	NEXUS Fusion Framework™ is a planning and response tool that visualizes intended and unintended effects and consequences of an event across multiple infrastructure, social, and population behavior models. It is a single framework that incorporates geospatial, graph based (social, economic), and population behavior models in the same simulation space for cross-infrastructure relationship analysis. The framework takes a holistic system-of-systems view to support cross system analyses of cascading events within and between complex networks. POC: IntePoint, LLC, Mark Armstrong, Mark.Armstrong@IntePoint.com
23	NGtools (natural gas infrastructure toolset). NGtools was developed to provide an analyst with a quick method to access, review, and display components of the natural gas network; perform varying levels of component and systems analysis, and display analysis results. POC: Argonne National Laboratory, Infrastructure Assurance Center (IAC), Dr. James Peerenboom, jpeerenboom@anl.gov
24	NSRAM (Network Security Risk Assessment Modeling) is centered on the analysis of large interconnected multi-infrastructure models. POC: Jim McManus, James Madison University, McManuJP@jmu.edu
25	PFNAM (Petroleum Fuels Network Analysis Model) was developed to perform hydraulic calculations of pipeline transport of crude oil and petroleum products. A network consists of links (pipe segments), nodes (pipe junctions), pump stations, valves, and pressure-reducing stations. The model tracks the flow of oil in each pipe and the pressure at each node. "Point-and-click" motions allow the analyst to create a representative model of the liquids pipeline network in order to set up and run a simulation. Graphical and tabular results provided for each simulation enable analysts to quantify the impact of infrastructure disruptions on the pipeline segment or system. This software tool provides a framework for introducing pipeline component dependencies into critical infrastructure analyses. POC: Argonne National Laboratory, Infrastructure Assurance Center, Steve Folga, sfolga@anl.gov
26	TRAGIS (Transportation Routing Analysis Geographic Information System), available via a client server architecture from a web server residing at ORNL. Calculates transportation rouge information based on regulatory guidance for shipping hazardous materials. POC: Paul E. Johnson, Oak Ridge National Laboratory, johnsonpe@ornl.gov
27	TRANSIM is an agent-based system capable of simulating a synthetic populations second-by-second movements of every person and vehicle through the transportation network of a large metropolitan area. TRANSIMS provides planners with a synthetic population's daily activity patterns (such as travel to work, shopping and recreation, etc.), simulates the movements of individual vehicles on a regional transportation network, and estimates the air pollution emissions generated by vehicle movements. POC: Randy Michelsen, Los Alamos National Laboratory, rem@lanl.gov
28	WISE (Water Infrastructure Simulation Environment) is an analytic framework supporting the evaluation of water infrastructure in terms of both infrastructure specific and interdependency issues. WISE involves the integration of geographic information systems with a wide range of infrastructure analysis tools including industry standard hydraulic simulation engines (e.g., EPANET and SWMM) as well as Los Alamos National Laboratory interdependency simulation systems such as the Interdependent Energy Infrastructure Simulation System (IEISS). POC: Randy Michelsen, Los Alamos National Laboratory, rem@lanl.gov

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INTRODUCTION

"The Nation's health, wealth, and security rely on the production and distribution of certain goods and services. The array of physical assets, processes, and organizations across which these goods and services move are called critical infrastructures."[2] This statement is as true in the U.S. as in any country in the world. Recent world events such as the 9-11 terrorist attacks, London bombings, and gulf coast hurricanes have highlighted the importance of stable electric, gas and oil, water, transportation, banking and finance, and control and communication infrastructure systems.

Be it through direct connectivity, policies and procedures, or geospatial proximity, most critical infrastructure systems interact. These interactions often create complex relationships, dependencies, and interdependencies that cross infrastructure boundaries. The modeling and analysis of interdependencies between critical infrastructure elements is a relatively new and very important field of study.

Much effort is currently being spent to develop models that accurately simulate critical infrastructure behavior and identify interdependencies and vulnerabilities. The results of these simulations are used by private companies, government agencies, military, and communities to plan for expansion, reduce costs, enhance redundancy, improve traffic flow, and to prepare for and respond to emergencies.

Modelers have developed various innovative modeling approaches including agent based modeling, effects-based operations (EBO) models, input-output models, models based on game theory, mathematical models, and models based on risk. These have been applied to infrastructure of shipboard systems, University campuses, large power grids, and waterways to name a few. Modeling is complicated by the quality and availability of data, intricacy of systems, complexity of interactions between infrastructure sectors, and implications and sensitivity of results.

This survey identifies and catalogs much of the state-of-the-art research being conducted in the area of infrastructure interdependency modeling and analysis.

Technical Support Working Group

The U.S. Technical Support Working Group (TSWG) is the sponsor for this effort.[3] TSWG is a national forum to identify, prioritize, and coordinate interagency and international research and development (R&D) requirements for combating terrorism. The aim of TSWG is to support rapidly developed technologies and product development to provide tools for combating terrorism. It supports multiple U.S. government agencies as well as major allies.

The main objective of this study is to develop a single source reference of critical infrastructure interdependency modeling tools (CIIMT) that could be applied to allow users to objectively assess the capabilities of CIIMT. This information will provide guidance for directing R&D to address the gaps in development. The results will inform the R&D efforts of the TSWG Infrastructure Protection Subgroup of R&D efforts and allow a more focused approach to addressing the needs of CIIMT end-user needs.

Background

The study and analysis of infrastructure interdependencies is relatively new. The interdependencies between critical infrastructures received little attention in the early 1990s. However, in the mid 1990s events such as the Oklahoma City bombing in 1995 and the report from the Defense Science Board Task Force on Information Warfare in 1996, and the increased reliance on information and computerized control systems brought the increasing importance of infrastructure interdependencies into focus. Also in 1996, President Clinton established the President's Commission on Critical Infrastructure Protection (PCCIP).[4]

The PCCIP report was released in 1997 and though it identified no immediate critical threats to national infrastructures, it did highlight the importance of interdependencies including those between power, transportation, emergency response, vital human services, banking and finance, and telecommunications, especially through digital means. A general recommendation of the commission was that since the lion's share (approximately 85%) of the nation's critical infrastructure is in private hands, there needs to be good cooperation and information sharing between government and private sector.

In May of 1998, Presidential Decision Directive (PDD) no. 63 was released. That directive set a national goal to protect the nation's critical infrastructure from deliberate attacks by 2003. PDD-63 was followed by executive orders (E.O.s) by both Presidents Clinton (E.O. 13130[5] in July 1999) and Bush (E.O. 13231[6] in 2001) establishing Information Sharing and Analysis Centers that were largely private-sector run and a National Infrastructure Advisory Council (NIAC). While there were some changes in the wording of the E.O.s, the functions of NIAC remained largely the same.

We have since seen the establishment of the U.S. Department of Homeland Security (DHS) in November of 2002 and the National Infrastructure Simulation and Analysis Center (NISAC) in fall of 2001. NISAC is a partnership between Sandia National Laboratory (SNL) and Los Alamos National Laboratory (LANL) established to develop advanced infrastructure modeling and simulation techniques that identify vulnerabilities and interdependencies.

This increased attention has been followed by increases in funding to universities, national laboratories, and private companies involved in modeling and simulation of critical interdependencies. Funding has come from national organizations, private investments, the Department of Defense (DoD), U.S. government agencies (DHS, U.S. Department of Energy [DOE], Department of Commerce, and others), and other governments and agencies.

The increased funding and level of efforts has led to much innovative work in this area. Thus, while efforts focusing on modeling of critical infrastructure interdependencies have only begun recently, much valuable work has already been done.

INFRASTRUCTURE INTERDEPENDENCIES

"One of the most frequently identified shortfalls in knowledge related to enhancing critical infrastructure protection capabilities is the incomplete understanding of interdependencies between infrastructures. Because these interdependencies are complex, modeling efforts are commonly seen as a first step to answering persistent questions about the "real" vulnerability of infrastructures."[7]

The importance of "What are infrastructure inter-dependencies, and how are they modeled?" is addressed in this section. References to interdependent relationships in this paper are actually referring to as dependent relationships or influences between infrastructures. Figure 1 illustrates common representations of infrastructure based on the scenario of a flooding event and the subsequent response. Parallels to this scenario with the events in New Orleans during Hurricane Katrina can easily be drawn. Within the figure, individual infrastructure networks are represented on a single plane. The parallel lines represent individual sectors or subsets within that particular infrastructure. The spheres or nodes represent key infrastructure components within that sector from the events in New Orleans

The energy sector infrastructure, for example, during Hurricane Katrina contains the sectors of electrical generation and distribution, natural gas production and distribution, etc. Ties and dependencies exist within each infrastructure and between the different sectors. The solid lines in Figure 1, crossing sectors and connecting nodes, represent internal dependencies, while the dashed lines represent dependencies that also exist between different infrastructures (infrastructure interdependencies).

The example in Figure 1 is a simple attempt to portray the complexity of dependencies that may exist between components. In chaotic environments such as emergency response to catastrophic events, decision makers should

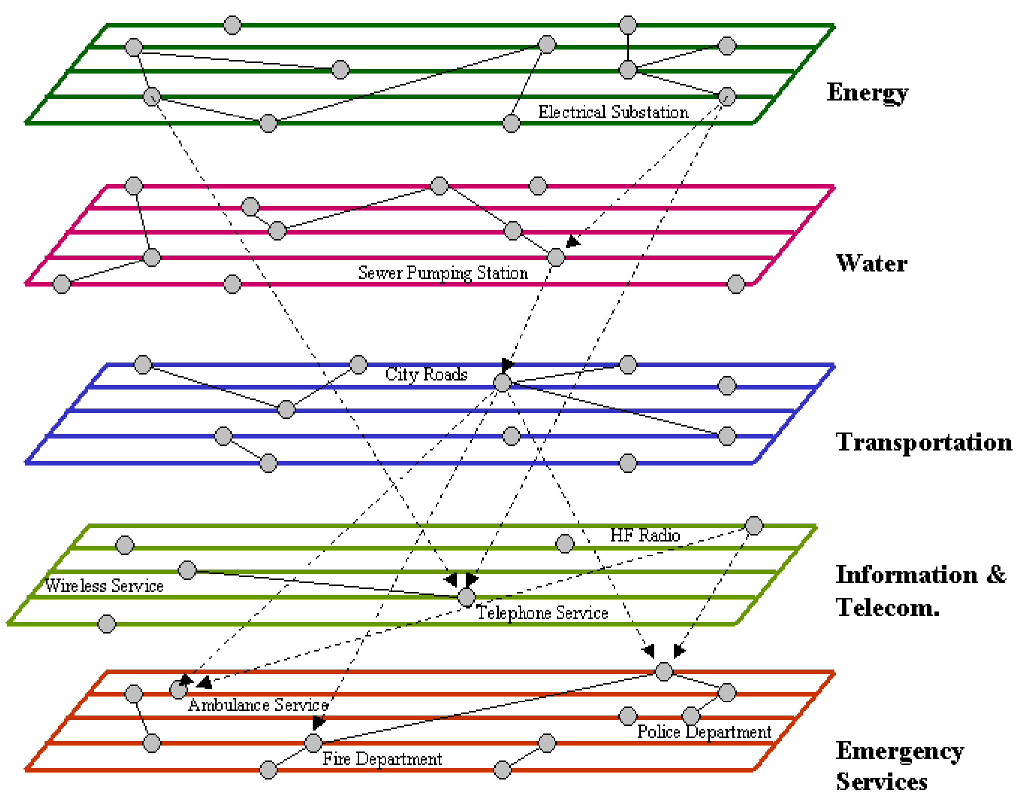


Figure 1. Infrastructure interdependencies.

understand the dynamics underlying the infrastructures. Failure to understand those dynamics will result in ineffective response and poor coordination between decision makers and agencies responsible for rescue, recovery, and restoration. It could also cause the mismanagement of resources, including supplies, rescue personnel, and security teams. At best, emergency responders will lose public trust, at worst, human life.

This interrelationship among infrastructures and its potential for cascading effects was never more evident than on July 19, 2001 when a 62-car freight train carrying hazardous chemicals derailed in Baltimore's Howard Street Tunnel, Figure 2.

This disaster, in addition to its expected effect on rail system traffic, automobile traffic, and emergency services, caused a cascading degradation of infrastructure components not previously anticipated. For example, the tunnel fire caused a water main to break above the tunnel shooting geysers 20 ft into the air, Figure 3. The break caused localized flooding which exceeded a depth of three feet in some areas.

Additionally, the flooding knocked out electricity to about 1,200 downtown Baltimore residences.[8] Fiber optical cables running through the tunnel were also destroyed. This resulted in major disruptions to phone and cell phone service, email service, web services, and data services to major corporations including WorldCom Inc., Verizon Communications Inc., the Hearst Corp. in New York City, Nextel Communications Inc., and the Baltimore Sun newspaper.[9] Disruption to rail services and its effects on the Middle Atlantic states were significant also.[10] These effects included delays in coal delivery and also limestone delivery for steel.

Figure 2. Thick, black smoke billows out of the railroad tunnel near Oriole Park at Camden Yards. Interstate 395 and the baseball park were closed, along with the Inner Harbor (see Reference 9).

Figure 3. An official surveys the gaping hole and broken 40-in. water main at Howard and Lombard streets (see Reference 10).

A dependency matrix is another way to represent interdependencies between infrastructure networks and their relative impact. The Critical Infrastructure Protection Task Force of Canada used a dependency matrix (see Figure 4) to relate the interdependency among six sectors identified as crucial: Government, Energy and Utilities, Services, Transportation, Safety, and Communications.[11] The matrix is their attempt to better understand the level of dependency and the potential impact among sectors.

Infrastructure owners historically concerned with the operation of their own, often well defined domains must now contend with unbounded networks brought about by greater information technology connectivity. There is a growing need to analyze and better understand the chains of influence that cross multiple sectors that can induce potentially unforeseen secondary effects. This survey addresses a growing concern dealing with the influence or impact, that one infrastructure can have, either directly or indirectly, upon another. The cross infrastructure effects continue to grow as information technology pushes interconnectivity between all aspects of business.

Infrastructure interdependencies therefore refer to relationships or influences that an element in one infrastructure imparts upon another infrastructure.

Interdependency Formalization

Precisely how is an infrastructure interdependency relationship defined? Dudenhoeffer, Permann and Manic[12] model the levels of infrastructure as a large graph in which nodes represent infrastructure components, and edges the relations between nodes.

Sector		Energy & Utilities					Services		
	Element	Electrical Power	Water Purification	Sewage Treatment	Natural Gas	Oil Industry	Customs and Immigration	Hospital & Health Care Services	Food Industry
Energy & Utilities	Electrical Power		L			M			
	Water Purification	H				M			
	Sewage Treatment	M	H			H			
	Natural Gas	L				L			
	Oil Industry	H	L						
Services	Customs & Immigration	H	L	L	L	L		L	
	Hospital & Health Care Services	H	H	L	H	H	M		H
	Food Industry	H	H	H	L	M	M	L	

Key: H High M Medium L Low

Figure 4. Sample dependency matrix.

A formal model of this infrastructure and the interrelationships is presented in the following definitions:

1. *An infrastructure network, I, is a set of nodes related to each other by a common function. The network may be connected or disjoint. It may be directional, bi-directional or have elements of both. Internal relationships/dependencies within the infrastructure I are represented by edge (a, b) with $a, b \in I$.*

2. *Given I_i and I_j are infrastructure networks, $i \neq j$, $a \in I_i$ and $b \in I_j$, an interdependency is defined as a relationship between infrastructures and represented as the edge (a,b) which implies that node b is dependent upon node a. Depending on the nature or type of the relationship, this relationship may be reflexive in that $(a,b) \rightarrow (b,a)$.*

Interdependency Types

Interdependencies can be of different types. Several taxonomies have been presented[3] to categorize the types of interdependencies.

Rinaldi, Peerenboom, and Kelly[13] describe dependencies in terms of four general categories:

- Physical – a physical reliance on material flow from one infrastructure to another
- Cyber – a reliance on information transfer between infrastructure
- Geographic – a local environmental event affects components across multiple infrastructures due to physical proximity
- Logical – a dependency that exists between infrastructures that does not fall into one of the above categories.

This study used a slightly expanded taxonomy developed by Dudenhoeffer and Permann.[4] The categorization classifies the following types of relationships:

- *Physical.* A requirement, often engineering reliance between components. For example: a tree falls on a power line during a thunderstorm resulting in a loss of power to an office building and all the computers inside.
- *Informational Interdependency*. An informational or control requirement between components. For example: a supervisory control and data acquisition (SCADA) system that monitors and controls elements on the electrical power grid. A loss of the SCADA system will not by itself shut down the grid, but the ability to remotely monitor and operate the breakers is lost. Likewise, this relationship may represent a piece of information or intelligence flowing from a node that supports a decision process elsewhere. An example is the dispatch of emergency services. While the responders may be fully capable of responding, an informational requirement exists as to answering where, what, and when to initiate response.
- *Geospatial Interdependency.* A relationship that exists entirely because of the proximity of components. For example: flooding or a fire may affect all the assets located in one building or area.
- *Policy/Procedural Interdependency.* An interdependency that exists due to policy or procedure that relates a state or event change in one infrastructure sector component to a subsequent effect on another component. Note that the impact of this event may still exist given the recovery of an asset. For example: after aircraft were flown into the World Trade Towers "all U.S. air transportation was halted for more than 24 hours, and commercial flights did not resume for three to four days."[14]
- *Societal Interdependency.* The interdependencies or influences that an infrastructure component event may have on societal factors such as public opinion, public confidence, fear, and cultural issues. Even if no physical linkage or relationship exists, consequences from events in one infrastructure may impact other infrastructures. This influence may also be time sensitive and decay over time from the original event grows. For example: air traffic following the 9-11 attack dropped significantly while the public evaluated the safety of travel. This resulted in layoffs within

the airline industry and bankruptcy filings by some of the smaller airlines (see Reference 12).

Again, while the dependencies within an individual infrastructure network are often well understood, the region of interest in interdependency and effects modeling is the influence or impact that one infrastructure can impart upon another. Therefore, the key effects to model and gain understanding of are the chains of influence that cross multiple sectors and induce potentially unforeseen n-ary effects. These chains, potentially composed of multiple interdependency types, compose the paths or arcs between infrastructure components or nodes denoted as *{(a,b), (b,c), (c,d), ...(y,z)}*. This particular path represents the cascading consequence of an event or the derived dependency of node *z* on node *a*, further denoted *(aDz)*. Likewise the genesis of the chain may not be singular in that the end effect is the influence of multiple nodes, denoted by *(abc..Dz)*.

These paths may not be unique in terms of effect, they may change over time, and their behavior may be cumulative in nature, i.e., the end effect may be the culmination of multiple predicated events. The intertwining of networks in this fashion represents a complex system where emergent behaviors are rarely fully understood. Rinaldi, Peerenboom and Kelly (see Reference 13) provide a nice visual representation of this intertwining and the potential cascading effects. This is shown in Figure 5.

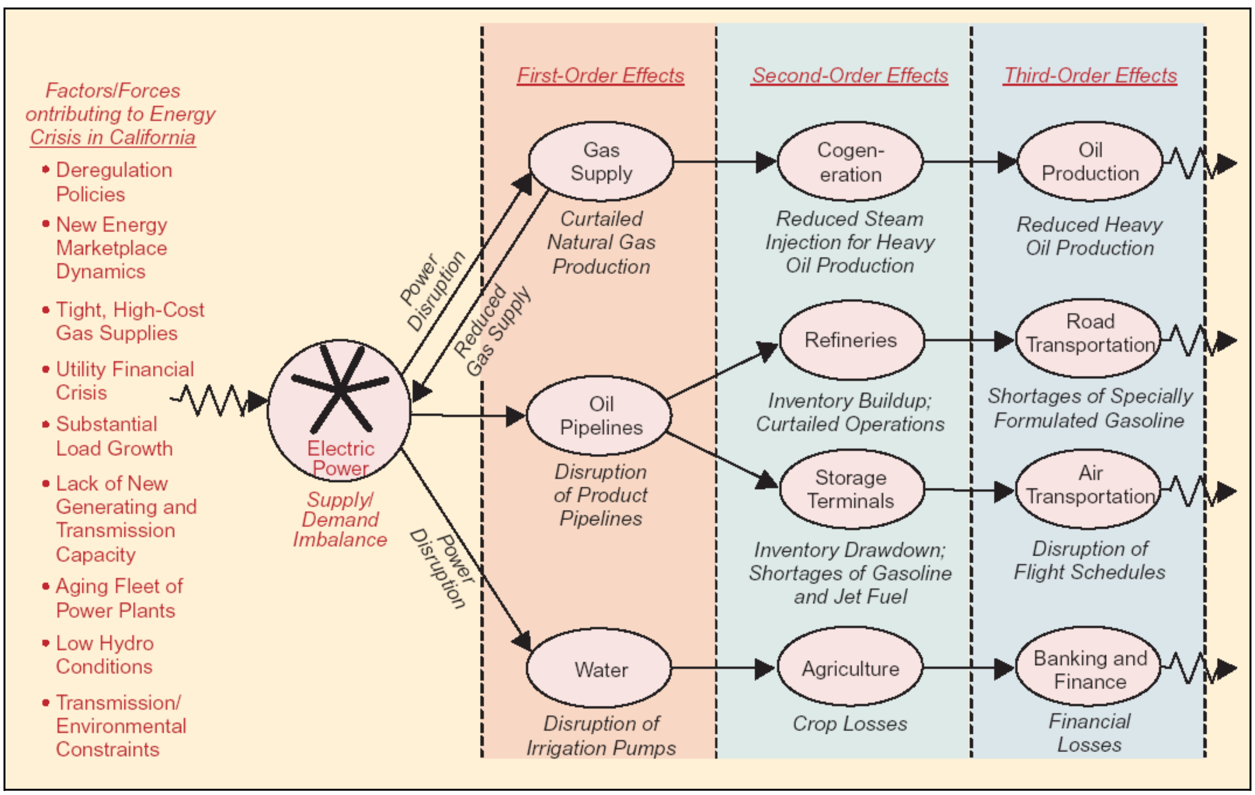


Figure 5. Cascading consequence example (see Reference 13).

Problem Space

Thus given the realm of interdependency analysis, what are the goals for modeling and simulation efforts? In the analysis of infrastructure interdependencies and the subsequent emergent system behaviors, some of the major problem areas being examined include:

1. Given a set of initiating events *{E(a), E(b), …}* what is the cascading impact on a subset of nodes *{x, y, z , …}?*

2. Given a set of nodes *{x, y, z,…}* and a desired end state, what is a set of events *{E(a), E(b), …}* that would cause this effect?

3. Given a set of events *{E(a), E(b), …}* and a set of observed outcomes of on nodes *{x, y, z,….},* is it possible to determine the derived interdependence *(abDxyz)?*

4. Given a set of infrastructure networks and a critical function, what is the subset of critical nodes *{x, y, z , …}* across all networks that will adversely impact a specific mission functionality due to direct or derived dependency?

SURVEY METHODOLOGY

The areas included in this survey were selected because they focus on modeling and simulation across multiple infrastructure layers. Systems such as geographical information systems (GIS), which may provide geospatial relationships, are not included unless they possess additional analytical capabilities.

Each model examined in the survey offers unique capabilities and provides specific insights into various aspects of the problem domain. The modeling approaches and the objectives of the efforts varied greatly. Specific parameters in the survey were of interest for comparison. One of the goals of the survey was to identify potential resources for a wide range of customers and domains.

Six major categories were considered in the survey:

- Infrastructures
- Modeling and simulation technique
- Integrated vs. coupled models
- Hardware/software requirements
- Intended user
- Maturity level.

Each of these categories is briefly discussed below.

Infrastructures

The U.S. Patriot Act defines critical infrastructure as "systems and assets, whether physical or virtual, so vital to the U.S. that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters."[15]

Further, congress set forth the following findings in Section 1016 of the U.S. Patriot Act:

- The information revolution has transformed the conduct of business and the operations of government as well as the infrastructure relied upon for the defense and national security of the U.S.
- Private business, government, and the national security apparatus increasingly depend on an interdependent network of critical physical and information infrastructures, including telecommunications, energy, financial services, water, and transportation sectors.
- A continuous national effort is required to ensure the reliable provision of cyber and physical infrastructure services critical to maintaining the national defense, continuity of government, economic prosperity, and quality of life in the U.S..
- This national effort requires extensive modeling and analytic capabilities for purposes of evaluating appropriate mechanisms to ensure the stability of these complex and interdependent systems, and to underpin policy recommendations, so as to achieve the continuous viability and adequate protection of the critical infrastructure of the Nation.[16]

Although countries tend to have slightly different lists detailing their "critical sectors," most contain elements of the following:

- Agriculture and food
- Water
- Public health and safety
- Emergency services
- Government
- Defense industrial base
- Information and telecommunications
- Energy
- Transportation
- Banking and finance
- Industry/manufacturing
- Postal and shipping.

These sectors in turn contain individual infrastructures such as highways, rail systems, electric power generation and distribution, etc.

Some of these systems are managed by government agencies, but the majority resides with industry.

This survey attempts to capture and describe the infrastructures/infrastructure sectors each program models. This report seeks to reflect only those infrastructures that have been actually modeled and not those presumed to be capable of being modeled.

Modeling and Simulation Technique

This category attempts to capture the modeling and simulation method used for the infrastructure and interdependencies. It has multiple dimensions that include those of time (continuous vs. discrete time step) and modeling technique (Markov chains, Petri Nets, dynamic simulation, agent-based, physics based, ordinary differential equations, input-output model, etc.).

Integrated vs. Coupled Models

During the course of the survey it became apparent that two different approaches were often used to conduct cross infrastructure analysis. One approach was to create an integrated system model that attempted to model multiple infrastructures and their interdependencies within one framework. The other approach coupled a series of individual infrastructure simulations together, which then illustrated the cascading influence between them. An example of this approach would be an electric grid simulation that determines an outage area for a specific event. The electrical outage area is then fed to a telecommunication model used to determine the subsequent impact on message routing. This impact is fed to a financial simulation that determines the loss of telecommunication impact on commerce and financial transactions. As one might expect, integrated models tend to model at a much higher level than coupled models.

Hardware/Software Requirements

In an effort to identify possible tool sets, the survey captures the portability and exportability of programs and data.

Intended user

The survey categorizes products as internal analytical tools intended for internal use only or external analytical tools available for use outside the developing organization. This decision relates to the level of expertise required to use the product, the application requirements, and the analytical output of the product. The requirement is sometimes driven by the size, complexity, or proprietary nature underlying the data

Maturity level

The following four categories were used to identify the product's level of maturity:

- *Research* – the product is still highly conceptual without vetted application in real-world domains.
- *Development* – the product has been applied and validated against real-world infrastructure. Beyond conceptual, the product has been used by internal or external customers, but is still undergoing substantial development.
- *Mature analytic* – the product has reached a high level of code stability and is part of a vested internal analytical process. The results of analysis may be an external report, but the tool usage is strictly internal to the organization.
- *Mature commercial* – the tool is a commercially licensed product.

STATE-OF-THE-ART REPORT

Appendix A contains data on U.S. and international efforts and interdependency modeling tools. The information is presented at a high level with POC information for those desiring greater detail.

POLITICAL, MILITARY, ECONOMIC, SOCIAL, INFORMATION, AND INFRASTRUCTURE MODELING ACTIVITIES

A modeling area that closely follows infrastructure interdependency modeling is EBO modeling and analysis. War and conflict are rarely confined to only the battlefield and force-on-force engagement. Potential U.S. adversaries comprise a complex and interdependent system of systems, all of which contribute, to some degree, toward their societal coherence, will, and capability to pursue a course of action contrary to U.S. interests.[17] Conflict, war, and reconstruction represent a complex set of influences, competing goals, and resources. The battle environment, and thus the means of victory, are often shaped by the intricate interactions between them.

Many point to the emergence of a new generation of warfare termed fourth generation warfare (4GW). Retired Colonel Thomas Hammes, U.S. Military Complex, describes this concept:

> "4GW uses all available networks—political, economic, social, and military—to convince the enemy's political decision makers that their strategic goals are either unachievable or too costly for the perceived benefit. It is an evolved form of insurgency. Still rooted in the fundamental precept that superior political will, when properly employed, can defeat greater economic and military power, 4GW makes use of a society's networks to carry on its fight. Unlike previous generations of warfare, it does not attempt to win by defeating the enemy's military forces. Instead, via the networks, it directly attacks the minds of enemy decision makers to destroy the enemy's political will."[18]

Operational Net Assessment (ONA) is the integration of people, processes, and tools that use multiple information sources and collaborative analysis to build shared knowledge of the adversary, the environment, and ourselves in understanding and effectively employing EBO. ONA analytical products are based on a system-of-systems analysis and the understanding of key relationships, dependencies, strengths, and vulnerabilities within and between the adversary's political, military, economic, social, information, and infrastructure (PMESII) elements. These products identify leverage points, key nodes, and links that we can act upon to decisively influence the adversary's behavior, capabilities, perceptions, and decisions.[19]

Within this operating environment, EBOs are actions that change the state of a system to achieve directed policy aims using the integrated application of the diplomatic, informational, military, and economic instruments of national power. In order to achieve EBO, however, it is imperative to understand the relationships and influences of the PMESII dimensions that shape the actions of the adversary, of allies, and of your organization. Figure 6 illustrates this concept showing a representation of the connectivity and interdependencies between these dimensions as both a strength and potential weakness.

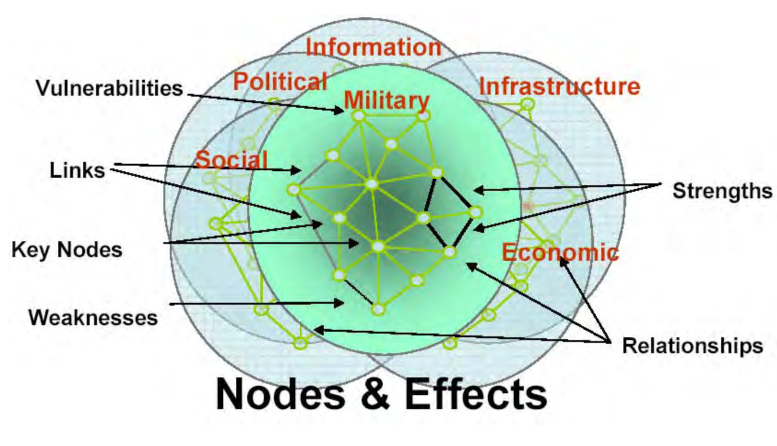


Figure 6. PMESII node and effects relation (see Reference 19).

DATA SOURCES

The paradigm of modeling and simulation is "garbage in, garbage out." Having credible and traceable data available to use is key to infrastructure and interdependency modeling. Gathering information on a particular infrastructure is possibly the most significant challenge. Interdependency modeling also requires that gathered information (assets) be linked across multiple infrastructures. Supporting data for these analyses often spread across multiple data sets. The fact that most infrastructures data is held by private industry and, to a large extent, considered proprietary in nature complicates the situation further. The data is often accompanied by the analytical requirement for a certain level of domain expertise in identifying and validating cross infrastructure influences.

The scale of the model also determines the possible sources of information. Consider, for example, the electrical power grid. If the goal is to model assets on a national scale, data equivalent to transmission level information may suffice with broad asset effects drawn from course outage area determination. If the goal is to evaluate a particular city, compound, or facility, distribution level information is required reflecting a far greater level of granularity.

Commercial geospatial data sets such as those provided by ESRI, Platts, etc., provide coarse level data that may suffice for initial model development, but they lack the detail needed to construct a more precise model. Public census provides a good data source for an initial data set. Recall however, that the census data reflects nighttime residential demographics in terms of grid-wise statistics, which may not be adequate in terms of population mobility and granularity.

To mitigate the shortcomings of data, several efforts have been made to compose and validate detail infrastructure and demographic data sources. Two of the data sets used by those surveyed are LandScan and National Asset Database:

- *LandScan* – The LandScan series of data sets have been developed and are maintained by Oak Ridge National Laboratory. They are a population distribution model, database, and tool developed from census data that incorporates other spatial information for greater accuracy and granularity. The LandScan series consist of LandScan Global representing data in 30 arc second grid cells for ~1 km resolution, LandScan Interim, which has a 15-arc (~450 m) second resolution, and LandScan USA with 3-arc-second resolution for ~90 m resolution with both day and night time population distributions and demographic and socio-economic characteristics data.[20]
- *National Asset Database* – In July 2004, the Office of Infrastructure Protection (DHS/IP) initiated a data call to states and territories requesting a listing of assets deemed of national or local importance. The collection, named the National Asset Database, contains basic asset and facility information, including data associated with location, POC, and risk attributes.

In addition to these specialized data sets, several DOE national laboratories maintain system expertise that includes detailed infrastructure data. These information sets are, to a large degree, the result of industry nondisclosure agreements and therefore are not generally releasable for public use.

- LANL – National electrical generation and transmission data
- Argonne National Laboratory (ANL) – Natural gas and oil pipeline data
- Oak Ridge National Laboratory (ORNL) – National transportation sector information including rail systems, highway, and waterway data and models
- Idaho National Laboratory (INL) – National electrical power SCADA system information.

U.S. RESEARCH AND SPONSORING ORGANIZATIONS

The modeling and simulation of infrastructure interdependencies is a substantial effort in terms of development resources such as infrastructure expertise, modeling and simulation, data accessibility, and so on. For this reason, U.S. government agencies are currently doing most of the research in this area. In order to understand the current focus on ongoing research, it is important to understand the thrust of these organizations. A brief description of the more prominent supporting agencies and their programs are described as follows:

- *Department of Homeland Security (DHS)* – The NISAC provides advanced modeling and simulation capabilities for the analysis of critical infrastructures, their interdependencies, vulnerabilities, and complexities. These capabilities help improve the robustness of our nation's critical infrastructures by aiding decision makers in the areas of policy analysis, investment and mitigation planning, education and training, and near real-time assistance to crisis response organizations. The NISAC program is sponsored by the DHS Information Analysis and Infrastructure Protection Directorate. NISAC is a core partnership of Los Alamos and Sandia National Laboratories. NISAC integrates the modeling and simulation expertise of both laboratories to address the nation's potential vulnerabilities and the consequence of disruption among our critical infrastructures.[21]

- *Department of Energy* (DOE) – The Visualization and Modeling Working Group (VMWG) sponsored by DOE's Office of Electricity Delivery and Energy Reliability activates in response to national energy emergencies to provide data, analyses, and visualization tools as was done for Hurricanes Katrina and Rita. The VMWG was formed in September 2003 to improve the ability of DOE to perform quick turn-around analyses during energy emergencies. It is comprised of energy experts from several DOE offices and energy infrastructure and modeling experts from various DOE national laboratories. Their technical expertise is combined with modeling, GIS, data libraries on past energy disruptions, and other tools to conduct in-depth analysis. DOE national laboratories provide the bulk of this modeling and analysis.[22]

- *Technical Support Working Group (TSWG)* – TSWG is an inter-agency organization tasked with providing technologies to a variety of government organizations. Their development and product deployment goals focus on identifying and answering specific programmatic needs versus sponsoring national infrastructure modeling and simulation initiatives. This study attempts to identify available and developing resources that may be utilized to address those needs.[23]

- *Defense Advanced Research Projects Agency (DARPA)* – DARPA is a central research and development organization for DoD. It manages and directs selected basic and applied research and development projects for DoD, and pursues research and technology where risk and payoff are both very high and where success may provide dramatic advances for traditional military roles and missions. DARPA also has a research program in the area of cross-dimensional infrastructure influence modeling. By focusing on PMESII dimension interactions, DARPA is leading the Integrated Battle Command. The objective of this program is the development of decision aids to support the commander in conducting a future, complex, multidimensional, coalition, and effects-based campaign. The decision aids will assist the commander and staff in generating, assessing, and visualizing the consequences of employing diplomatic, military, information operations and economic actions, singularly or in combinations, to achieve effects against the adversary's PMESII systems. The decision aids will also assist the commander and staff in constructing, visualizing, and evaluating campaign plans that exploit the impact of multidimensional effects and the interaction among effects. http://www.darpa.mil/ato/solicit/IBC/index.htm.

- *Department of the Air Force, Air Force Materiel Command, (AFRL)* – Similar to DARPA, AFRL is leading multiple research efforts in developing PMSEII analytical models. One effort is the Commander's Predictive Environment program, whose objective is to provide a decision support environment that enables the joint force commander to anticipate and shape the future battlespace. Similar in view to the DARPA effort, the battlespace is seen as a complex and interrelated system of PMESII dimensions. A full understanding of the battlespace requires comprehension of how these interrelated factors affect not only the adversary, but also friendly forces. The focus of this research program is to (1) model and analyze adversaries, self, and neutrals as a complex adaptive system; (2) understand key relationships, dependencies, and vulnerabilities of adversary/self/neutrals; and (3) identify leverage points that represent opportunities to influence capabilities, perceptions, decision making, and behavior.[24]

CHALLENGES AND RESEARCH NEEDS

Critical infrastructure interdependency modeling has many of the same challenges that one can expect with any modeling and simulation domain: data accessibility, model development, and model validation. Interdependency modeling is further complicated by the extremely large and disparate cross sector analysis required. Many extremely detailed single sector models have been developed. One driving research question asks: “How do we leverage these existing models into a common operating picture?” Such a question is further exasperated by the granularity and the time factors associated with the models. For example, Table 1 illustrates the multiple time scales that exist within the electrical power sector.

While currently no standards exists that directly address infrastructure and specifically cross sector modeling, standards do exists for exchanging information between distributed simulations. The two most common methods are the High Level Architecture (HLA) and the Distributed Interactive Simulation (DIS) frameworks.

HLA, developed under the leadership of the Defense Modeling and Simulation Office is a general purpose high-level simulation architecture/framework to facilitate the interoperability of multiple types of models and simulations. The purpose of its development is to support reuse and interoperability across the large numbers of different types of simulations developed and maintained by DoD. Within HLA, simulation objects exist as federates in a larger simulation federation. HLA was approved as an open standard through the Institute of Electrical and Electronic Engineers (IEEE) — IEEE Standard 1516 — in September 2000.

Table 1. Multiscale time hierarchy of power systems.[25]

Action/Operation	Time frame
Wave effects (fast dynamics, lightning caused over voltages)	Microseconds to milliseconds
Switching over voltages	Milliseconds
Fault protection	100 milliseconds or a few cycles
Electromagnetic effects in machine windings	Milliseconds to seconds
Stability	60 cycles or 1 second
Stability augmentation	Seconds
Electromechanical effects of oscillations in motors & generators	Milliseconds to minutes
Tie line load frequency control	1 to 10 seconds; ongoing
Economic load dispatch	10 seconds to 1 hour; ongoing
Thermodynamic changes from boiler control action (slow dynamics)	Seconds to hours
System structure monitoring (what is energized & what is not)	Steady state; ongoing
System state measurement and estimation	Steady state; ongoing
System security monitoring	Steady state; ongoing
Load management, load forecasting, generation scheduling.	1 hour to 1 day or longer; ongoing
Maintenance scheduling	Months to 1 year; ongoing.
Expansion planning	Years; ongoing
Power plant site selection, design, construction, environmental impact, etc.	10 years or longer

Table 2 provides a listing of HLA strengths and weaknesses as detailed by Schmitz and Neubecker.[26] Additional information on HLA can be found by contacting hla@dmso.mil or via the website https://www.dmso.mil/public/transition/hla/.

Table 2. Strengths and weaknesses of HLA.

HLA Strengths	HLA Weaknesses
HLA is an open standard that will be supported beyond 2006 (ref. IEEE 1516).	HLA developments may be subject to significant changes in order to meet future needs.
The architecture can be implemented across different computing environments.	Changes to future HLA standards may have significant impact on local implementations.
Provides a documented process for developing distributed simulation systems, e.g., the federation development execution process.	U.S. will continue to lead HLA development and thus there may be dependence on U.S. support for software implementations.
More "bandwidth" friendly.	The resources and time required to implement an HLA federation can be significant — up to double that required for noncompliant implementations.
Supports real-time, faster than real-time, and event-driven time domains.	HLA does not ensure plug-and-play interoperability, it facilitates communication.
Availability of commercial off the shelf (COTS) software support tools, e.g., data capture/replay, simulation (federation) exercise management (reduces the requirements for bespoke developments).	HLA compliance cannot be established in abstract, but only by reference to a defined federation.

DIS is another framework for linking real-time and potentially distributed simulations. Defined under IEEE Standard 1278, the chief objective of DIS was to create real-time, synthetic, virtual representations of the warfare environment. This environment is created by interconnecting separate, distributed computers/simulators, called component simulator nodes. These nodes typically represent entities on the order of a military unit. DIS has its roots in the DARPA simulation networking program. Table 3 provides an assessment of the strengths and weakens of DIS by the IAPG. Further information on DIS can be found at http://www.sei.cmu.edu/architecture/Architectures_for_DIS.html#291.

Table 3. Strengths and weaknesses of DIS.

DIS Strengths	DIS Weaknesses
DIS is an open standard (ref: IEEE 1278.x).	Scalability – difficult to scale up to very large exercises, e.g., >500 simulation entities.
The architecture can be implemented across different computing environments.	Efficiency – rigid structure of data protocols (PDUs) leads to inefficiency of network resources, e.g., wide area network (WAN) bandwidth.
Provides a set of well defined data protocols to support the interaction of real-time simulation systems.	IEEE standards will not be developed to meet future simulation requirements.
Availability of COTS software support tools (e.g., DIS Stealth Viewers, DIS Data Loggers) reduces the requirements for bespoke developments.	DIS only supports real-time simulations, it does not support event driven, faster than real-time applications.
DIS is a stable "product."	Limited number of PDUs.

HLA and DIS are examples of frameworks that integrate "real-time" simulation models. Information is passed actively between models and timing between models is synchronized. This method may support some aspects of infrastructure model integration. The issue may arise however when the computational time for processing a model makes this type of integration unrealistic, i.e., the computational requirements greatly exceed real-time.

One potential method to address this issue and also to provide a more rapid response capability is to develop scenario libraries consisting of preprocessed scenarios with run profiles available for immediate access. Los Alamos National Laboratory utilizes this approach with their Scenario Library Visualizer.

Another method of model integration consists of devising a common architecture to distribute information between models. This method is currently used by Los Alamos National Laboratory and NISAC to relate impacts across different infrastructure models. In a broad sense, a damage profile based on expected physical damage is constructed first. An example of this is determining power outages based on projected high wind profiles, surge, and flooding models associated with hurricanes. The physical impact of the event is transformed into impact on the power grid in terms of outage areas. This information is then passed to other models (water, financial, transportation, etc.) such that the corresponding impact in the electrical power sector integrates into other sectors. In this way, impact cascades across infrastructure boundaries and presents potential effects via infrastructure interdependencies. This type of model integration works well when the timing between infrastructures precludes a true federation of simulations.

Interdependency discovery and validation is another challenging area of research. Although physical interdependencies can be derived by subject matter experts, doing so on a large scale is a resource challenge. Discovery methods and tools, including automated mapping, are essential for high-fidelity models. Fast Analysis Infrastructure Tool (FAIT) by Sandia National Laboratory conducts rough first order interdependency mapping based on simple rule sets. The IEISS model and Los Alamos National Laboratory suite of models use outage areas to identify geospatial and gross order dependencies. The Critical Infrastructure Modeling System (CIMS) developed by Idaho National Laboratory likewise supports geospatial dependencies, but requires manual direct association for other dependencies.

Identifying and mapping societal interdependencies is perhaps the most challenging aspect in terms of discovery, mapping, and validation. Identifying a multicultural response and the duration of impacts on a society is challenging. The impact of “like” events can be speculated, but drawing inferences to unforeseen and rare events relative to the other infrastructure sectors is a challenging area of active research. This is one of the main focuses of PMESII research that is underway.

CONCLUSIONS

Infrastructure interdependency modeling is a relatively new area of research and analysis, but recent events of both natural disasters and malicious acts have shown that the impact of these cross infrastructure relationships can be measured. Significant research efforts are underway in the U.S. and abroad.

One observation resulting from this effort is that no cross program working group or forum is specifically dedicated to this critical area of research. Most research exchange occurs within specific programs. Consequently, a limited exchange of ideas has occurred across the sponsoring agencies in this area. The strongest collaboration exists between DHS and DOE, mainly due to the fact that the same research teams are sponsored by both organizations. One suggestion from our study is the development, whether formally or informally, of a national or international working group with a central focus of infrastructure interdependency analysis. It is hoped that this state-of-the-art report will serve to not only report on current activities, but will also act as a catalysts for information exchange for such activities.

ACKNOWLEDGEMENT

We appreciate the many contributors to this report. Our preferred method has been to directly interact with the project leaders in collecting this information. All that have participated have been extremely supportive. Again, this is an ongoing project and we apologize to those efforts which were not recognized in this first report.

Please forward comments on material contained within this document and also points of contacts for those efforts not covered in this initial document to Donald.Dudenhoeffer@inl.gov.

Finally, we would like to express our gratitude to Dr. Steve Fernandez of Los Alamos Laboratory who acted as a constant guide and source of data for this report.

Appendix A

Table Abbreviations:

Infrastructure Sectors	
EP	Electric Power
NG	Natural Gas
DW	Drinking Water
SW	Sewage Water
ST	Storm Water
HA	Human Activity
FN	Financial Networks
SCADA	Supervisory Control and Data Acquisition
TC	Telecom
CN	Computer Networks
OL	Oil Pipeline
RL	Rail System
HW	Highway System
WW	Waterway System
POL	Policy/Regulatory constraints
Simulation Type	
I	Input-Output Model
A	Agent-based
Intended Users Types	
IA	Internal Analyst
EA	External Analyst
B	Both
Maturity Level	
RS	Research
DV	Development
MI	Mature Internal
MC	Mature Commercial

Model Name	Agent-Based Infrastructure Modeling and Simulation (AIMS)	
Organization **POC**	University of New Brunswick Dr. Ali Ghorbani, Professor ghorbani@unb.ca Dr. Stephen Marsh, Adjunct Professor Stephen.Marsh@nrc-cnrc.gc.ca	**Infrastructures** Various

Description

Overview – AIMS is an agent-based system to simulate and model the (national and cross-border) interdependencies and survivability of Canada's Critical Infrastructures.

Development goals – Goals are to incorporate into complete critical infrastructure (CI) crisis management system and plan to model New Brunswick's Information and Communication Technology (ICT), power, water, etc.

Intended users – Users will include CI managers, users, planners, and emergency services personnel.

System output – Visualization for training monitoring and planning. It's a possibility to add mapping systems.

Maturity – The system is in development.

Areas modeled – New Brunswick Critical Infrastructures.

Customers/sponsors – National Research Council Canada (CNRCC).

Model Framework

Underlying model – Agent-based modeling uses universal mark-up language (UML) and service oriented architectures. Plans are to use a multi-agent development kit in the future such as Agent Oriented Software Group (AOS) JACK^{TM}, Java Agent DEvelopment (JADE) framework, or other agent software.

Simulation – Simulation scenarios have included the Moncton area forest fire, the Saint John Port disaster, and a Border incident.

Data format – The data and text are in UML and Environmental Systems Research Institute, Inc. (ESRI)'s ArcGIS formats.

Sensor data – Not specified.

Coupling with other models – This model is designed to couple with other models, but that capability has not been tested to date.

Human activity modeling – Included in model.

System Requirements

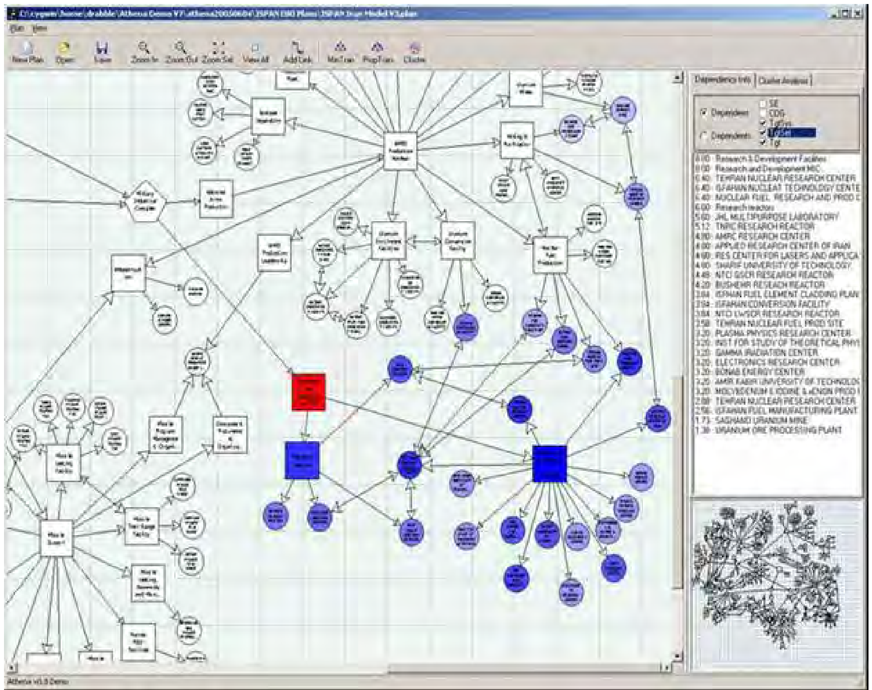
Hardware	Not specified.
Software	Not specified.

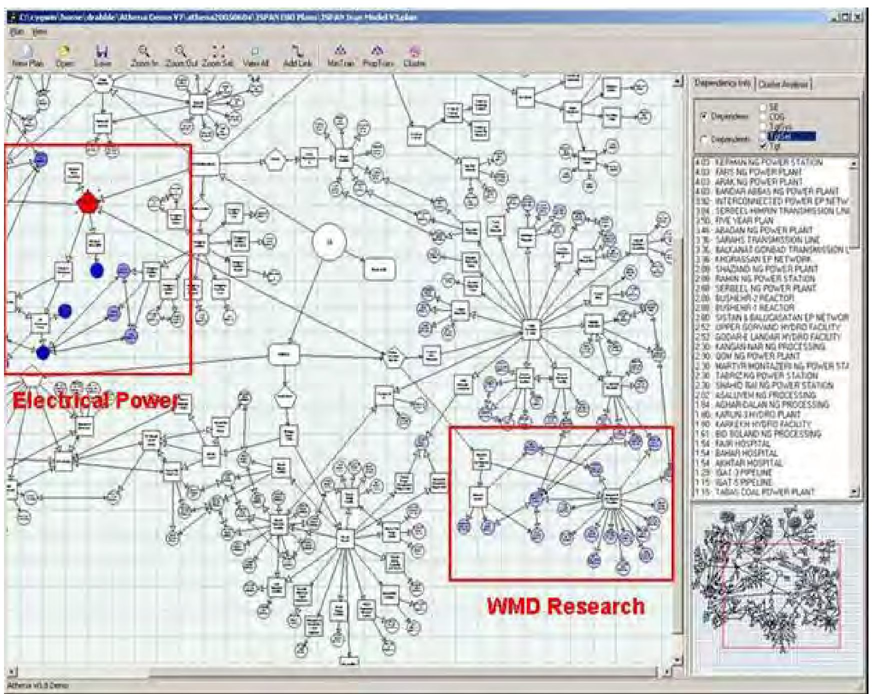
Other Notes

References

Stephen Marsh, *Critical Infrastructure Interdependencies,* http://iit-iti.nrc-cnrc.gc.ca/colloq/0405/04-11-04_e.html, November 4, 2004, Webpage visited July 10, 2006.

<table>
<tr><td>Model Name</td><td colspan="3">Athena</td></tr>
<tr><td colspan="2">Organization
POC</td><td>On Target Technologies, Inc.
Dr. Brian Drabble
brain@ontgttech.com
Dr. Maris “Buster” McCrabb
buster@dmmventures.com</td><td>Infrastructures
All (physical to conceptual)</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">Overview – Athena is an analysis and modeling tool that is designed to analyze a network of nodes (actors, concepts and physical) as a “system of systems” by merging various political, military, economic, social, information, and infrastructure (PMESII) models and their associated cross-dependencies. Athena incorporates several reasoning algorithms that allow sophisticated inter- and intra-dependency analysis between and through nodes. Model construction is quick and simple point and uses a simple point and click interface.
Development goals – Automatic Network Extraction (engineering models), Semantic Reasoning across transitive dependencies & Interfacing to different information sources.
Intended users – Military for in analyzing disruptive military effects, Law Enforcement for analyzing disruptions of criminal gangs and enterprises, Disaster/Network Recovery to determine repair priorities, and Economic for competitive analysis.
Output – Graphical interface showing nodes and linkages with criticalities and interdependencies indicated. Multiple analytical capabilities. Can be linked to GIS data.
Maturity – Evolving.
Areas modeled – Athena is capable of modeling any entity including countries, states, cities, roads, and facilities.
Customers/sponsors – Air Force Research Laboratory (AFRL) IFSA sponsored the original work. Funding is now provided by DARPA and USSTRATCOM who will deploy the tool in late 2006.</td></tr>
<tr><td colspan="4">Model Framework</td></tr>
<tr><td colspan="4">Underlying model(s) – Fusion of Barlow’s model of horizontal cross-dependency with weighting, Warden’s model of vertical cross-dependency, and the McCrabb-Drabble model of time-phased linkages between models. This is a fractal model that allows the description of a Strategic Entity through Centers of Gravity (COG) to Target Systems to Target sets and where appropriate targets.
Simulation – System allows full-scale simulations.
Data format – Accepts data in variety of formats.
Sensor data – Accepts sensor data/feeds to update model nodes and changing interactions (e.g., strength) between nodes.
Human activity – This tool models human activity/capability as part of the network (e.g., loss of plant manager may decrease network capability). Nodes may be humans or concepts.
Coupling with other models – Couples readily with other engineering models, databases, sensor networks, etc.</td></tr>
<tr><td colspan="4">System Requirements</td></tr>
<tr><td>Hardware</td><td colspan="3">Laptop 2 GB processor speed, 60 GB hard drive, 500 MB RAM.</td></tr>
<tr><td>Software</td><td colspan="3">Windows XP or similar, program is written in C.</td></tr>
<tr><td colspan="4">Other Notes</td></tr>
</table>





References

Athena: Effects-based Cross-Dependency Modeling for Target Systems Analysis Final Report. (Limited distribution) Final Athena Demonstration (Microsoft PowerPoint presentation).

Model Name	CARVER^{2} ™	
Organization POC	National Infrastructure Institute Center for Infrastructure Expertise Ronald Peimer rpeimer@ni2.org	**Infrastructures** User defined

Description

Overview – CARVER^2 is a simple software program that provides a quick and easy way to prioritizes potential terrorist targets. It compares and rates the critical infrastructure and key assets in jurisdictions by producing a mathematical score for each potential target. It is the first step for conducting more in-depth vulnerability assessments. CARVER^2 helps users make "apples vs. oranges" comparisons such as a water system vs. an energy grid vs. a bridge.

Development goals – None goals have been stated.

Intended users – Federal, state and local government officials are the intended users for this program.

Output – The CARVER^2 tool outputs various reports with priority scores and background information for different infrastructure elements.

Maturity – This is a free product by request.

Areas modeled – Determined by user.

Customers/sponsors – This tool is Sponsored by the US Department of Commerce, National Institute for Standards and Technology (NIST).

Model Framework

Underlying model(s) – The support is a relational database.

Simulation – This tool has no simulation capability.

Data format – Text.

Sensor data – No sensor data has been incorporated in the tool.

Human activity – Not modeled.

Coupling with other models – There is no coupling with other models.

System Requirements

Hardware	PC or laptop running Microsoft Windows operating system.
Software	Distributed via CD no other software needed.

Other Notes

References

NI2 Center for Infrastructure Expertise Critical Infrastructure Library, http://www.ni2ciel.org/,Webpage visited July 3, 2006.

National Infrastructure Institute home page, http://www.ni2.org/default.asp, Webpage visited July 3, 2006

CARVER2 Project Page, http://www.ni2cie.org/CARVER2.asp, Webpage visited July 3, 2006.

<table>
<tr><td>Model Name</td><td colspan="3">COMM-ASPEN</td></tr>
<tr><td>Organization
POC</td><td colspan="2">Sandia National Laboratory</td><td>Infrastructures
FN, TEL</td></tr>
<tr><td colspan="4">Description</td></tr>
</table>

Overview – CommAspen is a new agent-based model for simulating the interdependent effects of market decisions and disruptions in the telecommunications infrastructure on other critical infrastructures in the U.S. economy such as banking and finance, and electric power. CommAspen extends and modifies the capabilities of Aspen-EE, an agent-based model previously developed by Sandia National Laboratories to analyze the interdependencies between the electric power system and other critical infrastructures. CommAspen has been tested on a series of scenarios in which the communications network has been disrupted, due to congestion and outages. Analysis of the scenario results indicates that communications networks simulated by the model behave as their counterparts do in the real world. Results also show that the model could be used to analyze the economic impact of communications congestion and outages.

Development goals – To analyze interdependent infrastructure systems in a more holistic way, Sandia and other research institutions have developed models of critical infrastructure systems using agent-based approaches. Sandia's first agent-based model of the U.S. economy, developed in the mid-1990s, is called Aspen. This model is a Monte Carlo simulation that uses agents to represent various decision-making segments in the economy, such as banks, households, industries, and the Federal Reserve. An agent is a computational entity that receives information and acts on its environment in an autonomous way; that is, an agent's behavior depends at least partially on its own experience. Through the use of evolutionary learning techniques, Aspen allows us to examine the interactive behavior of these agents as they make real-life decisions in an environment where agents communicate with each other and adapt their behaviors to changing economic conditions, all the while learning from their past experience. In 2000, Sandia developed a new model of infrastructure interdependency called Aspen-EE. This model extended the capabilities of Aspen to include the impact of market structures and power outages in the electric power system, a critical infrastructure, on other infrastructures in the economy.

One of the limitations of agent-based models in current development at Sandia and other research institutions is that communication is treated simply as a message passing between agents. Effectively, the telecommunications infrastructure is not specifically represented. None of the models simulates the differences in communication over telephone, computer, wireless, or other networks and therefore cannot model the impact of specific communication failures on the whole system. Nor can current models simulate the impact of other infrastructure failures on telecommunications.

To address the communications deficiencies described above, Sandia revised and restructured the Aspen-EE model to include a more realistic representation of the telecommunications infrastructure. This new model of infrastructure interdependency is called CommAspen. In CommAspen, communication is treated as an integrated agent system capable of creating, transforming, sending, receiving, and storing information and messages over time and across distance. With CommAspen, we can model communication networks or medium-specific vulnerabilities to failures and their dependence on supporting infrastructures like power.

Intended users – Internal analyst.

System output – Not specified.

Maturity – Development.

Areas modeled – Not specified.

Customers/sponsors – Not specified.

Model Framework	
Underlying model – There are several ways that we can implement the notion of infrastructures in CommAspen. One method of representing certain types of infrastructures in CommAspen is through the use of spigots and sinks. Such infrastructures are for commodities that run continuously, like water from a municipality and electricity from a local utility. A sink is where a producer puts product into an infrastructure. For example, a power company may have a natural gas-fired electric generating plant producing power. It would put power on the transmission lines by passing the power into the associated sink. A spigot is where a consumer gets the product, such as turning on the lights in a residence or getting water from a faucet. **Simulation** – Agent Based Model. **Data format** – Not specified. **Sensor data** – None. **Coupling with other models** – No. **Human activity modeling** – Not Known.	
System Requirements	
Hardware	Not specified.
Software	Not specified.
Other Notes	

Images: None.

References
Barton, Dianne C., Eric D. Edison, David A. Schoenwald, Roger G. Cox, and Rhonda K. Reinert, "Simulating Economic Effects of Disruptions in the Telecommunications Infrastructure", SAND REPORT, SAND2004-0101, Printed January 2004.

Model Name	Critical Infrastructures Interdependencies Integrator (CI^3)		
Organization **POC**	Argonne National Laboratory Dr. James Peerenboom jpeerenboom@anl.com	**Infrastructures**	EP,NG,SCADA,TC

Description

Overview – CI^3 is a software tool for emulating (Monte Carlo simulation) the amount of time or cost (or both) needed for activities that must be completed to restore a given infrastructure component, a specific infrastructure system, or an interdependent set of infrastructures to an operational state. The software tool provides a framework for recognizing interdependencies and incorporating uncertainty into the analysis of critical infrastructures.

Development goals – No goals stated.

Intended users – Infrastructure owners.

System output – Graphs and tables of completion time and cost distributions for repairs to quantify the impacts of infrastructure disruptions.

Maturity – The system is in development.

Areas modeled – No specific areas are mentioned. Argonne has developed transition diagrams for repair of damages to the following: natural gas transmission pipeline, petroleum, oil, liquids (POL) pumping station, natural gas city gate station, propane air plant, natural gas compressor station, natural gas underground storage facility, supervisory control and data acquisition (SCADA) communications tower, electrical substation, transformer, and an optical telecommunications cable.

Customers/sponsors – U.S. Department of Energy.

Model Framework

Underlying model – Transition diagrams coupled to Monte Carlo simulator.

Simulation – Transition diagrams are easy to create via point-and-click techniques to simulate recovery and restoration activities for covered infrastructure.

Data format – Not specified.

Sensor data – Model does not accept sensor data.

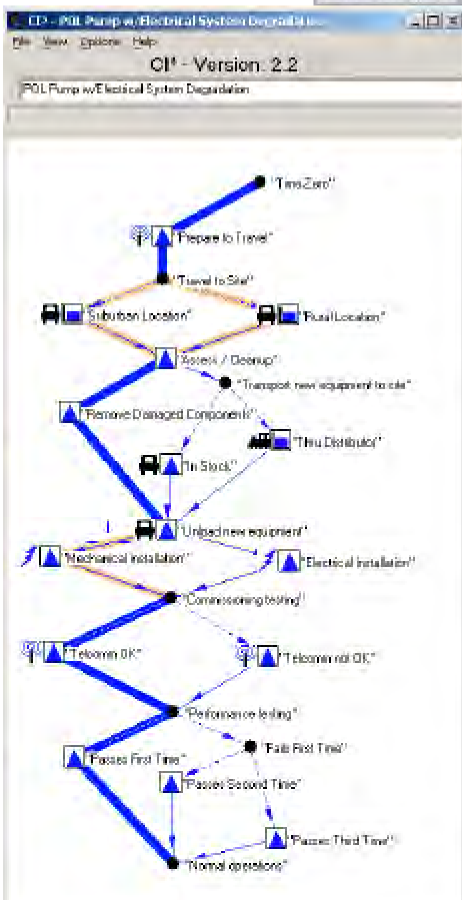
Coupling with other models – None.

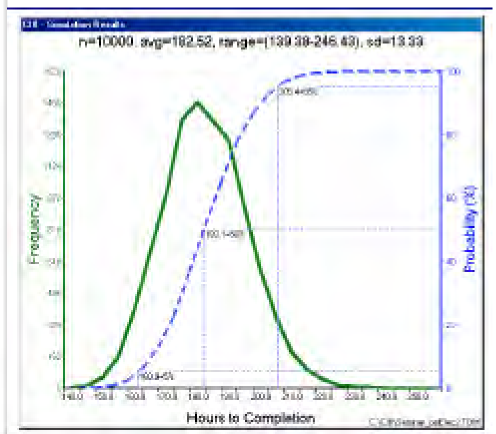
Human activity modeling – Human activities (travel, repair, assessment) are included in simulations.

System Requirements

Hardware	Not specified.
Software	Not specified.

Other Notes

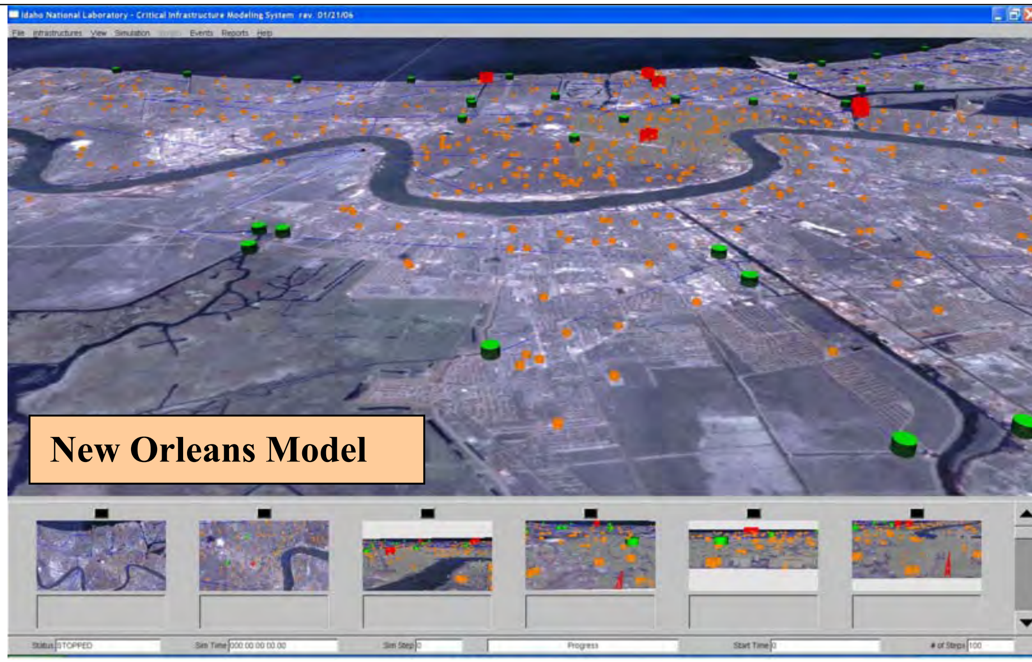

CI³ - POL Pump w/Electrical System Degradation
File View Options Help
CI³ - Version: 2.2
POL Pump w/Electrical System Degradation
"Time Zero"
"Prepare to Travel"
"Travel to Site"
"Suburban Location"
"Rural Location"
"Access / Cleanup"
"Transport new equipment to site"
"Remove Damaged Components"
"Thru Distributor"
"In Stock"
"Unload new equipment"
"Mechanical installation"
"Electrical installation"
"Commissioning testing"
"Telecomm OK"
"Telecomm not OK"
"Performance testing"
"Fails First Time"
"Passes First Time"
"Passes Second Time"
"Passes Third Time"
"Normal operations"

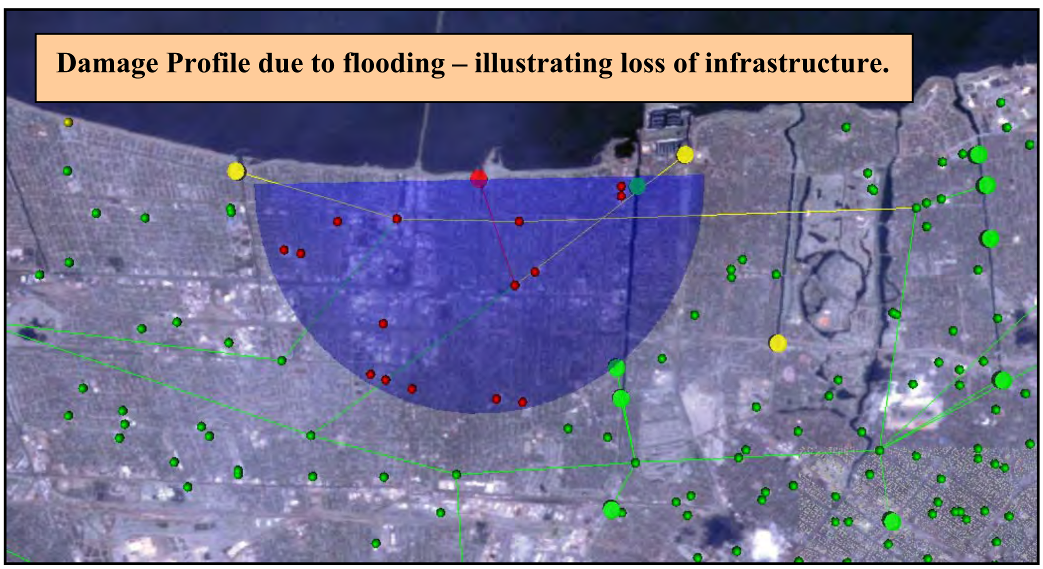

n=10000, avg=182.52, range=(139.38-246.43), sd=13.33
Frequency
Probability (%)
Hours to Completion

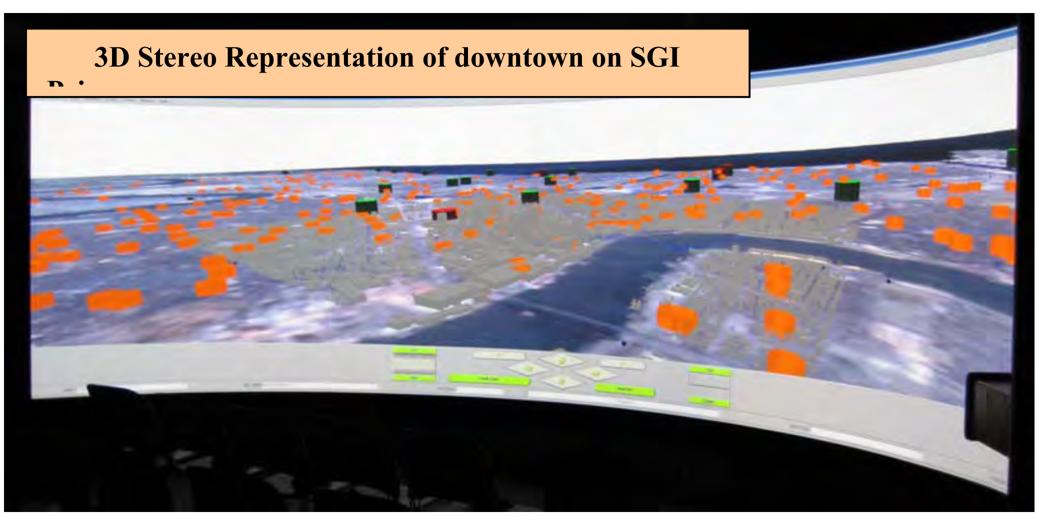
References

<table>
<tr><td>Model Name</td><td colspan="2">Critical Infrastructure Modeling System (CIMS©)</td></tr>
<tr><td>Organization
POC</td><td>Idaho National Laboratory (INL)
Donald Dudenhoeffer
Donald.Dudenhoeffer@inl.gov</td><td>Infrastructures
EP, SCADA, HW, HA, POL, PMESII</td></tr>
<tr><td colspan="3">Description</td></tr>
<tr><td colspan="3">Overview – A modeling and simulation framework that combines geospatial information and a four dimensional (4D) environment (time-based) to support 'what if' analysis.
Development goals – Provide decision makers with a highly adaptable and easily constructed 'wargaming' tool to assess infrastructure vulnerabilities including policy and response plans. Operating at a high level of simulation, it supports rapid 'point and click' model development to allow the adaptation of models to rapidly changing environments.
Intended users – Emergency planners and responders.
System output – Four dimensional geospatial visualization in a VTK framework along with report generation.
Maturity – Development – in the process of commercial licensing.
Areas modeled – Idaho National Laboratory, New Orleans Louisiana.
Customers/sponsors – Research has been ongoing for the past 4 years under the INL National Security Divisions. Sponsors have included the INL's internal research program, the Department of Energy, the U.S. Air Force Research Laboratory (AFRL), and negotiations are underway with the State of Louisiana.</td></tr>
<tr><td colspan="3">Model Framework</td></tr>
<tr><td colspan="3">Underlying model – The underlying model is a network representation of infrastructure utilizing nodes and edges for assets and relationships. Graphical objects such as aerial images, 3DS images, or VRML models can be tied to the assets. Additionally, information can be embedded within nodes such as documents, web site hyperlinks, web cams, avis, etc
Simulation – Agent-based discrete event simulation.
Data format – Flat files are used as direct feeds to the simulations. These files can be fed by a multitude of different databases including Access, GIS, etc
Sensor data – Agent objects(nodes) can have autonomous behaviors or they can be fed by external sensor input.
Coupling with other models – Yes.
Human activity modeling – Human activity can be modeled directly or as the result of policy/procedure enactment.</td></tr>
<tr><td colspan="3">System Requirements</td></tr>
<tr><td>Hardware</td><td colspan="2">Cross platform compatibility – Windows, UNIX/LINUX, and Solaris. Internet connectivity required to access embedded links.</td></tr>
<tr><td>Software</td><td colspan="2">No external software to CIMS ~ requires < 5 meg of disk space.</td></tr>
</table>

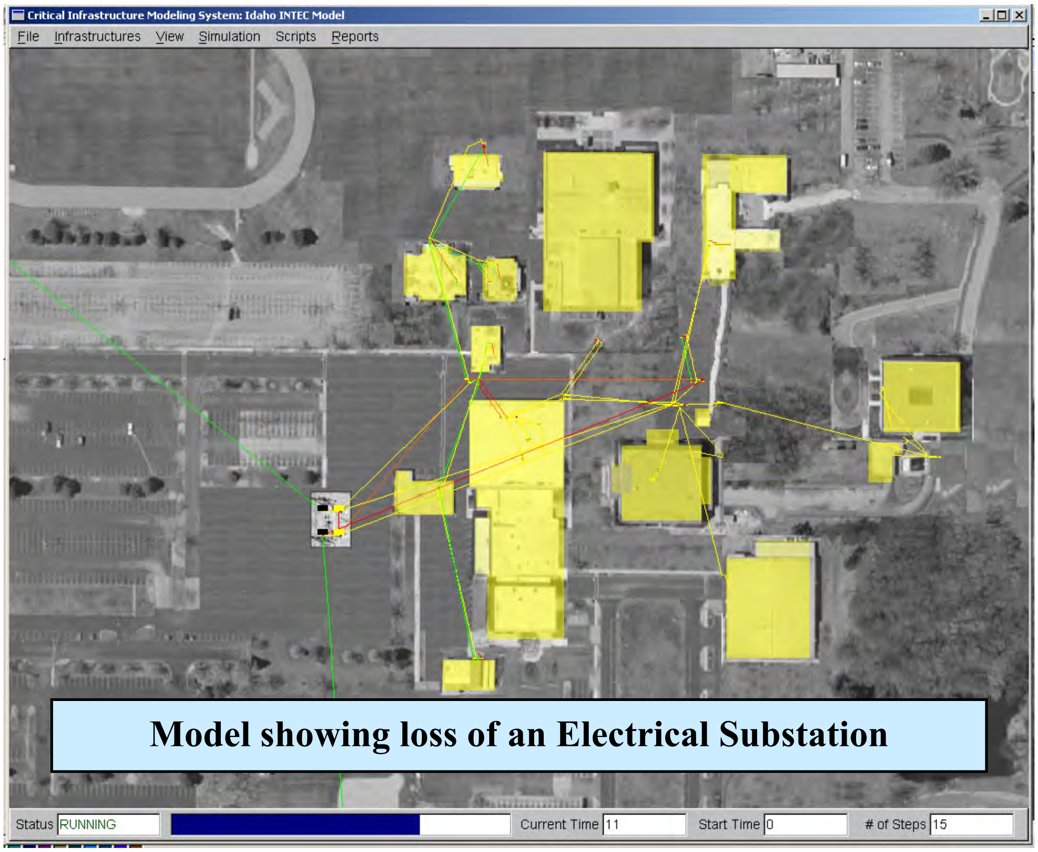
Other Notes
The objective of CIMS was to create a rapid modeling and analysis capability that did not require extensive data collection or proprietary GIS software. As such, CIMS allows the ability to create models and infrastructure simulations on the fly embedding new intelligence as it becomes available. Model development can start with an aerial image or a scanned/sketched chart/map image. All information is georeferenced. Models construction can occur via one of three methods. • Direct manipulation of the network descriptor flat files • Conversion from a database to the flat file format • Point and click network construction via the Model Builder Application. User interactivity with the Model. The models were developed with a wargaming approach to allow maximum user interaction with the simulation. Thus the user has several different ways to interact with the data: • An event script can be created to initiate specific events at a designated time • The user can select and directly manipulate the state of individual nodes and edges, i.e., shutting down an electrical substation or making a bridge impassible • The user can inject events during runtime, i.e., placing and detonating a bomb to observe cascading impacts.

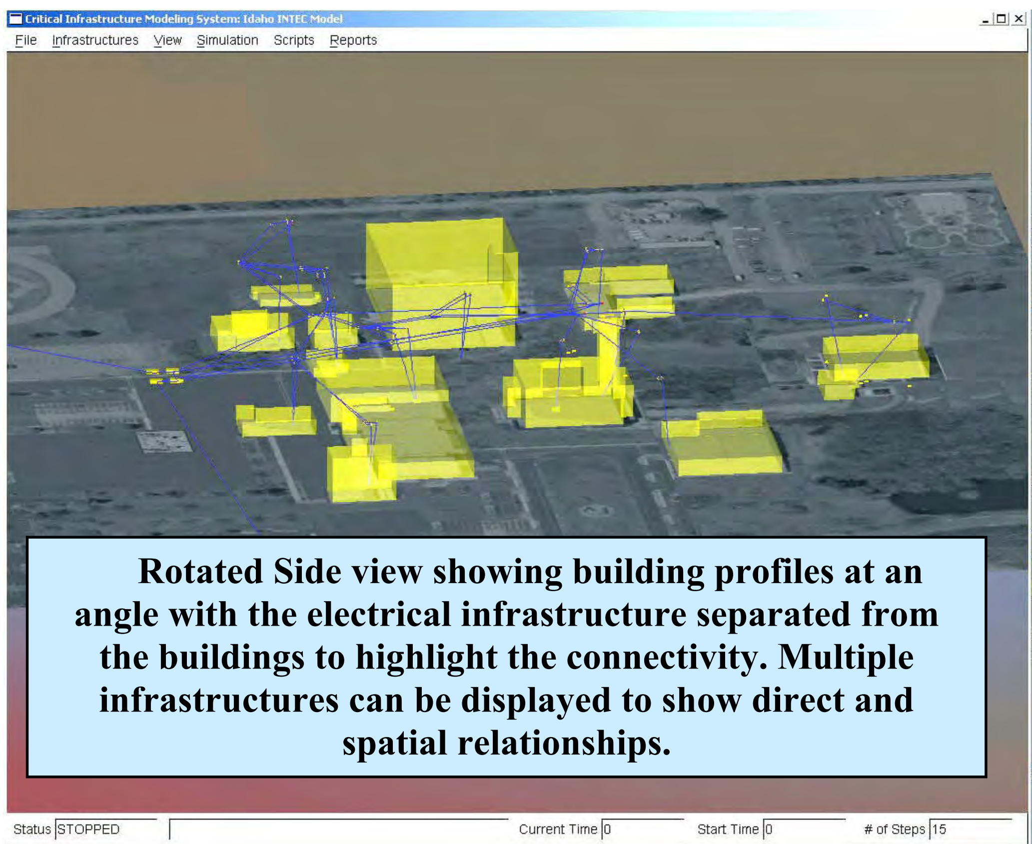

New Orleans Model


Damage Profile due to flooding – illustrating loss of infrastructure.


3D Stereo Representation of downtown on SGI

Images


Critical Infrastructure Modeling System: Idaho INTEC Model
File Infrastructures View Simulation Scripts Reports
Model showing loss of an Electrical Substation
Status RUNNING
Current Time 11
Start Time 0
# of Steps 15


Critical Infrastructure Modeling System: Idaho INTEC Model
File Infrastructures View Simulation Scripts Reports
Rotated Side view showing building profiles at an angle with the electrical infrastructure separated from the buildings to highlight the connectivity. Multiple infrastructures can be displayed to show direct and spatial relationships.
Status STOPPED
Current Time 0
Start Time 0
# of Steps 15

References
Dudenhoeffer, D.D, M. R. Permann, and M. Manic, "CIMS: A Framework For Infrastructure Interdependency Modeling And Analysis." *Submitted to Proceedings of the 2006 Winter Simulation Conference*, ed L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, 2006. Dudenhoeffer, D. D., M. R. Permann, and R. L. Boring, 2006. Decision consequence in complex environments: Visualizing decision impact. In *Proceeding of Sharing Solutions for Emergencies and Hazardous Environments. American Nuclear Society Joint Topical Meeting: 9th Emergency Preparedness and Response/11th Robotics and Remote Systems for Hazardous Environments*. Dudenhoeffer, D. D., M. R. Permann, and E.M. Sussman. 2002. A Parallel Simulation Framework For Infrastructure Modeling And Analysis. *In Proceedings of the 2002 Winter Simulation* Conference, ed E. Yücesan, C. H. Chen, J. L. Snowdon, and J. M. Charnes, 1971-1977. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers. Critical Infrastructure Modeling System Fact Sheet <http://www.inl.gov/nationalsecurity/factsheets/docs/cims.pdf>

Model Name	The Critical Infrastructure Protection Decision Support System (CIP/DSS)	
Organization **POC**	Los Alamos National Laboratory Randy Michelsen rem@lanl.gov Sandia National Laboratories Theresa Brown tjbrown@sandia.gov	Infrastructures ALL

Description

Overview – The Critical Infrastructure Protection Decision Support System (CIP/DSS) simulates the dynamics of individual infrastructures and couples separate infrastructures to each other according to their interdependencies. For example, repairing damage to the electric power grid in a city requires transportation to failure sites and delivery of parts, fuel for repair vehicles telecommunications for problem diagnosis and coordination of repairs, and the availability of labor crews. The repair itself involves diagnosis, ordering parts, dispatching crews, and performing work. The electric power grid responds to the initial damage and to the completion of repairs with changes in its operating characteristics. Dynamic processes like these are represented in the CIP/DSS infrastructure sector simulations by differential equations, discrete events, and codified rules of operation. Many of these variables are output metrics estimating the human health, economic, or environmental effects of disturbances to the infrastructures.

CIP/DSS will assist decision makers in making informed choices by:

- Functionally representing all 14 critical infrastructures with their interdependencies
- Computing human health and safety, economic, public confidence, national security, and environmental impacts
- Synthesizing a methodology that is technically sound, defensible, and extendable.

Development goals – Charter is to model all infrastructures and key assets. Used for quick response on areas Los Alamos National Laboratory (LANL) doesn't have data for.

Intended users – Internal analyst at LANL.

System output – Graphs representing the impact on multiple state variables such as hospital beds occupied, etc.

Maturity – Development – Initiated as a proof-of-concept in August 2003. Completed a prototype model and two case studies in February2004.

Areas modeled – Not specified.

Customers/sponsors – DHS.

Model Framework

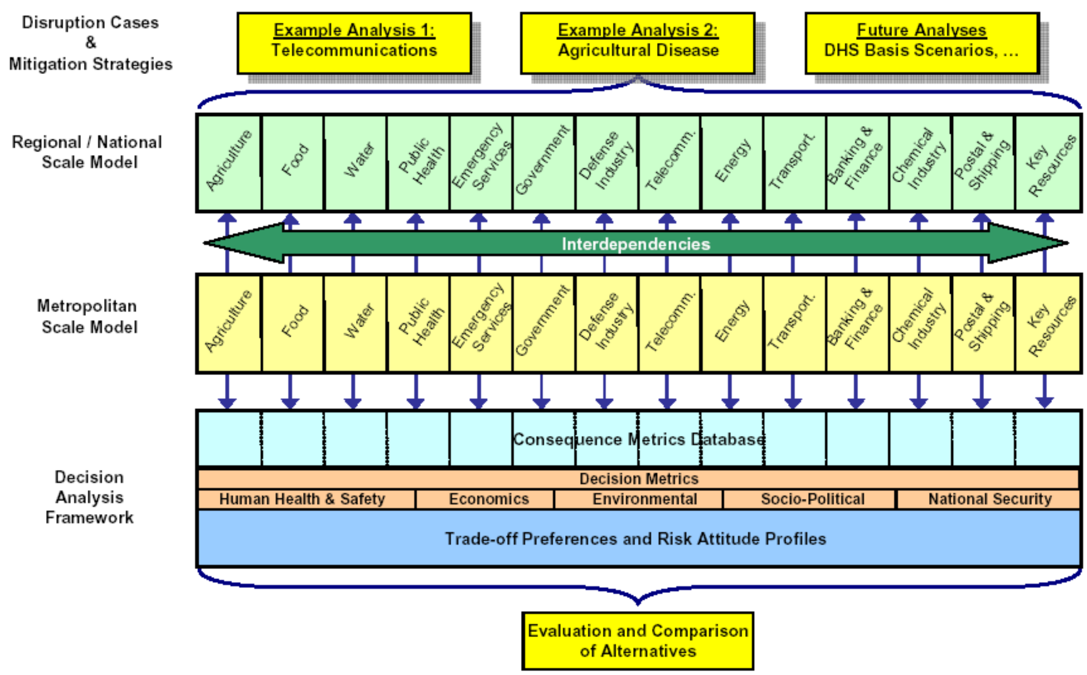
Underlying model – The national and metropolitan consequence models are implemented using Vensim, which reads input parameters from and writes output time series to an Oracle relational database of "consequence" metrics, which are abstracted into a much smaller set of "decision" metrics. The decision support software (written in Visual Basic) accesses the decision database to compute utility values for various scenarios and alternatives.

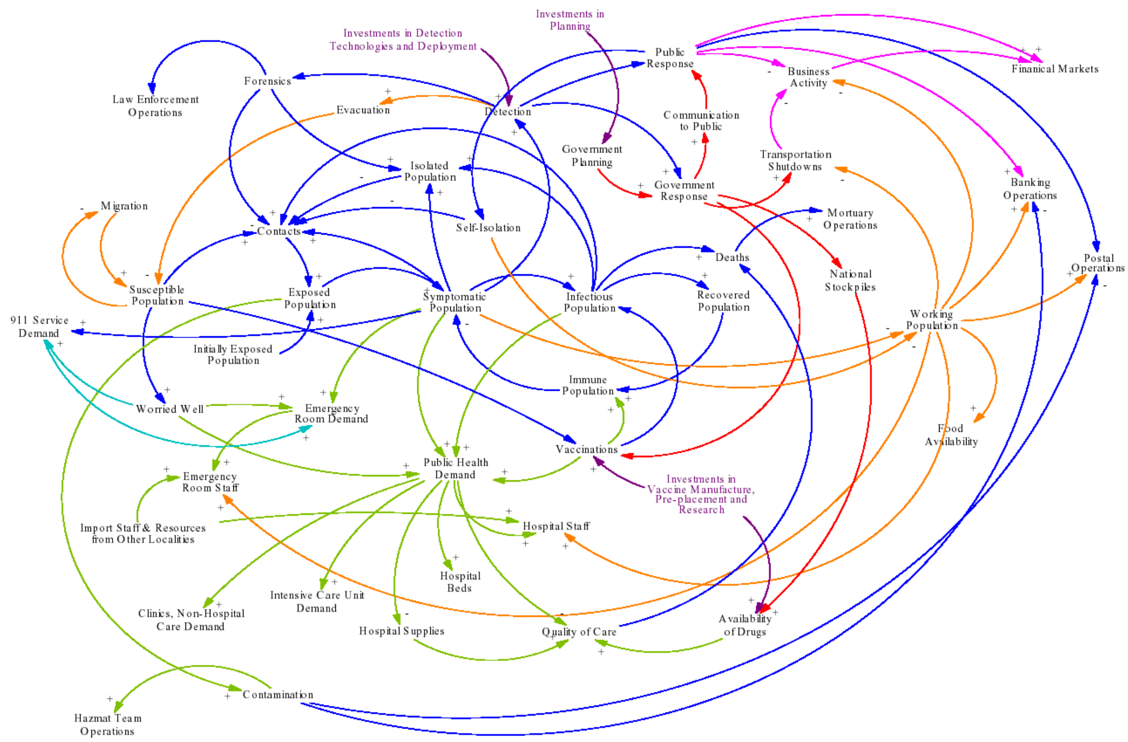
Simulation – Vensim is used for developing, analyzing, and packaging high quality dynamic feedback models. Models are constructed graphically or in a text editor. Features include dynamic functions, subscripting (arrays), Monte Carlo sensitivity analysis, optimization, data handling, and application interfaces.

Data format – Vensim Model.

Sensor data – No ability to input live data feeds.

Coupling with other models – No. **Human activity modeling** – Human activity can be modeled directly or as the result of policy/procedure enactment.	
System Requirements	
Hardware	The Vensim family of software runs on Windows (95/98/Millennium/NT/2000/XP) and the Power Macintosh running System 7 or higher (in Classic mode under OSX). Vensim requires 8 MB of memory and 8 MB of disk space for a full installation. A demonstration version of Vensim is available free for either Windows or Macintosh.
Software	CIPDSS is a model built within Vensim simulation software by Ventura (http://www.vensim.com/brochure.html).
Other Notes	
CIP/DSS (Critical Infrastructure Protection Decision Support System) simulates the dynamics of individual infrastructures and couples separate infrastructures to each other according to their interdependencies. CIP/DSS models asset information at the aggregate level. For example with a focus area, it can estimate the number of hospital beds affected by an event, but it cannot directly retrieve information relative to a particular hospital. It utilizes the commercial simulation software Vensim.	





References

Bush B, L. Dauelsberg, R. LeClaire, D. Powell (LANL), S. DeLand (SNL), and M. Samsa (ANL), Critical Infrastructure Protection Decision Support System (CIP/DSS) Project Overview, LA-UR-05-1870, July 2005.

Model Name	Critical Infrastructure Protection (CIP) Modeling and Analysis (CIPMA) Program	
Organization **POC**	Australian Government – Attorney General's Department (AGD) Michael Jerks – Director, Major Projects Michael.Jerks@ag.gov.au	**Infrastructures** FN, TC, EP, NG, OL

Description
Overview – The Critical Infrastructure Protection Modeling and Analysis program (CIPMA) is a computer based tool to support business and government decision making for critical infrastructure (CI) protection, counter-terrorism and emergency management, especially with regard to prevention, preparedness, and planning and recovery. CIPMA is designed to examine the relationships and dependencies within and between critical infrastructure systems, and to demonstrate how a failure in one sector can greatly affect the operations of critical infrastructure in other sectors. CIPMA uses a vast array of data and information from a range of sources to model and simulate the behavior and dependency relationships of critical infrastructure systems. The capability will include a series of impact models to analyze the effects of a disruption to CI services. The CIPMA Program currently focuses on three priority sectors: banking and finance, communications, and energy. The capability was launched by the Attorney-General in February 2006. "Proof of concept" of the capability was successfully demonstrated to key business and government stakeholders in May 2006. Although CIPMA is still in development, results from the capability are already assisting the development and direction of government policy in national security and critical infrastructure protection (CIP), and helping owners and operators to better protect their critical infrastructure.
Development goals – The current focus is on broadening and deepening CIPMA coverage of the three priority sectors, the Sydney commercial business district (CBD) precinct, and development of impact models for the Decision Support Module. The impact models will assess the flow-on consequences of a CI service disruption, the economic impacts of the disruption, the effects on population, time/duration and area of the disruption, and the behavior of networks and clusters of infrastructure as a result of the service interruption. Work on a fourth sector will commence by July 2007.
Intended users – Users include CI owners and operators and Australian local governments.
System output – Output will include geographic information system (GIS) functionality for data capture, management, and visualization. System behavior will determine dependencies and time-based impacts of disruptive events on infrastructure networks.
Maturity – In development, some tools are complete.
Areas modeled – Australian critical infrastructure networks and high priority precincts (e.g., capital cities).
Customers/sponsors – Australian government, state and territory governments, CI owners and operators.
Model Framework
Underlying model(s) – System Dynamic Models.
Simulation – Telecommunication connectivity matrix and expert systems.
Data format – The format is geographic information system (GIS) and relational database.
Sensor data – Not currently equipped for sensor input.
Human activity – Contains human activity model.
Coupling with other models – Model couples with earthquake, tsunami inundation, bomb blast, and plume models.

System Requirements	
Hardware	Not specified.
Software	ArcGIS, ArcSDE, Oracle, Vensim DSS, Dynamic Network System (DNS), CLIPS,

	Java Runtime Environment (JRE).

Other Notes

CIPMA is a very detailed modeling and analysis initiative which contains sensitive business information about the operation of Australia's critical infrastructure networks, relationships and dependencies. The IP is owned and managed by Attorney-General Department (AGD) on behalf of the Australian Government. The CIPMA Development Team of AGD, Geoscience Australia (GA) and the Commonwealth Scientific and Industrial Research Organization (CSIRO) has been in discussions with the US Department of Homeland Security (DHS) and Argonne, Sandia, and Los Alamos National Laboratories regarding the Critical Infrastructure Decision Support System (CIP-DSS), and the similarities and differences between the two capabilities, since November 2004. AGD is currently preparing a Project Arrangement for ongoing consultation with DHS and the three National labs under the Homeland Security Science and Technology Treaty (HSST).

References

Fact sheet on CIPMA program
http://www.tisn.gov.au/agd/WWW/rwpattach.nsf/VAP/(7A188806B7893EBA0402BC1472412E58)~
Overview+of+CIPMA.PDF/$file/Overview+of+CIPMA.PDF, Webpage visited July 3, 2006.

AusGeo News, *Protecting the Nation*, http://www.ga.gov.au/ausgeonews/ausgeonews200509/cip.jsp, Issue No. 79, September 2005, Webpage visited July 3, 2006.

<table>
<tr><td>Model Name</td><td colspan="2">Critical Infrastructure Simulation by Interdependent Agents (CISIA)</td></tr>
<tr><td>Organization
POC</td><td>Universita Roma Tre
Stefano Panzieri
panzieri@uniroma3.it
Giovanni Ulivi
ulivi@uniroma3.it</td><td>Infrastructures
EP,SCADA</td></tr>
</table>

Description

Overview – This model is described by the authors as a hybrid of the two modeling approaches; interdependency analysis and system analysis. It is a bottom-up complex adaptive systems (CAS) model using interactive agents. The critical infrastructure simulation by interdependent agents (CISIA) simulator is designed to analyze short term effects of failures in terms of fault propagation and performance degradation (Panzieri, 2004). The simulator is based on Recursive Porus Agent Simulation Toolkit, Repast, open-source agent-based development software with libraries of classes for creating, running, displaying and collecting data from a agent based simulations. It extends the Java classes of Repast defining a new class for each type of macro component present into any infrastructure: such as, electric power plant, transmission line, telecommunication channel, waste-water system, etc.

Development goals –Work is ongoing to further validate the CISIA approach and to analyze how intelligent reaction, and autonomy capabilities (e.g., decentralized control strategies), might be used to improve the robustness of the system of system's composed by different heterogeneous and interdependent infrastructures.

Intended users – Infrastructure owners, planners, and emergency responders.

System output – Graphic models showing the operative level incidence matrix and physical fault incidence matrices (FIMs) between elements in the model. In this case air conditioning, electric power, and SCADA.

Maturity – The system is in development.

Areas modeled – An unspecified (for security reasons) University Campus.

Customers/sponsors – Not indicated.

Model Framework

Underlying model – Agent-based model based on Repast, in order to handle many heterogeneous infrastructures into a single framework. Agent behavior is abstracted to allow use of a small set of common quantities; operative level, requirements (needs), and faults. Agent interactions include; induced faults, input requirements, and input operative level. Outputs include: propagated faults, output requirements, and output operative level.

Simulation – During simulation agents communicate via messages. An agent sends messages to its neighbors to specify its requirements to communicate its level of service (operative level), and to propagate faults (physical-faults, geographical-faults, and cyber faults).

Data format – Relational database.

Sensor data – Model does not accept sensor data.

Coupling with other models – CISIA implements an easy-linkage/black box philosophy: any model obtains connecting together agents without any modification of their internal structure.

Human activity modeling – Not incorporated.

System Requirements	
Hardware	Not specified.
Software	Not specified.

Other Notes

Each agent class defines the behavioral roles of the element and its input/output quantities in term of which resources the agent needed and supply. Moreover, the class defines which type of failure can be propagated to (generated from) the agent. An agent may propagate different types of failure to a different set of neighbors.

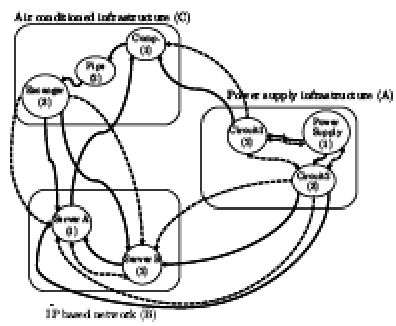


Fig. 3. CISIA model of the test-bed; inks related to operative level incidence matrix (continuos line) and the Physical FIM incidence matrix (dotted line).

References

Panzieri, S., R. Setola, G. Ulivi (2004). An agent based simulator for critical interdependent infrastructures. *Proc. 2nd International Conference on Critical Infrastructures,* October 24-27, 2004.

Panzieri, S., R. Setola, G. Ulivi , *An Approach to Model Complex Interdependent Infrastructures, International Federation of Automatic Control (IFAC)*, http://www.dia.uniroma3.it/~panzieri/Articoli/WorldIFAC05-CIIP.pdf#search='An%20Approach%20to%20Model%20Complex%20Interdependent%20Infrastructures', Webpage visited July 10, 2006.

<table>
<tr><td>Model Name</td><td colspan="2">Distributed Engineering Workstation (DEW)</td></tr>
<tr><td>Organization
POC</td><td>Electrical Distribution Design, Inc.
Dr. Robert Broadwater
dew@vt.edu</td><td>Infrastructures
EL, SCADA</td></tr>
</table>

Description

Overview – The Distribution Engineering Workstation (DEW) provides over 30 applications for analysis, design, and control of electrical and other physical network systems. DEW allows all of its components (data sets and algorithms) to be reused by a new application, allowing new solutions to build on top of existing work. This provides for cross collaborations among different groups and the emergence of solutions to complex problems. DEW is being used to identify and analyze interdependencies in large scale electrical power systems and fluid systems of aircraft carriers. DEW is open architecture, non-proprietary.

Development goals – Electrical Distribution Design, Inc. (EDD) continues to develop and support DEW. They aspire to achieve combined analysis of systems with millions of nodes and to develop a seamless approach to asset management. DEW's architecture provides an open platform for development. The DEW system model can be linked to asset management records, daily operational procedures, events, long- and short-term planning, and more.

Intended users – Users are utilities, analysts, and military.

System output – The system is used for operation and control of electrical system and analysis of reconfiguration of damaged systems.

Maturity – Mature product is in broad use.

Areas modeled – This model has been used in St. Louis, MO, Detroit, MI, Consolidated Edison, NY, Aircraft Carriers.

Customers/sponsors – Electric Power Research Institute (EPRI) along with Department of Defense and Department of Energy sponsored the original development. Users include Northrop Grumman (naval applications), Detroit Edison (Detroit, MI), Ameren (St. Louis, MO), Orange and Rockland (Pearl River, NY), and Consolidated Edison (New York).

Model Framework

Underlying model – EDD's approach is built around a combination of concepts from graph theory, physical network modeling, and generic programming. The DEW model incorporates power flow, fault, reliability, reconfiguration for restoration, and over 30 other algorithms.

Simulation – Simulations may be run manually with mouse and keyboard, automatically controlled from user developed applications, or set up to run in batch mode over numerous systems and/or time points.

Data format – Model data is stored in relational SQL-compliant databases; real-time measurement data comes from common object request broker architecture (CORBA) interface or plant information (PI) time series databases.

Sensor data – DEW can handle any number of measurements and any types of measurements that are modeled, through its PI or CORBA interface.

Coupling with other models – DEW can attach to other models, such as geographic information system (GIS) models, via provided interface.

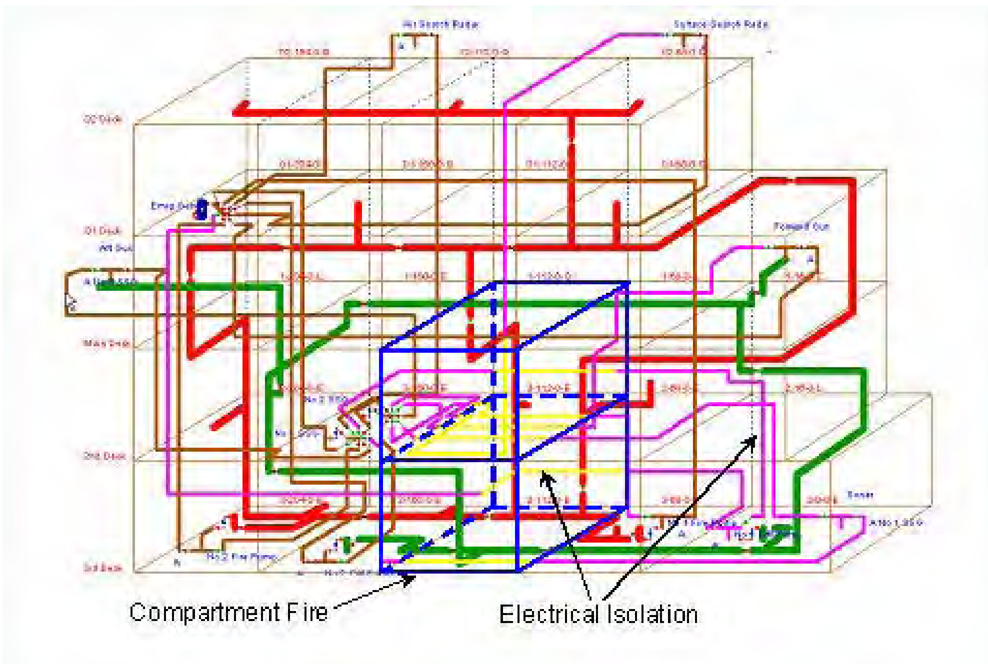
System Requirements

Hardware	Laptop/Server/Circuit server.
Software	Win 2000, XP, User interface.

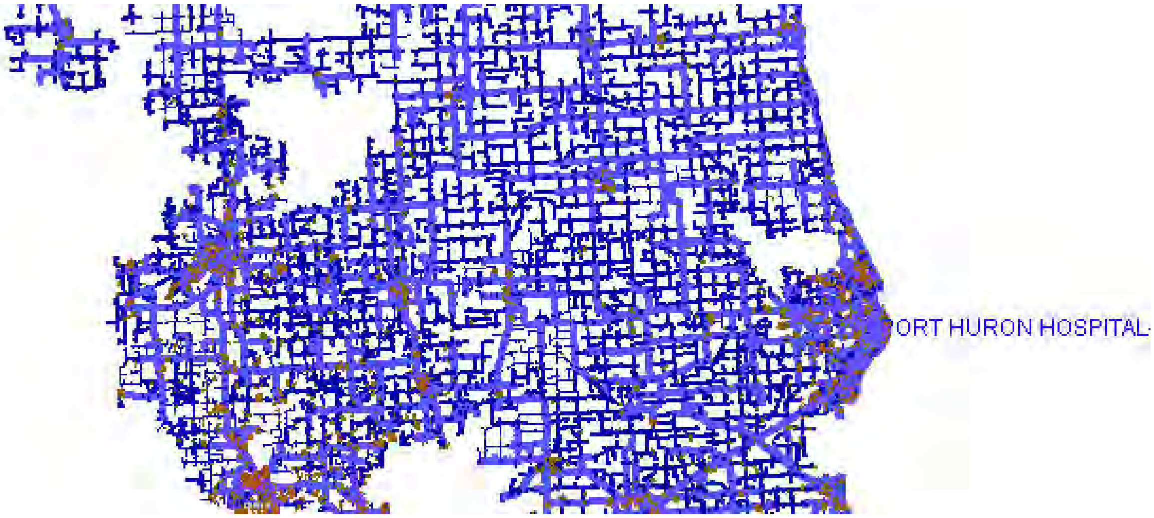
Other Notes

EDD is working with the utility industry, Virginia Tech, and other universities to develop a comprehensive Integrated System Model (ISM) based design, operations and maintenance management system. This concept is being applied to critical infrastructures including naval ships and gas and water utilities. Through work with the utility industry and Department of Energy, EDD has demonstrated it is possible to use the same ISM for analysis, design, operations, and real-time control. EDD has also used ISM based analysis to manage reconfigurable system models with more than 3 million objects and 200 million attached historical measurement values. The ISM provides a complete, seamless view of a physical plant that forms a common context for multi-discipline team collaboration, distributed processing, synergistic research and development, and providing infinite extensibility. Any data or algorithm that can be attached to the ISM is also associated with all other data and algorithms attached to the ISM. The ISM uses linked list type traces to dynamically adapt data management and analysis whenever the system is changed through modification, maintenance or operation.

EDD is structuring its current research and development work so that it that can eventually be combined into a generic integration platform for collaborative analysis, design, and operations for energy systems (CADOE). CADOE will directly support and structure low overhead collaboration among electric utilities, gas utilities, regulatory and policy making agencies, suppliers, integrators, aggregators, and customers. CADOE is envisioned to encompass simulation, analysis, alternative design evaluation, training, and real-time operations support.



Model of Ship Critical Infrastructure.



Dense Electrical Power System Model

References
Broadwater, Robert, et al., *Power Engineering*, http://www.ecpe.vt.edu/news/ar04/power2004.pdf#search='distributed%20engineering %20workstation%20epri', Webpage visited July 3, 2006. SAM Six, *Products: Dew,* http://www.samsix.com/dew.htm, Webpage visited July 3,2006. Tam, Kwa-Sur and Robert Broadwater, *Virginia Tech Presentation,* http://www.eng.vt.edu/research/dom_pres/Tam-Broadwater%20Systems%20Presentation.pdf#search='vt%20dew' Webpage visited July 3, 2006.

<table>
<tr><td>Model Name</td><td colspan="3">Electricity Market Complex Adaptive System (EMCAS)</td></tr>
<tr><td colspan="2">Organization
POC</td><td>Argonne National Laboratory
Guenter Conzelmann (ANL)
guenter@anl.gov</td><td>Infrastructures
Power Systems and Markets</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">Overview – Electricity Market Complex Adaptive System (EMCAS) uses agent-based modeling to simulate the operation of complex power systems. EMCAS can be used as an “electronic-laboratory” to probe the possible operational and economic impacts on the power system of various external events. Market participants are represented as “agents” with their own set of objectives, decision-making rules, and behavioral patterns. Agents are modeled as independent entities that make decisions and take actions using limited and/or uncertain information available to them, similar to how organizations and individuals operate in the real world. EMCAS includes all the entities participating in power markets, including consumers, generation companies (GenCos), Transmission Companies (TransCos), Distribution Companies (DisCos), Demand Companies (DemCos), Independent System Operators (ISO) or Regional Transmission Organizations (RTO), and regulators.
Development goals – Continue to develop EMCAS as a new approach to model and simulate the operations of restructured electricity markets.
Intended users – EMCAS was first applied for a regulatory commission in the mid-western United States. At the beginning of 2005, the software became commercially available and current clients include research institutes, power companies, transmission companies, and regulatory offices in South Korea, Portugal, and Spain. The Iberian EMCAS application includes the simulation of hydropower, wind power, and a variety of other renewable resources.
System output – EMCAS utilizes a graphical user interface to develop market configurations, display model inputs, and analyze simulation results (see screen captures on next page). Results are stored in HDF format and can be exported in text and spreadsheet formats. In addition to the energy spot markets and bilateral financial contract markets, EMCAS also includes a simplified representation of ancillary services markets; Detailed representation of the transmission system, using a Direct Current Optimal Power Flow (DC OPF) algorithm to compute locational marginal prices (LMP) and identify transmission congestion and price impacts of congestion; Chronological simulation of hourly market prices over short or long time periods; Hourly bid-based market clearing, scheduling and dispatch in day-ahead and real-time markets; Representation of different bidding strategies, from production cost bidding to various forms of physical and economic withholding strategies; Ability to change prevailing market rules (regarding congestion management, pricing mechanisms, price caps etc.) provides the opportunity to test the robustness and vulnerability to gaming of different market designs; and Calculation of cost, revenues, and profits for all relevant agents in the system.
Maturity – Commercial Product distributed by ADICA Consulting, LLC.
Areas modeled – Illinois electrical market, Iberia, France, South Korea, Poland, Central Europe
Customers/sponsors – At the beginning of 2005, the software became commercially available and current clients include research institutes, power companies, transmission companies, and regulatory offices in South Korea, Portugal, and Spain.</td></tr>
</table>

Model Framework
Underlying model(s) – Agent-based modeling and simulation.
Simulation – EMCAS simulates the operation of a power system and computes electricity prices for each hour and each location in the transmission network. Electricity prices are driven by demand for electricity, cost of electricity production, the extent of transmission congestion, external random or non-random events, such as unit outages or system disruptions, and company strategies. Model results include the economic impacts on individual companies and consumer groups under various scenarios.
Data format – The user builds the system configuration either within the EMCAS graphical user interface or by preparing and importing a set of well-defined input files.
Sensor data – The model also includes bilateral financial contracts. Real-time prices are calculated in a real-time dispatch using a DC optimal power flow model.
Human activity – Model includes different types of consumers (e.g., residential, industrial, and commercial) with their respective electricity consumption profiles.
Coupling with other models – Couples with hydropower models (e.g., VALORAGUA) and detailed power flow models (e.g., PowerWorld).

System Requirements	
Hardware	A network with 10 nodes (buses or locations), 70 aggregated thermal generating units, 13 generation companies, one transmission company, one ISO, and one regulator takes approximately 60 minutes for a one-year simulation (8760 hours) on a desktop PC with a 2.0 GHz AMD Athlon2000+ processor and 1 GB of RAM. For multi-year simulations, it is recommended to use a brand-new, high-end PC, preferably with dual core processors and 2+ GB of RAM.
Software	Commercial optimizer (LINGO), long-term hydro model (e.g., VALORAGUA).

Other Notes
Adaptability to Local Market and System Conditions:
The EMCAS model is fully customizable and not hardwired to any particular system. Network configurations can be simple and aggregate consisting of a few to several dozen network nodes and links, or detailed bus-level representations with several thousand network elements. The level of detail largely depends on data availability and particular analysis objectives.

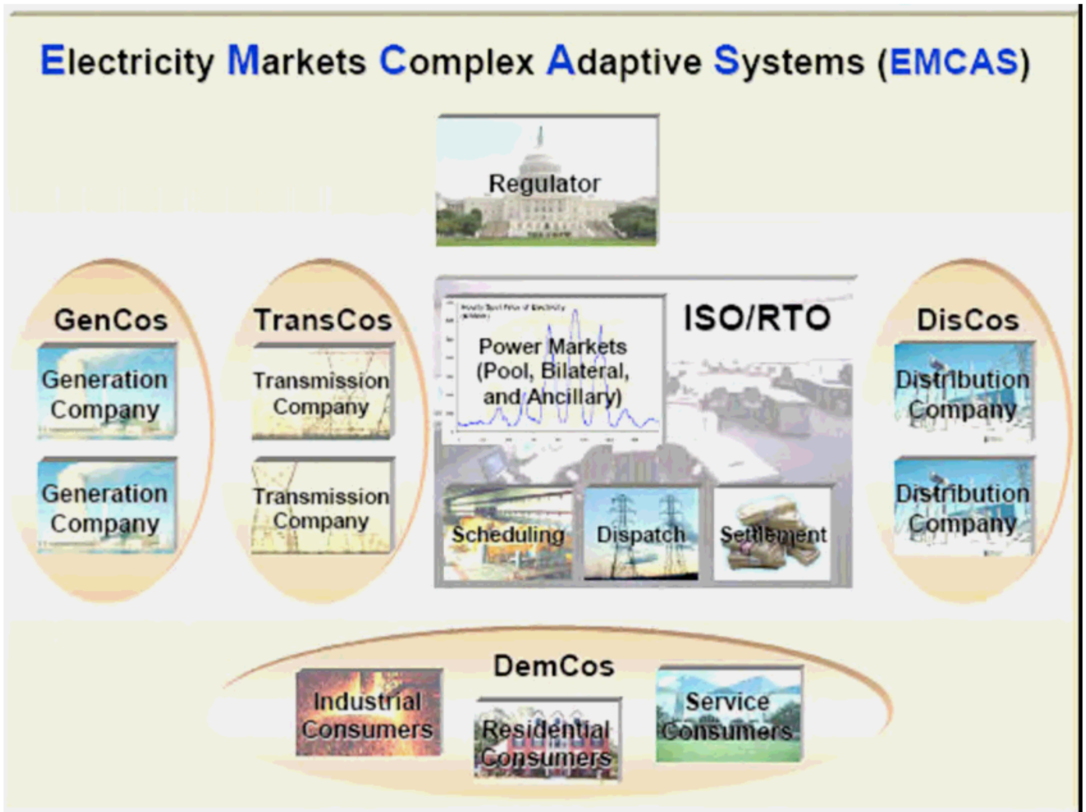
References

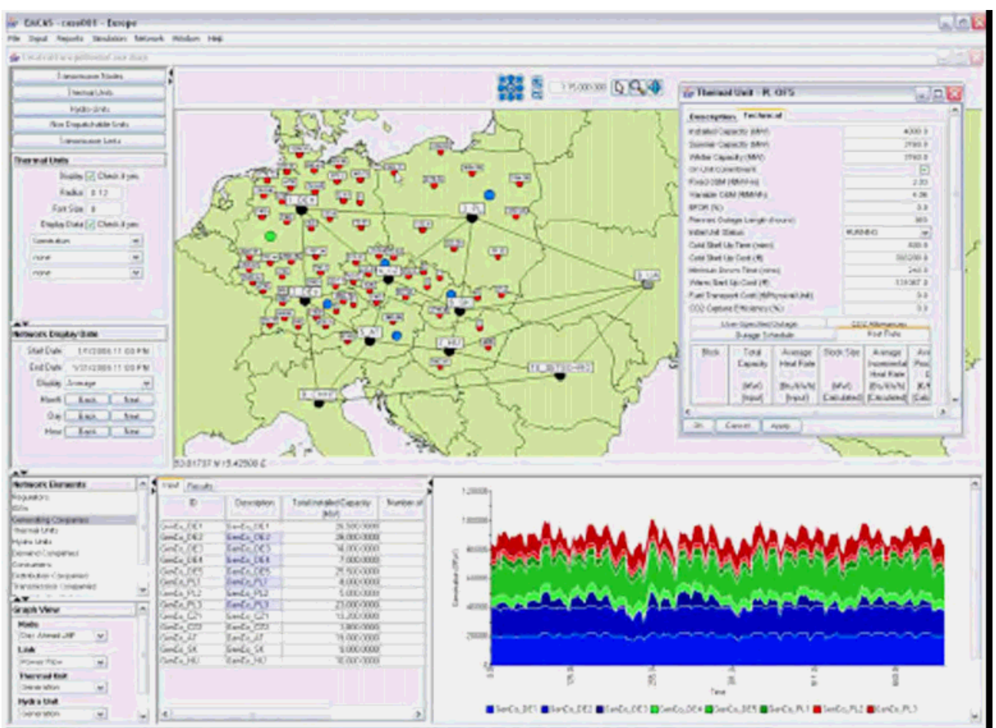
ADICA Consulting, LLC., *Innovative Solutions for Analyzing Energy Markets,* http://www.adica.com/media/downloads/ADICA_Overview_2006.pdf, Webpage visited July 3, 2006.

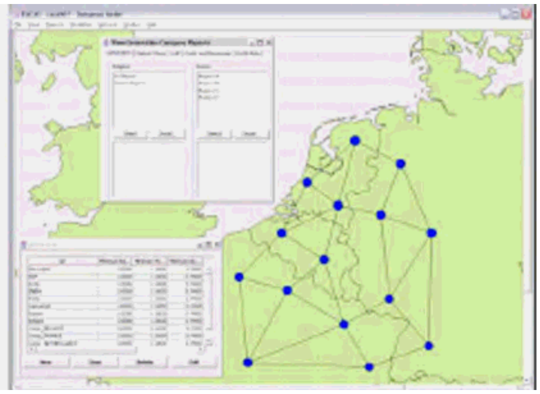
ADICA Consulting, LLC., *Electricity Market Complex Adaptive System (EMCAS) Software,* http://www.adica.com/media/downloads/EMCAS_Model_Overview.pdf, Webpage visited July 3, 2006.

ADICA Consulting, LLC., *Electricity Market Complex Adaptive Systems (EMCAS),* http://www.adica.com/media/downloads/EMCAS_Specifications_2006.pdf, Webpage visited July 3, 2006.

Argonne National Laboratory, *Simulating GenCo Bidding Strategies in Electricity Markets with an Agent-Based Model,* http://www.iaee.org/documents/denver/Thimmapuram.pdf#search='emcas', Webpage visited July 3, 2006.


Electricity Markets Complex Adaptive Systems (EMCAS)
Regulator
GenCos
Generation Company
Generation Company
TransCos
Transmission Company
Transmission Company
Power Markets (Pool, Bilateral, and Ancillary)
ISO/RTO
Scheduling
Dispatch
Settlement
DisCos
Distribution Company
Distribution Company
DemCos
Industrial Consumers
Residential Consumers
Service Consumers





Model Name	Fast Analysis Infrastructure Tool (FAIT)	
Organization	Sandia National Laboratory (SNL)	**Infrastructures**
POC	Theresa Brown tjbrown@sandia.gov	EP, NG, POL, TL, Emergency Services

Description

Overview – National Infrastructure Simulation and Analysis Center (NISAC) analysts are regularly tasked by the Directorate for Preparedness in the Department of Homeland Security (DHS) with determining the significance and interdependencies associated with elements of the nation's critical infrastructure. The Fast Analysis Infrastructure Tool (FAIT) has been developed to meet this need. FAIT utilizes system expert-defined object-oriented interdependencies, encoded in a rule-based expert systems software language (JESS), to define relationships between infrastructure assets across different infrastructures. These interdependencies take into account proximity, known service boundaries, ownership, and other unique characteristics of assets found in their associated metadata. In a similar fashion, co-location of assets can be analyzed based exclusively on available spatial data. The association process is dynamic, allowing for the substitution of data sets and the inclusion of new rules reflecting additional infrastructures, as data accuracy is improved and infrastructure analysis requirements expand. FAIT also utilizes established Input/Output (I/O) methods for estimating the economic consequence of the disruption of an asset. Each of these analysis elements (interdependency, co-location, economic analysis) have been extended from their original 'asset-level' analysis, to allow for the analysis of a specified region. Here, rules written for individual assets are executed en masse on classes of demand infrastructures, like assets of the emergency services (e.g., fire and police stations) and public health (e.g., hospitals) infrastructures, which lie in a defined analysis area, such as a hurricane damage zone, to identify those elements of supply infrastructures (e.g., electric power and telecommunications) which serve the largest number of particular sets of demand infrastructures. FAIT's regional economic analysis takes as input economic data (from the Bureau of the Census) for the disrupted area (as modeled by other NISAC capabilities). When coupled with other NISAC modeling results (estimates for the duration of the disruption and recovery, and the range of magnitude of disruption for the disrupted region), FAIT creates a regional economic analysis, an understanding of the direct and indirect economic consequences, for each sector of the economy in each county in the analysis area.

Development goals – The FAIT development team is constantly modifying their development goals to best support the requirements of NISAC analysts, in responding to questions from DHS. Current goals include the following:

Expansion of existing FAIT capabilities to cover infrastructures not in the current analysis set;

Enhancement of economic analysis capability to more accurately represent the consequences of the loss of infrastructure services on the performance of individual industrial sectors;

Incorporation of infrastructure-specific models to define areas of consequence due to the failure of asset(s) in a given infrastructure; and

Development of a network 'metacrawler' designed to associate sparse metadata (e.g., transportation system commodity throughput) with fragmented system elements (e.g., segments of the national rail network).

Intended users – Analysts on NISAC's Fast Analysis and Simulation Team.

System Output – Web-based, printer-friendly description of assets, their interdependencies, economic consequence of disruption, and other information associated with asset by system users.

Maturity – In development, utilized by NISAC Fast Analysis and Simulation Team to support NISAC analyses for DHS/Preparedness.

Areas modeled – First-order interdependencies for selected classes of assets in the energy, telecommunications, emergency services, and public health sectors, nationwide (based on data availability).

Customers/sponsors – DHS/IP – NISAC.

Model Framework	
Underlying model – Dependency model is an object-oriented expert system model of infrastructure interdependencies. The economic model centers on the economic disruption over an area or region from a discrete event. Economic methodology best employed for disruptions with a timeframe of 1 week to 1 month. **Simulation –** For identification of interdependencies, FAIT utilizes an expert system developed in JESS. Economic analysis within FAIT is performed utilizing Input-Output methodologies. Both elements are coded in Java. **Data format –** FAIT utilizes spatial and tabular data **Sensor data** – None. **Ability to couple with other models** – None; though results of other models (documents, files) can be coupled through the FAIT architecture to particular assets, classes of assets, or infrastructures with which they are associated. **Human Activity modeling –** None.	
System Requirements	
Hardware	None, for the end user. Program resides on a SNL server and supports web access.
Software	Internet Browser
Other Notes	
FAIT allows for external information, (e.g. web addresses or files), to be 'attached' to specific assets, classes of assets, or infrastructure sectors, such that when those areas are examined in the future, the associated information is accessible to future users.	

References
National Infrastructure Simulation and Analysis Center, *Fait Analysis Infrastructure Tool Fact Sheet*,http://www.sandia.gov/mission/homeland/factsheets/nisac/FAIT_factsheet.pdf.

<table>
<tr><td>Model Name</td><td colspan="3">Financial System Infrastructure (FinSim)</td></tr>
<tr><td>Organization</td><td colspan="2">Los Alamos National Laboratory</td><td>Infrastructures</td></tr>
<tr><td>POC</td><td colspan="2">Sam Flaim</td><td>FIN</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">Overview – The Financial System Infrastructure (FinSim) is an agent-based model of cash and barter transactions that is dependant on contractual relationships and a network at the federal reserve level. Agent based models create transactions which rely on telecommunications and electric power. Dependencies can cause deadlocks in the situation where one is unable to pay until being paid. The MIITS module asks every transaction whether there is an electronic connection available to make the transaction. The payments and settlement systems (PSS) module makes the validity checks.
Development goals – Development started in January 2005 to protect the physical infrastructure of payment and trading systems initiated by the events of 9-11. All current models didn’t address the transaction system, just the economic impact.
Intended users – Internal analyst.
System output – The system output is the number of financial institutions affected. Output is in a text-based format.
Maturity – Development.
Areas modeled – National Federal Reserve Banking System — Financial
Customers/sponsors – Sponsor is the National Infrastructure Simulation and Analysis Center (NISAC), Department of Homeland Security (DHS).</td></tr>
<tr><td colspan="4">Model Framework</td></tr>
<tr><td colspan="4">Underlying model – Agent-based model.
Simulation – FinSim models financial transactions modeling the 12 FRB, about 9,700 FedWire participants, and almost 28,000 financial institutions registered with FedACH.
This includes the electronic PSS—networks with contractual as well as electronic links and nodes
PSSs include: FedWire, FedNet, CHIPS, FedACH, Commercial ACHS ~50
Cash & barter (excluded from FinSim)
Data format – Not specified.
Sensor data – No direct sensor feeds.
Coupling with other models – Yes, coupling is done indirectly. Electrical power failure (IEISS output) ➟ Telecom failure (MIITS output) ➟ PSS failures (FINSIM)
Human activity modeling – None.</td></tr>
<tr><td colspan="4">System Requirements</td></tr>
<tr><td>Hardware</td><td colspan="3">Larger models require a computer cluster.</td></tr>
<tr><td>Software</td><td colspan="3">Java.</td></tr>
<tr><td colspan="4">Other Notes</td></tr>
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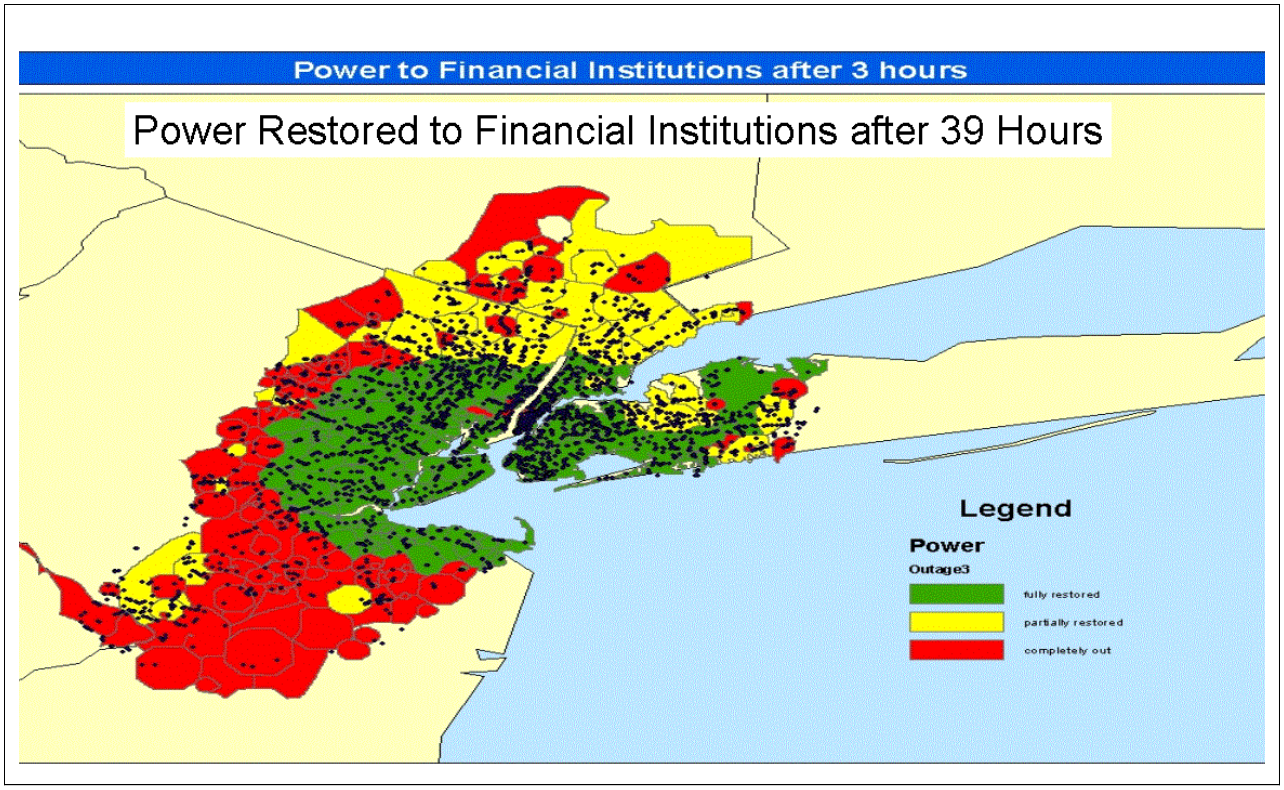


References
Financial System Infrastructure—FinSim, LAUR-05-9147.

<table>
<tr><td>Model Name</td><td colspan="3">Fort Future</td></tr>
<tr><td colspan="2">Organization

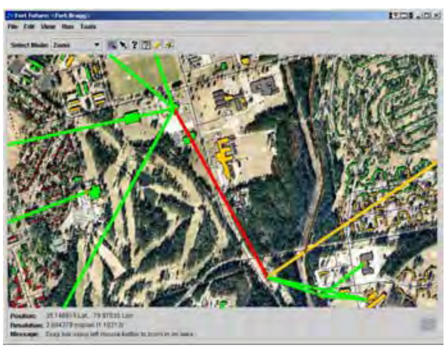
POC</td><td>U.S. Army Corps of Engineers, Engineer Research and Development Center, Construction Engineering Research Laboratory (CERL)
Dr. Michael P. Case
Michael.P.Case@erdc.usace.army.mil</td><td>Infrastructures
All support infrastructures for a military installation</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">Overview – Fort Future is a collaborative, web-based planning system that uses simulation to test plans for Department of Defense (DoD) installations. It uses an open, service-oriented architecture to allow multiple simulations to be run simultaneously from the same set of alternative, organized into a study. The web-based workbench provides geographic information system (GIS)-based plan editors, controls simulations, and organizes results into a decision matrix. Fort Future assesses the impact of critical infrastructure on mission using a “Virtual Installation” simulation that contains models for transportation, electrical power, water systems, including waterborne chemical/biological/radiological (CBR) agents, airborne CBR plume, facilities, mission tasks and processes, agents, and dynamic plans. The Virtual Installation simulation was built using Argonne National Laboratory’s Dynamic Information Architecture System (DIAS) framework and will be ported to the Repast agent modeling toolkit by September of 2006. Other models support analysis of encroachment, sustainability, and facility design.
Development goals – Demonstrate the use of simulation to improve planning for DoD Installations. Incorporate scenario descriptions into Simulation Interoperability Standards Organization (SISO) Military Scenario Definition Language (MSDL).
Intended users – Users will include installation and regional planners, US Army Corps of Engineers, and researchers.
System output – Output of the simulations is collected by a web-based collaborative workbench and presented as a decision matrix. The workbench can be customized to present output specific to particular simulations.
Maturity – This product is in development with some tools complete. The product will be complete by October, 2006.
Areas modeled – Fort Benning, Fort Shafter, Fort Bragg, and Fort Carson.
Customers/sponsors – United States Army.</td></tr>
<tr><td colspan="4">Model Framework</td></tr>
<tr><td colspan="4">Underlying model(s) – The agent-based Virtual Installation is based on DIAS and Repast. Water modeling uses EPAnet. CBR plume model uses the Defense Threat Reduction Agency (DTRA) Hazardous Prediction and Assessment Capability (HPAC) Tool.
Simulation – This model supports complex and lengthy scenario simulations
Data format – GIS – Environmental Systems Research Institute, Inc. (ESRI) Geodatabase and SHP files (Tri-service Spatial Data Standards). Scenarios – XML.
Sensor data – Not accepted.
Human activity – Human activities are modeled, however there are no humans in the simulation loop.
Coupling with other models – Fort Future is built to collaborate with multiple models using simple object access protocol (SOAP).</td></tr>
</table>

System Requirements	
Hardware	Fort Future is a server-based application, accessed over the internet using a web-browser.
Software	Fort Future has been tested on Windows and Linux servers. The workbench runs as a J2EE application on JBoss 3.x. Persistence is provided by MySQL or Oracle relational databases. Geospatial information is provided by ESRI ArcSDE and ArcGIS server. Users access the workbench using a web-browser.

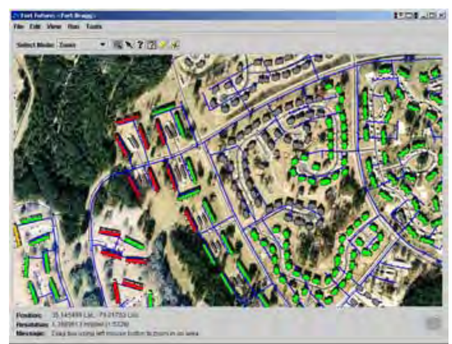
Other Notes

Users of Fort Future at the installation, regional, or national level will be able to set up planning scenarios, conduct dynamic analyses over time periods of up to 30 years, and compare scenario results. Fort Future will allow decision makers to:

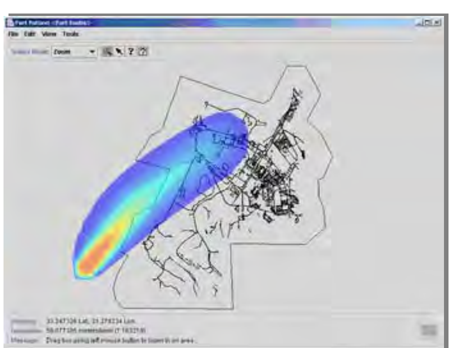
- Provide an integrated sustainability planning capability to support mission-essential task list (METL) analysis, master planning, and natural and cultural resource planning.
- Simulate the impact of critical infrastructure failure on the installation mission.
- Simulate and optimize planning for force projection. Metrics will focus on risk-based evaluation of an installation's ability to project forces over time.
- Simulate urban and regional growth around installations as a foundation for analysis of mission sustainability. Factors to be evaluated include encroachment, noise, traffic congestion, habitat, and threatened and endangered species.
- Manage facility requirements to rapidly generate, visualize, and analyze facilities for the Objective Force. The analysis will include force protection and sustainability issues.



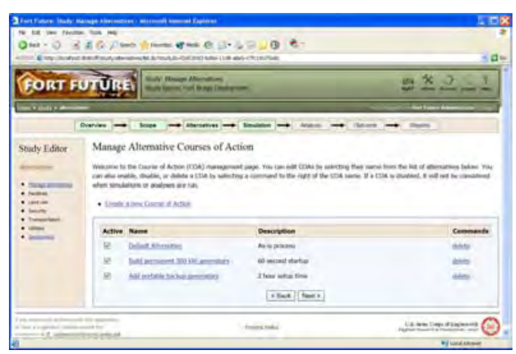
Electrical Infrastructure (capacity & interruption)



Water Infrastructure(flow & CBR)

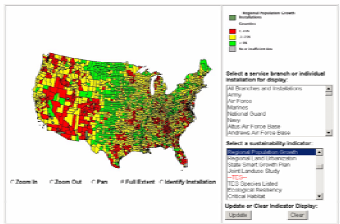


CBR Plume Modeling



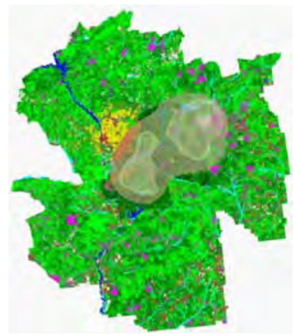
Collaborative Web-based Decision Support

National/Regional
Scale



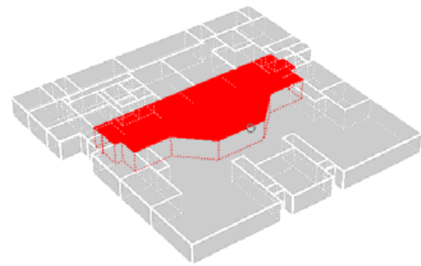
SIRRA
Sustainable Installation
Regional Resource
Assessment

Installation
Scale



LEAM
30 Year
Encroachment
Simulation

Facility
Scale



Facility Composer:
Accelerating MILCON
Transformation
SPiRiT & LEED
Sustainability Rating
AT Standards

References

Fact sheet on Fort Future, www.erdc.usace.army.mil/pls/erdcpub/docs/erdc/images/ERDCFactSheet_Research_FortFuture.pdf#search='fort%20future', Webpage accessed July 3, 2006.

US Army Corps of Engineers, www.erdc.usace.army.mil, Webpage visited July 3, 2006.

Discussion of US Army Corps of Engineers ongoing research,
http://www.erdc.usace.army.mil/pls/erdcpub/WWW_WELCOME.NAVIGATION_PAGE?tmp_next_page=61605&tmp_Main_Topic=51585, Webpage visited July 3, 2006.

Model Name	Inoperability Input-Output Model (IIM)	
Organization POC	University of Virginia Center for Risk Management of Engineering Systems, Director and founder – Lawrence R. Quarles Professor of Systems and Information Engineering and Civil Engineering Yacov Y. Haimes Yyh4f@virginia.edu	**Infrastructures** Financial networks, highway networks

Description

Overview – Inoperability Input-Output Model (IIM) is a computer-based analytical model capable of analyzing the impacts of an attack on an infrastructure and the cascading effects (in economic and inoperability terms) on all other interconnected and interdependent infrastructures. The model uses U.S. Bureau of Economic Analysis (BEA) data for assessing economic interdependencies. IIM allows systematic prioritization of infrastructure sectors that are economically critical and identifies sectors whose operability is critical during recovery. The model can be used to represent workforce recovery following a terrorist attack and identify essential response personnel. IIM also models recovery rates of different infrastructure sectors following an event.

Development goals – Not specified.

Intended users – Analysts and emergency planning and response organizations are the intended users.

System output – The model outputs various data and metrics in text and graphically.

Maturity – The model has been used with cooperation of various local and state governments.

Areas modeled – IIM has been used to model Virginia's transportation systems in various cities (e.g., Hampton City, Norfolk, and Virginia Beach) and support Department of Homeland Security (DHS) security alert levels for the greater New York area and to support a commission on high-altitude electromagnetic pulse (HEMP) attacks.

Customers/sponsors – Customers and sponsors of IIM include the State of Virginia, U.S. DHS, Defense Threat Reduction Agency (DTRA), the Department of Defense (DoD) and the Commission on High Altitude EMP Attacks on the U.S.

Model Framework

Underlying model – IIS is a mathematical model based on Wassily Leontif's input-output model for the U.S. economy which describes economic interdependencies.

Simulation – IIM simulates the behaviors of multiple infrastructure sectors during and following perturbations (such as terrorist attacks on modeled infrastructure) using economic and other data to assess the criticality of the effects.

Data format – Data are retrieved from and stored in relational databases containing information including employment and earnings data, commodity flow data, and geographic location data.

Sensor data – Not specified.

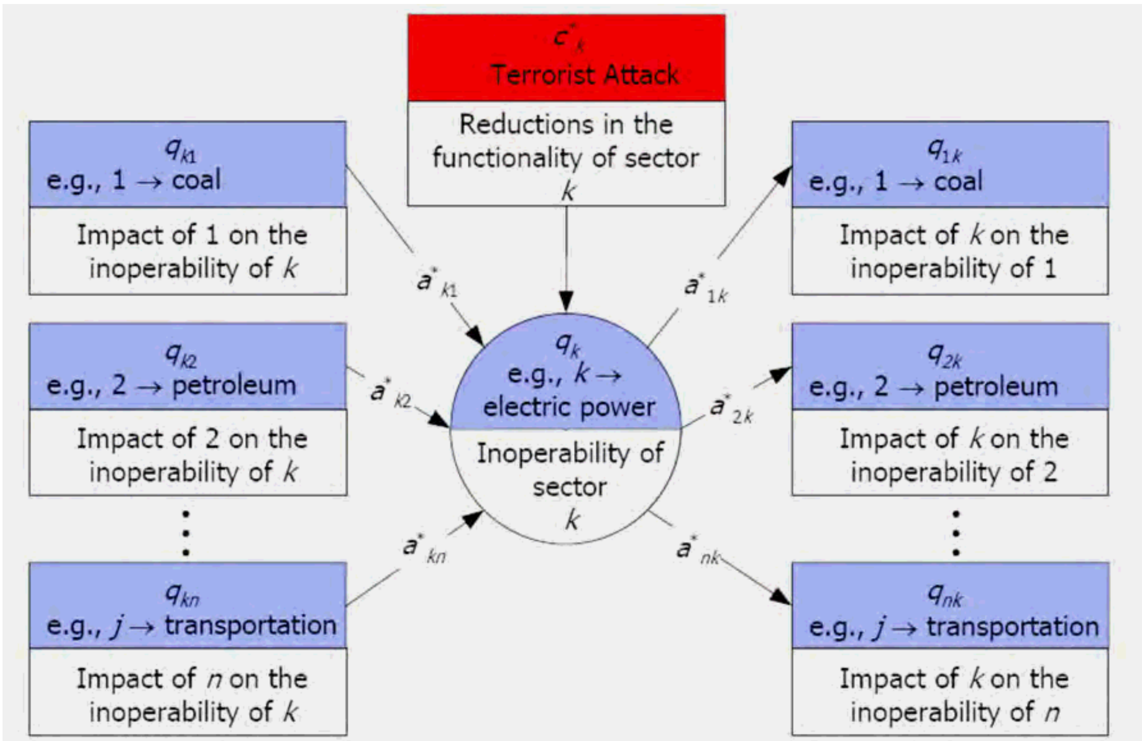
Coupling with other models – Not specified.

Human activity modeling – IIM has been used to model human activity in response to transportation disruptions.

System Requirements

Hardware	Not specified.
Software	Not specified.

Other Notes



IIM Calculates Propagating Effects.

References

Haimes, Y. (2005), *Risk-Based Framework for Modeling Infrastructure Interdependencies*, University of Southern California Terrorism Risk Analysis Symposium, Los Angeles, California, January 14, 2005, http://www.usc.edu/dept/create/events/2005_01_31/Risk_Based_Framework_for_Modeling_Infrastructure_Interdependencies.pdf#search='yacov%20Haimes%20interdependencies', Webpage visited July 12, 2006.

Haimes, Yacov Y., et al., "Inoperability input-output model for interdependent infrastructure sectors. I: Theory and methodology," *Journal of Infrastructure Systems*, Vol. 11, No. 2, June 2005, pp. 67-79.

Haimes, Y. (2004). *Assessment and Management of Transportation Infrastructure Security using the Inoperability Input-Output Model (IIM)*, October 19, 2004, http://www.virginiadot.org/infoservice/resources/TransConfHaimes%20-%20VDOT-Roanoke-October-19-2004-2.pdf#search='Yacov%20Y.%20Haimes%20interdependencies', Webpage visited July 12, 2006.

<table>
<tr><td>Model Name</td><td colspan="3">Interdependent Energy Infrastructure Simulation System (IEISS)</td></tr>
<tr><td>Organization</td><td>Los Alamos National Laboratory</td><td>Infrastructures</td></tr>
<tr><td>POC</td><td>Joe Holland</td><td>EP, NG</td></tr>
<tr><td colspan="3">Description</td></tr>
<tr><td colspan="3">Overview – The Interdependent Energy Infrastructure Simulation System (IEISS) is an actor-based infrastructure modeling, simulation, and analysis tool designed to assist individuals in analyzing and understanding interdependent energy infrastructures. The actor-based infrastructure components were developed in IEISS to realistically simulate the dynamic interactions within each of the infrastructures, as well as, the interconnections between the infrastructures. In particular, it has the ability to analyze and simulate the interdependent electric power and natural gas infrastructures. IEISS Water is a water distribution simulation capability for simulating urban scale water infrastructures and their interdependencies.

Development goals – The ultimate goal for IEISS is a multi-infrastructure modeling framework that can be used to analyze the complex, nonlinear interactions (interdependencies) among interdependent infrastructures including electric power, natural gas, petroleum, water, and other network based infrastructures that is scalable to multiple spatial (e.g., urban to regional) and temporal resolutions

Intended users – Internal Analyst – IEISS used to support the development of an impact report on for specific infrastructure events (such as, hurricanes, terrorist attacks, etc.).

System output – System output include the identification of outage areas (e.g., electrical outage areas). Output visualization is current in Java OpenMaps and is exportable to ESRI compatible shape files.

Maturity – Mature Internal.

Areas modeled – numerous US metropolitan areas.

Customers/sponsors – Sponsor is NISAC – DHS.</td></tr>
<tr><td colspan="3">Model Framework</td></tr>
<tr><td colspan="3">Underlying model – IEISS is an actor-based infrastructure modeling, simulation, and analysis tool designed to assist individuals in analyzing and understanding interdependent energy infrastructures.

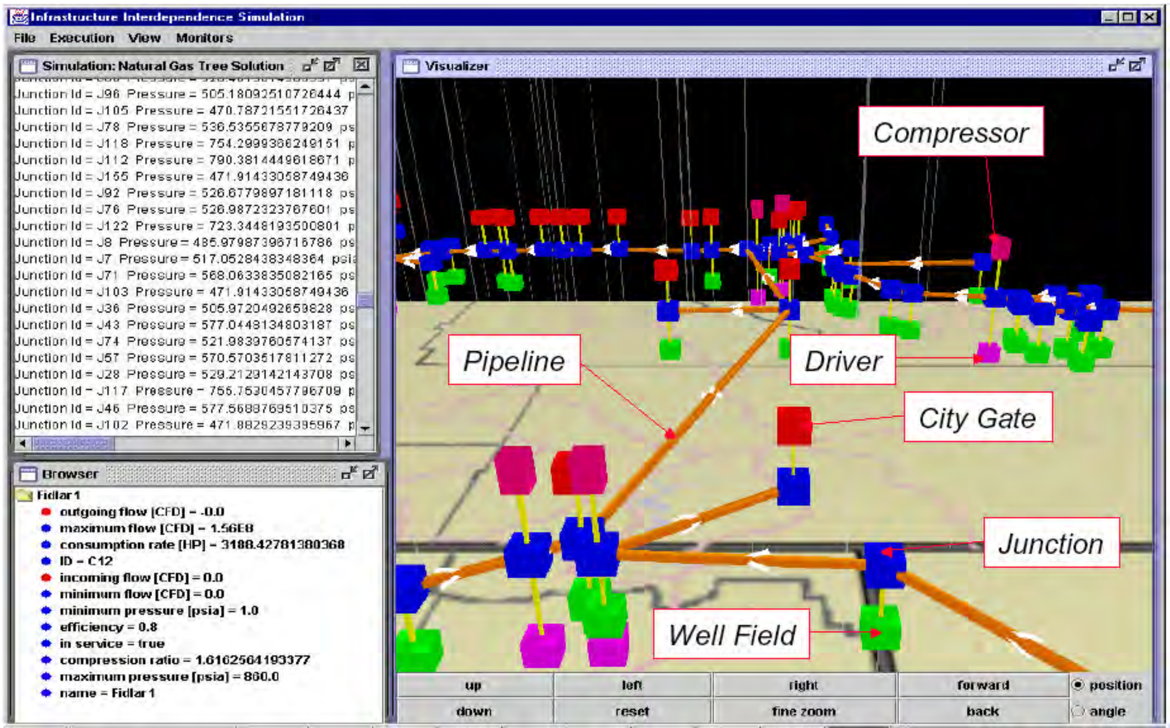
Simulation – A continuous time based model with an underling physical engine for system dynamics.

Data format – Data is input via xml format from a variety of databases.

Sensor data – no direct sensor feeds.

Coupling with other models – Yes, coupling is done indirectly. The output of IEISS will serve as the input to other infrastructure models to identify cross infrastructure effects.

Human activity modeling – None at this time.</td></tr>
<tr><td colspan="3">System Requirements</td></tr>
<tr><td>Hardware</td><td colspan="2">Cross platform compatibility – Windows and LINUX compatibility.</td></tr>
<tr><td>Software</td><td colspan="2">Requires the Java Virtual Machine.</td></tr>
<tr><td colspan="3">Other Notes</td></tr>
<tr><td colspan="3">IEISS is coupled with other LANL modeling tools. Of particular note is the Scenario Library Visualizer (SLV). SLV is a scenario library of outage simulations, which includes a custom visualization tools to provide map-based view of scenarios that have been evaluated in IEISS. The goal has been to identify potential impacts to critical infrastructures dependent upon electric power. SLV has principally been used during fast-response exercises for analysis of hurricane impacts (restoration of hurricanes Charlie and Ivan in ’04; Dennis, Katrina, Ophelia, Rita, Wilma in ‘05) SLV has also modeled electric power restoration during ice storms and during DOE-sponsored exercises involving low-voltage scenarios.</td></tr>
</table>



References

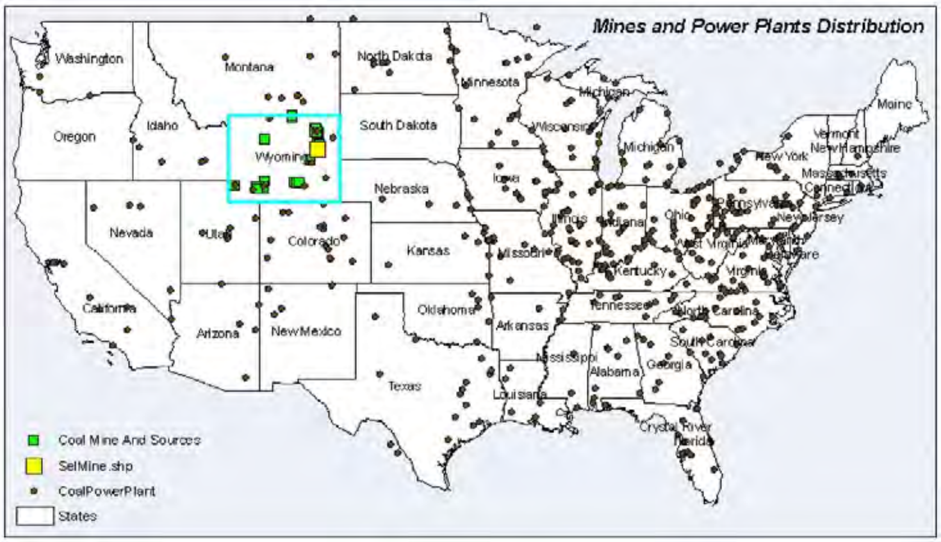
"NISAC Energy Sector – IEISS," NISAC Capabilities Workshop, LA-UR-03-1159, Portland, Oregon, 26-27 March 2003.

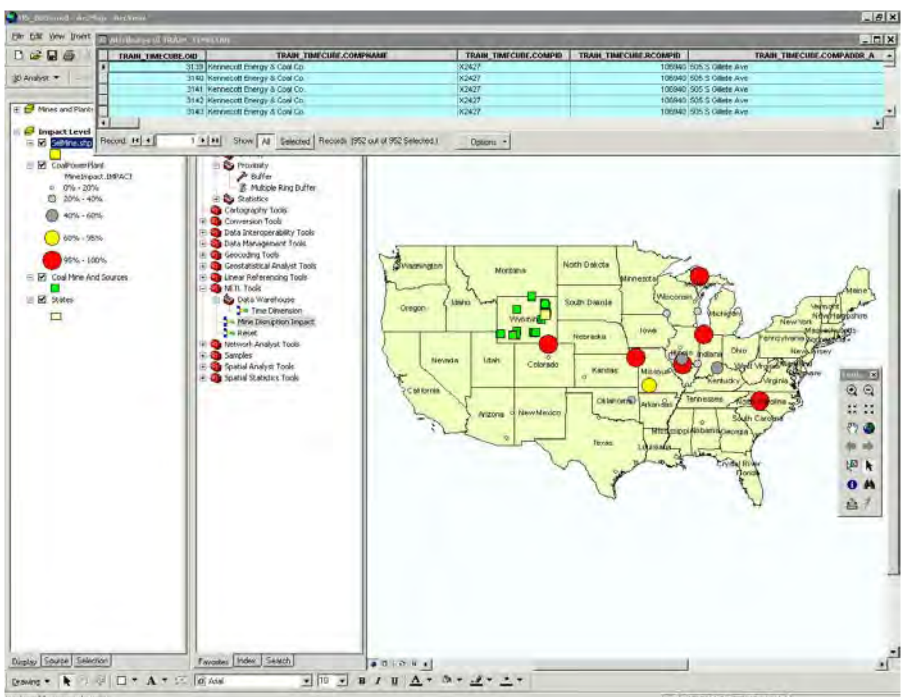
Los Alamos National Laboratory, "Energy Infrastructure Modeling at LANL," LALP-03-027, LA-UR-03-0658.

Los Alamos National Laboratory, "Energy and Environmental Programs Compendium," LA-LP-02-216.

<table>
<tr><td>Model Name</td><td colspan="3">Knowledge Management and Visualization in Support of Vulnerability Assessment of Electricity Production</td></tr>
<tr><td rowspan="2">Organization
POC</td><td rowspan="2">Carnegie Mellon University
H. Scott Matthews
hsm@cmu.edu
Department of Energy (DOE) National Energy Technology Laboratory (NETL) Pittsburgh and Morgantown Campuses</td><td>Infrastructures</td></tr>
<tr><td>EP (RL, WW, HW limited)</td></tr>
<tr><td colspan="3">Description</td></tr>
<tr><td colspan="3">Overview – This is a research project to analyze vulnerabilities associated with delivery of fuel. It is designed to help ensure availability of supply and to visualize the impacts for decision support. The project has focused on coal deliveries to power plants because, while vulnerabilities at the power plant level (production) are easier to identify, vulnerabilities and impacts associated with delivery of fuel are more uncertain. Also, data on coal shipments is readily available.
Development goals – The first phase of the project focused on the origin (mines) and destination (power plant) layers of the coal model. The middle (transportation) layer will be focused on in the future. Additional work will also be done to improve tools for data mining such as, classification of transportation assets, better prediction of impacts, and improved sequential pattern analysis tools.
Intended users – Planners are the intended users.
System output – Output includes maps and chart graphics showing mines, transportation routes, and affected (with degree of vulnerability to disruption) power plants.
Maturity – This project is currently in the prototype stage with ongoing research.
Areas modeled – United States with emphasis on coal mines in Wyoming.
Customers/sponsors – Department of Energy (DOE) National Energy Technology Laboratory (NETL).</td></tr>
<tr><td colspan="3">Model Framework</td></tr>
<tr><td colspan="3">Underlying model(s) – Statistical data and analysis tools drawing on data derived from data warehouses.
Simulation – Mines can be removed from the network and a simulation run to identify plants affected and the degree of the impact on production.
Data format – Data were used from several databases including; Coaldat (developed by Platts containing ~ 2500 coal transactions per month), Coal Transportation Rate Database developed by the Energy Information Administration supplemented with data from the Department of Transportation (DOT) Surface Transportation Board (STB), National Transportation Atlas Database (NTAD), and PowerMAP, a geographical information system (GIS) developed by Platts containing map layers of power plants and mines.
Sensor data – Not included.
Human activity – Not modeled.
Coupling with other models – Not specified.</td></tr>
<tr><td colspan="3">System Requirements</td></tr>
<tr><td>Hardware</td><td colspan="2">Not specified.</td></tr>
<tr><td>Software</td><td colspan="2">Not specified.</td></tr>
</table>

Other Notes
The Transportation Routing Analysis Geographic Information System (TRAGIS) developed by Oak Ridge National Laboratory (ORNL) was evaluated to help with the problem of routing (of coal supplies). TRAGIS is designed to schedule possible routes by selecting the origin and destination with one transportation mode (e.g., highway, rail, and waterway modes) and route type (e.g., commercial [default], quickest, shortest, and others). Currently, it is not able to schedule routes for multimodal transportation as is often used to deliver coal. While the most frequently used mode of transporting coal is railroad, many transactions are shipped multimode, such as by barge then by railroad. Therefore, a multimodal route scheduling solution is necessary for acquiring more accurate transportation analyses.





References
Information in the preceding section was obtained from draft report and communications with point of contact.

Model Name	Multi-Layer Infrastructure Networks (MIN)	
Organization **POC**	Purdue School of Civil Engineering Dr. Srinivas Peeta peeta@purdue.edu George Mason University Dr. Terry Friesz tfriesz@gmu.edu	**Infrastructures** HW, HA

Description

Overview – This is a preliminary network flow equilibrium model of dynamic multi-layer infrastructure networks (MIN) in the form of a differential game involving two essential time scales. In particular, three coupled network layers—automobiles, urban freight, and data—are modeled as being comprised of Cournot-Nash dynamic agents. An agent-based simulation solution structure is introduced to solve the flow equilibrium and optimal budget allocation problem for these three layers under the assumption of a super authority that oversees investments in the infrastructure of all three technologies and thereby creates a dynamic Stackelberg leader-follower game.

Development goals – Continue to develop a generalized framework to address both equilibrium and disequilibrium scenarios.

Intended users – Community planners and engineers.

System output – Charts, graphs, behavioral trends.

Maturity – Research.

Areas modeled – Urban transportation (e.g., auto, urban freight, and data).

Customers/sponsors – The National Science Foundation sponsored the work.

Model Framework

Underlying model – Agent based simulation of multi-layer infrastructure networks. The three-layer model consists of an auto, urban freight, and data layer flow sub models. These three sub models are combined and solved using an agent-based simulation approach.

Simulation – Temporal dynamic flow model involving producers and consumers.

Data format – Not specified.

Sensor data – Not incorporated.

Coupling with other models – Unknown.

Human activity modeling – Models human activity as consumers.

System Requirements

Hardware	Not specified.
Software	Not specified.

Other Notes

References

Model Name	Multi-Network Interdependent Critical Infrastructure Program for Analysis of Lifelines (MUNICIPAL)	
Organization **POC**	Rensselaer Polytechnic Institute (RPI) Earl E. Lee II Leee7@rpi.edu William A. Wallace wallaw@rpi.edu John E. Mitchell mitchj@rpi.edu David M. Mendonca mendonca@njit.edu	**Infrastructures** TC, EP, RL

Description

Overview – Multi-Network Interdependent Critical Infrastructure Program for Analysis of Lifelines (MUNICIPAL) is a geographic information system (GIS) user interface, built on a formal, mathematical representation of a set of civil infrastructure systems that explicitly incorporates the interdependencies among them. The mathematical foundation or decision support system is called the Interdependent Layered Network (ILN) model. ILN is a mixed-integer, network-flow based model implemented in software drawing on a database containing infrastructure attributes. MUNICIPAL provides the capability to understand how a disruptive event affects the interdependent set of civil infrastructures. This can help communities train for and respond to events that disrupt services required for their health, safety, and economic well being. It can be used to help assess the vulnerability of systems due to their reliance on other systems. The model is generic (applicable to more than one location) and not specific to a particular type of event, such as an earthquake or hurricane.

Development goals – Once the Los Angeles and Manhattan data sets are complete, mathematical and technical assessments will be conducted. The system will also be evaluated by infrastructure system managers and emergency response organizations.

Intended users – MUNICIPAL is intended for use by personnel in charge of response and restoration efforts following a disruptive event and as a training tool for personnel who guide response and restoration efforts.

System output – A GIS interface displays systems and identifies affected areas. An operator can update the conditions of components of the set of systems modeled, add temporary systems during restoration, and display areas affected by inabilities to meet demands.

Maturity – Prototype system.

Areas modeled – Manhattan, NY and Los Angeles, CA.

Customers/sponsors – National Science Foundation.

Model Framework

Underlying model – MUNICIPAL consists of a GIS interface for the user, a database with the attributes of the set of infrastructures, the ILN module, and the vulnerability module.

Simulation – With identification of paths or components of concern, MUNICIPAL identifies components in the parent system which these paths or components rely on. For example, placing power supply components in a failed condition will identify telecommunications components that rely on these sections of power to fail. By proposing new connections within telecomm, MUNICIPAL can help to determine if a feasible path (or paths) exists and the set of nodes that constitute this path (or set of paths). MUNICIPAL can also be used for the addition of temporary or alternative power sources or any other analyses relating to improving reliability by adding redundancy.

Data format – ESRI ArcGIS, relational database, text.

Sensor data – Not currently configured for sensor data. **Coupling with other models** – Not specified. **Human activity modeling** – Not specified.	
System Requirements	
Hardware	Not specified.
Software	Not specified.
Other Notes	

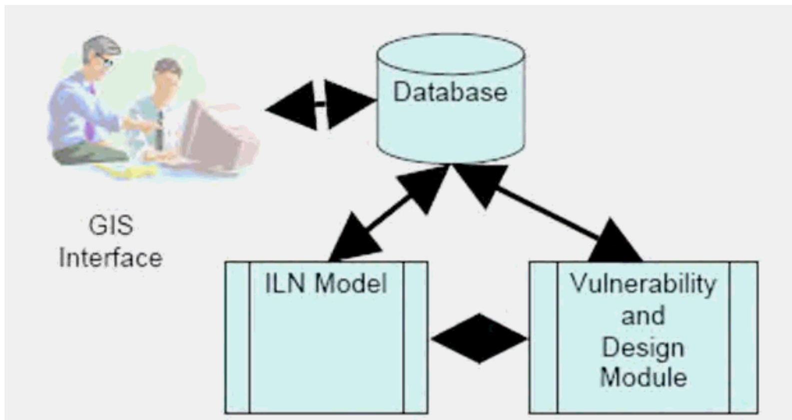
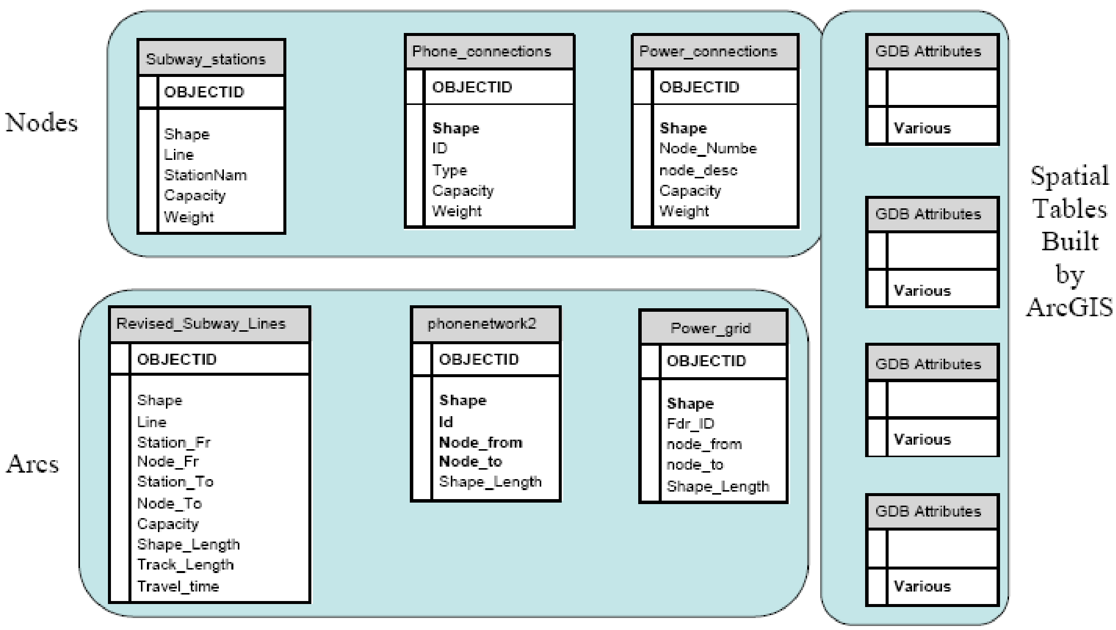
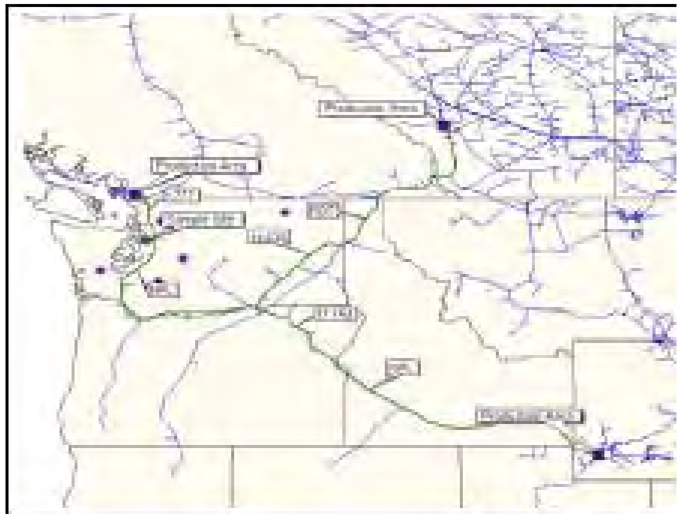


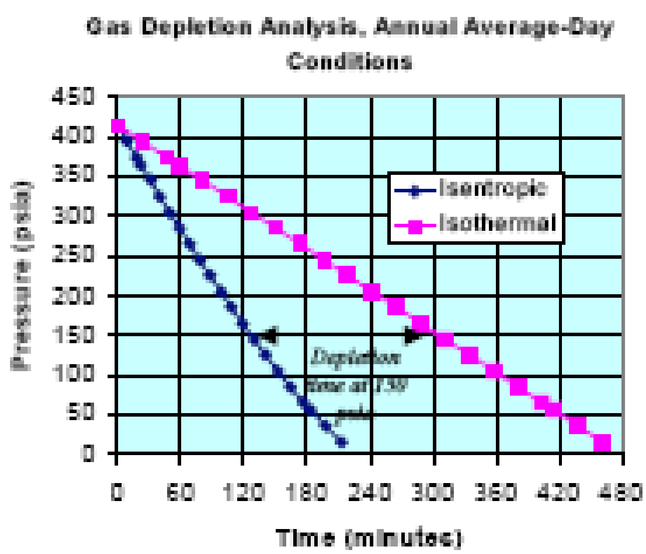
Figure 1



References
Lee, Earl E. II, et al., *Decision Technologies for Protection of Critical Infrastructures,* http://www.rpi.edu/~mitchj/papers/decisiontechnologies.pdf#search='decision%20technologies, Webpage visited July 10, 2006.

Model Name	Natural Gas Infrastructure Toolset (NGtools)	
Organization **POC**	Argonne National Laboratory, Infrastructure Assurance Center (IAC) Dr. James Peerenboom jpeerenboom@anl.gov	**Infrastructures** NG, EL
Description		
Overview – The Infrastructure Assurance Center (IAC) has developed a set of tools to represent the physical components of the natural gas network. The Natural Gas Infrastructure Toolset (NGtools) was developed to provide an analyst with a quick method to access, review, and display components of the natural gas network; perform varying levels of component and systems analysis, and display analysis results. **Development goals** – Not specified. **Intended users** – Natural gas suppliers and users (e.g., electric utilities). **System output** – Geographic (using GIS) or schematic view of pipeline system, charts and graphs showing failure sets (e.g., pumping stations and power stations) and the amount of time to gas depletion. The system allows various analyses on component and system level, and displays results. **Maturity** – The system is in development. **Areas modeled** – Not specified. **Customers/sponsors** – US Department of Energy.		
Model Framework		
Underlying model – Agent-based. **Simulation –** NGflow simulates steady-state gas network flows and provides gas flow movements under various operating conditions based on gas flow balancing algorithms and available system flow data. **Data format –** Not specified. **Sensor data** – Not specified. **Coupling with other models** – Not specified. **Human activity modeling** – Human activities are not modeled.		
System Requirements		
Hardware	Not specified.	
Software	Not specified.	
Other Notes		
There are four tools in the toolset; NGanalyzer, NGcut, NGflow, and NGdepletion as described in the following: NGanalyzer assists in analyzing gas system characteristics and vulnerabilities. Key considerations include the number of city-gates, available storage, and pipeline capacity and interconnections. The figure below shows an example of the shortest path distance from major gas supply areas to a sample site as calculated by the model. NGcut determines network component failure sets that could isolate a specific location or site from all supply sources. One of the advantages of using this model is that it significantly decreases the time needed to analyze site isolation issues by automating the construction of failure sets. The model also allows analysts to consider a larger number of failures and to broaden an analysis. Failure sets identified by NGcut provide an initial set of components that require closer examination. NGflow identifies critical links and nodes in a network topology. This tool provides an alternative to using very detailed, data-intensive commercial flow simulation models. The model also gives a unique snapshot of the gas transmission infrastructure that supports a certain location or site. NGdepletion addresses outage duration times and determines whether and when a component outage will affect a specific location or site. The model computes the amount of time that line pack can continue supplying gas to a site.		



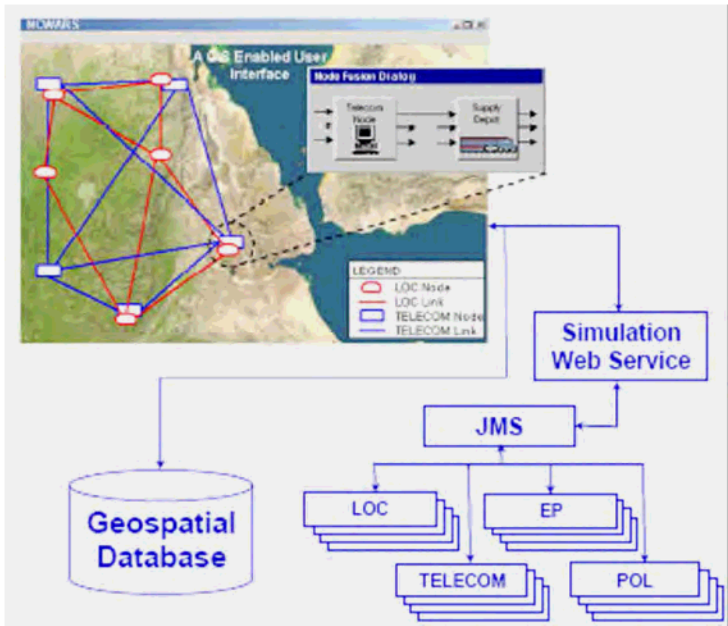


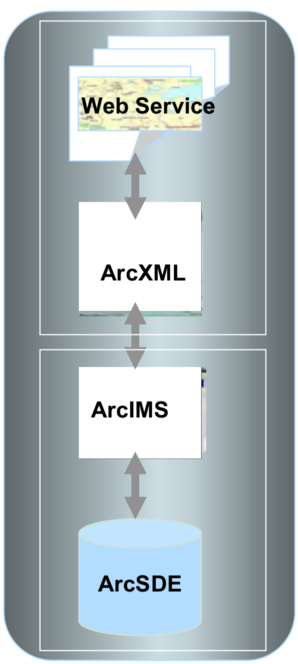
Gas Depletion Analysis, Annual Average-Day Conditions
Pressure (psia)
450
400
350
300
250
200
150
100
50
0
0
60
120
180
240
300
360
420
480
Time (minutes)
Isentropic
Isothermal
Depletion time at 150 psia

References

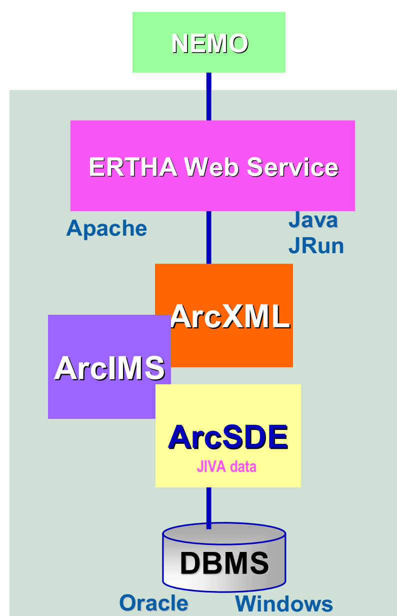
<table>
<tr><td>Model Name</td><td colspan="2">Net-Centric Effects-based operations MOdel (NEMO)</td></tr>
<tr><td>Organization
POC</td><td>SPARTA
Brent L. Goodwin
Brent.goodwin@sparta.com
Laura Lee
Laura.lee@sparta.com</td><td>Infrastructures
TC, EP, NG, DW</td></tr>
<tr><td colspan="3">Description</td></tr>
<tr><td colspan="3">Overview – Net-Centric Effects-based operations MOdel (NEMO) is an effects-based planning and analysis application for modeling the cascading effects of events across multiple infrastructure networks. It is a Net-Centric compliant application, relying on a service oriented architecture (SOA) approach to access infrastructure models, data repositories, and mapping tools. NEMO models interactions across electrical power, water, gas, and road networks using an on/off interaction behavior between the components of the different networks, and provides a solid foundation for advancement. NEMO provides a first of its kind capability for observing second and higher order effects of operations against opponents' infrastructure networks.
Development goals – Efforts are underway to integrate social/political networks into the effects-based operation (EBO) process. Future development needs to enhance the program capabilities for integrating additional relationship definitions, multi-agent capabilities, and optimization.
Intended users – Planners and analysts are the intended users.
System output – NEMO displays maps overlaid with nodes and linkages between various infrastructures. Disruptions and cascading effects are highlighted during simulations.
Maturity – This is a prototype system.
Areas modeled – Not specified.
Customers/sponsors – NEMO was internally developed by SPARTA.</td></tr>
<tr><td colspan="3">Model Framework</td></tr>
<tr><td colspan="3">Underlying model – The graphical user interface (GUI) is backed by an SOA consisting of two web services; one accesses to a geo-spatial database for storage and retrieval of network databases, and the other coordinates interaction with the various infrastructure models used to provide network status feedback. The geo-spatial database web service, Earth Resource Terrain Hierarchical Archive (ERTHA), contains nearly 200GB of network definitions that may be accessed via the NEMO GUI and used to support effects-based analysis. ERTHA is a geographical information system (GIS) database, based on ESRI products, of infrastructure data items (e.g., power lines, road networks) that were developed as an unclassified source. Abstracting access to data through a web service decouples NEMO from a specific database and specific vendors, making it possible to integrate other data sources in the future.
Simulation – NEMO provides a basic capability for effects-based planning and performing "what if" analysis of actions.
Data format – Data is in Environmental Systems Research Institute's (ESRI) ERTHA relational database format. Other models utilize a model interface client (MIC) translator and eXtensible Markup Language (XML).
Sensor data – Not included.
Human activity modeling – Changes to include human activity modeling are in progress.
Coupling with other models – NEMO integrates four infrastructure models: lines of communications, electrical power, gas pipelines, and water pipelines. The models used to evaluate these networks are industry best-of-breed simulation tools for their domains. CitiLabs' Voyager simulation provides road and rail network analysis, while Advantica (formerly Stoner Engineering) provides the Solver tools for electrical power networks as well as the water and gas pipelines.</td></tr>
<tr><td colspan="3">System Requirements</td></tr>
<tr><td>Hardware</td><td colspan="2">Windows XP/2000.</td></tr>
<tr><td>Software</td><td colspan="2">Not Specified.</td></tr>
</table>

Other Notes
Efforts are ongoing and mostly complete to integrate social/political networks into the EBO process. For the most part, these efforts are complete. We have integrated the Political Science-Identity (PSI) model (from University of Pennsylvania, Dr. Ian Lustick) into our architecture, and have developed operators that alter the contentedness of a population based on associated physical infrastructure. Further information on PS-I is available at http://jasss.soc.surrey.ac.uk/5/3/7.html.





- **ERTHA Web Service**
  - Interface for all GIS Infrastructure Models
    - "Get" shape files and associated attributes
- **ArcIMS and ArcXML**
  - ESRI's interface to ArcSDE and its Data
  - ArcIMS : Internet Map Server
  - ArcXML : Layer Definition and Query Language for ArcIMS
- **ArcSDE**
  - Spatial Database Engine
  - Centralized management of geographic information in a DBMS
    - Vector, raster, table, annotation, relationships, CAD
  - Contains a subset of JIVA's data
- **DBMS**
  - Oracle database
  - Features as objects
    - Geometry
    - Attributes
    - Behavior (rules, methods, relationships)
  - Uses ArcSDE for multi-user access and versioning



References
JASSS, *PS-1: A User-Friendly Agent-Based Modeling Platform for Testing Theories of Political Identity and Political Stability*, http://jasss.soc.surrey.ac.uk/5/3/7.html, Webpage visited July 3, 2006.
Sparta, *Planning and Assessing Effects Based Operations,* www.**sparta**.com/sew/publications/**NEMO-**for-ICCRTS.pdf, Webpage visited July 3, 2006.

<table>
<tr><td>Model Name</td><td colspan="3">Network-Centric GIS</td></tr>
<tr><td colspan="2">Organization
POC</td><td>York University, Toronto, Ontario, Canada
Rifaat Abdalla
abdalla@yorku.ca</td><td>Infrastructures
RL, HW, WW</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">Overview – This system is a framework for using geographical information system (GIS) interoperability for supporting emergency management decision makers by providing effective data sharing and timely access to infrastructure interdependency information.
Development goals – There are no development goals identified at present.
Intended users – This is intended for emergency planners and responders.
System output – Output are GeoServNet (York University GeoICT Lab Product) GIS 2 and 3D images.
Maturity – Proof of principle.
Areas modeled – This has been modeled in Vancouver, British Columbia (Earthquake scenario) and Toronto, Ontario (Flood scenario).
Customers/sponsors – Ongoing research began under Canada's Joint Infrastructure Interdependencies Research program (JIIRP), which is jointly funded by the Natural Sciences and Engineering Research Council (NSERC) and the department of Public Safety and Emergency Preparedness Canada (PSEPC).</td></tr>
<tr><td colspan="4">Model Framework</td></tr>
<tr><td colspan="4">Underlying model – Underlying models are GIS technologies including ArcGIS 9 (desktop) and GeoServNet (web-based), GSNBuilder, GSNAdministrator, GSNServer, GSNPublisher, GSNViewer, and HEC-RAS (used for hydraulic simulation with ArcView GIS).
Simulation – The system has GIS-based spatial-temporal simulations.
Data format – Data formats are GIS data, graphics, and text. Knowledge-base information is stored in a specially designed object-oriented database. The project used Environmental Systems Research Institute's (ESRI) Geodatabase model.
Sensor data – Hydraulic gauges provide information for water surface levels and there exists a capability for integrating other live sensor information.
Coupling with other models – None.
Human activity modeling – Not included.</td></tr>
<tr><td colspan="4">System Requirements</td></tr>
<tr><td>Hardware</td><td colspan="3">Pentium 4 with 512 RAM, broadband connection.</td></tr>
<tr><td>Software</td><td colspan="3">ESRI ArcGIS, GeoServNet.</td></tr>
<tr><td colspan="4">Other Notes</td></tr>
<tr><td colspan="4">Model creation process for the flood model:
• Preparation of different data layers
• Digitize floodplain, banks, stream centerline, and stream cross section using HEC-GeoRAS extension for ArcView
• Input flood parameters using channel geometry created in ArcView and model a flood scenario using HEC-RAS, GIS interoperability is utilized for sharing and visualization of the disaster model
• Delineate flood layers using HEC-RAS export ASCII data and data layers with help of ArcView and HEC-GeoRAS extension.
Populate flood layers produced in GeoServNet using standard processing procedures.
The following steps are useful for defining location based infrastructure interdependencies (LBII) for a particular area:</td></tr>
</table>

- Identify critical infrastructure sectors in the study area
- Analyze processes and operations for each sector
- Analyze dependencies
- Determine Interdependencies
- Collect data
- Model and visualize (interoperable 3D internet-based).

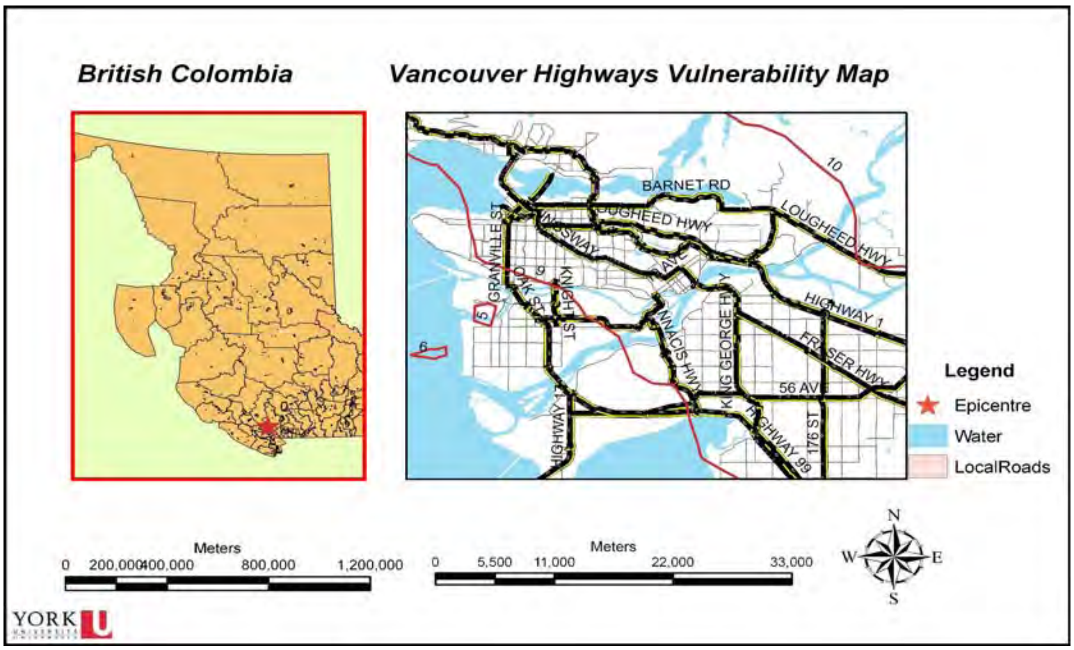
Earthquake scenario modeling is based on using a Geological Survey of Canada Shakemap for the city of Vancouver.

Critical infrastructure at risk was identified based on GIS modeling.

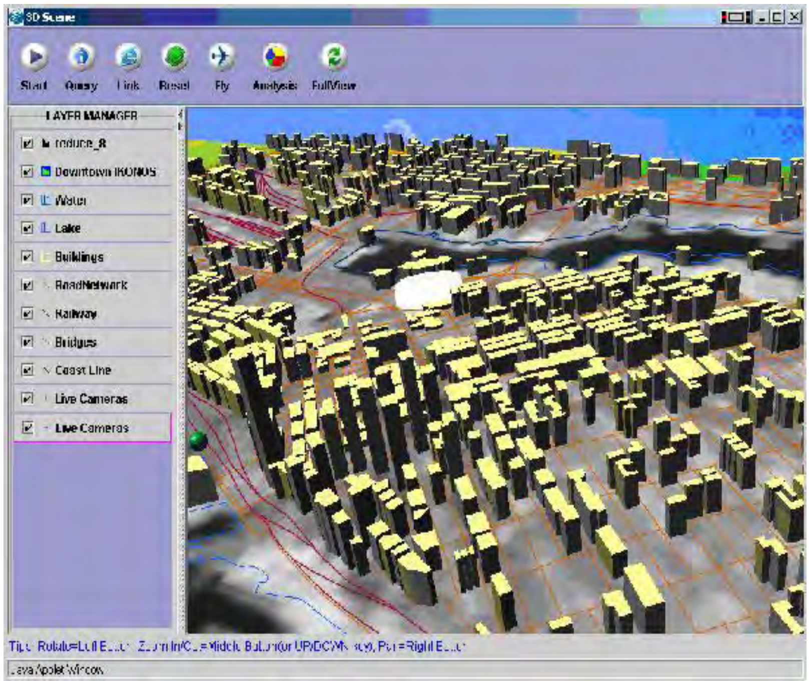
Building damage density was analyzed based on IKONOS satellite imagery.

Population at risk was identified based on census information and the Shakemap.

Location based infrastructure interdependency was modeled.



Spatial Model Showing Critical Infrastructures at Risk



GeoServNet 3D Damage Assessment Model of Downtown Vancouver

References

Abdalla, R. Tao, V. and H. Ali., 2005. "Location-Based Infrastructure Interdependency: New Term, New Modeling Approach," *Proceedings of Geoinformatics 2005, Toronto, August 17-19*, 2005 CD.

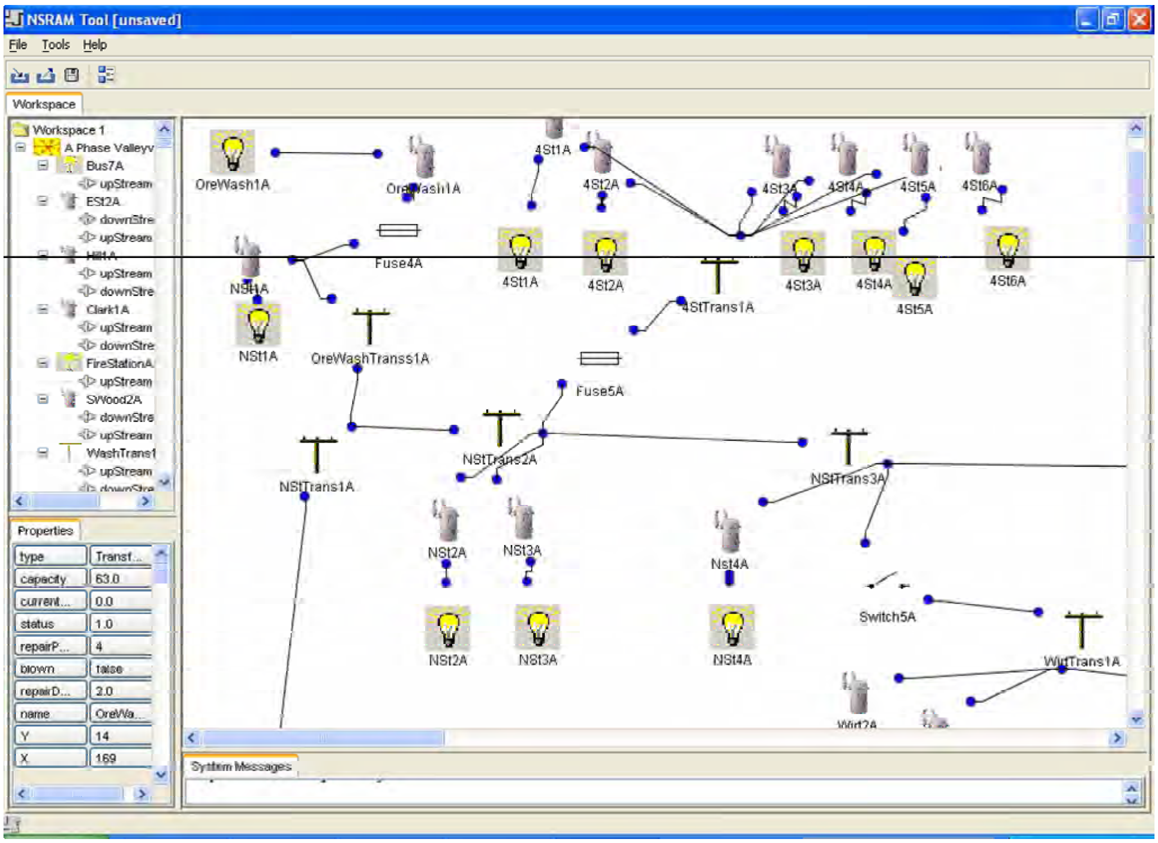
Abdalla, R., K. Niall, and V. Tao, 2005. "A framework for modeling Critical Infrastructure Interdependency Using GIS," *Canadian Risk and Hazard Symposium, Toronto, 19-21 November 2005*.

Joint Infrastructure Interdependency Research Program, *Modeling Infrastructure Interdependency for Emergency Management Using a Network-Centric Spatial Decision Support System Approach*, www.geoict.yorku.ca/JIIRP/Jiirp.htm, Webpage visited July 10, 2006.

<table>
<tr><td>Model Name</td><td colspan="2">Network Security Risk Assessment Model (NSRAM) Tool for Critical Infrastructure Protection (CIP) Project</td></tr>
<tr><td>Organization

POC</td><td>James Madison University (JMU), Institute for Infrastructure and Information Assurance
Philip Riley
RileyPB@jmu.edu
Jim McManus
McManuJP@jmu.edu
Samuel T. Redwine, Jr.
RedwinST@jmu.edu
George Baker
BakerGH@jmu.edu
Taz Daughtrey
DaughtHT@jmu.edu</td><td>Infrastructures
EP, CN</td></tr>
<tr><td colspan="3">Description</td></tr>
<tr><td colspan="3">Overview – The network security risk assessment model (NSRAM) tool is a complex network system simulation modeling tool that emphasizes the analysis (including risk analysis) of large interconnected multi-infrastructure models. It is designed to be portable, and uses portable and expandable database and model structures. The tool also provides a framework to simulate large networks and analyze their behavior under conditions where the network suffers failures or structural breakdowns. In order to accurately portray the severity of network failures, repair variables (time to repair, cost to repair, repair priorities) must be considered. NSRAM's unique repair element set consists of repair entities with specialized functions that allow users to accurately simulate any configuration of fault detection and repair schemes. The intent of these repair element sets is to more accurately model the human response to perceived system damage. The repair element sets identify symptoms, test the system to determine the elements that are damaged, attempt to repair the damage, and then attempt system recovery. If symptoms are still present, the repair elements repeat the above cycle until the system is recovered. Inspection routines will also be accommodated so that preventative maintenance effects are accurately incorporated. The tool is flexible and can be used to model different infrastructure networks, such as computers, electrical systems, and highway systems.
Development goals – James Madison University (JMU) is continuing development to add strong security features, improve the graphical user interface (GUI) and database efficiency, and to develop an emergency radio system element set. JMU is also developing the concept of sophisticated repair element sets that interact via predefined algorithms to more accurately simulate repair personnel reaction to system insults or malfunctions. These repair element sets are unique in that they interact with the simulation network model in a predetermined manner, but their operating rules can be changed to allow the user to optimize repair strategies.
Intended users – Analysts are the intended users.
System output – NSRAM contains a GUI for developing models and scenarios, and interpreting output. The data output is flexible to facilitate post simulation processing.
Maturity – NSRAM is currently in development as part of the CIP project.
Areas modeled – Not specified.
Customers/sponsors – Not specified.</td></tr>
<tr><td colspan="3">Model Framework</td></tr>
<tr><td colspan="3">Underlying model – Not specified.
Simulation – Developed simulation elements for computer and electrical power distribution networks.</td></tr>
</table>

Data format – Not specified. **Sensor data** – Not specified. Human Activity – NSRAM models human activities such as responses to system damage. **Coupling with other models** – Not specified.	
System Requirements	
Hardware	Not specified.
Software	Not specified.
Other Notes	



References	
McManus, Jim, et al., *Network Security Risk Assessment Model(NSRAM) Tool for Critical Infrastructure Protection Project*, http://www.jmu.edu/iiia/webdocs/ppt_NSRAM_Tool.ppt, July 12, 2006. Redwine, Sam, et al., *Network Security Risk Assessment Model Tool*, http://www.jmu.edu/cisat/frd/abstracts04/redwine_sam.html, April 3, 2006.	

Model Name	Next-generation agent-based economic 'laboratory' (N-ABLE)	
Organization **POC**	Sandia National Laboratory Theresa Brown tjbrown@sandia.gov	**Infrastructures** FIN, POL

Description	
Overview – The NISAC Agent-Based Laboratory for Economics (N-ABLE) is a software system for analyzing the economic factors, feedbacks, and downstream effects of infrastructure interdependencies. N-ABLE is a simulation environment in which hundreds of thousands to millions of individual economic actors simulate real-world manufacturing firms, households, and government agencies. N-ABLE can specifically address questions such as: 1. Which economic sectors are most vulnerable to infrastructure disruptions and interdependencies? 2. What firms are most affected — who does well, poorly? 3. What are the different qualitative and quantitative ways in which economic sectors use the energy, transportation, financial, and communication sectors? 4. What short-run infrastructure changes affect economic performance (and vice versa)? 5. How do systems of firms and individuals respond and adapt over time and over regions? 6. What economic mechanisms do national, state, and local governments have or need to have to assist firms and other economic sectors in their regions? **Development goals –** Developed to provide decision makers with a firm-level understanding of the interdependencies between infrastructure sectors and the economy. **Intended users –** Economic Analysts. **System Output –** Geographical charts and statistical output. **Maturity –** Mature Internal. **Areas modeled –** Examples: chemical, food, financial, manufacturing sectors. **Customers/sponsors –** Department of Homeland Security	
Model Framework	
Underlying model – N-ABLE models the economy at the level of the individual firm; each N-ABLE firm is complete with individual buyers, production supervisors, sellers, and strategic planners who collectively navigate through economic disruption and recovery. N-ABLE's simulations of thousands to millions of firms provide the fidelity necessary to understand and implement better infrastructure policies. **Simulation –** Agent Based. N-ABLE microsimulates the economy using an agent-based discrete-event model. This modeling approach is well suited for investigating the behavior of complex, nonlinear stochastic systems like the economy. Agents start each time increment making decisions much like their real-life counterparts. Decisions about what actions to take are based either on probabilities computed from actual microeconomic data or on results of learning models such as genetic algorithms. These decisions include setting sales prices, purchasing products, setting production schedules, hiring workers, buying and selling financial instruments, conducting open market operations, and others. Macroeconomic variables, such as gross domestic product, inflation (CPI), and the unemployment rate are computed as individual-firm and aggregate system measures of the performance of the economy. **Data format –** not specified. **Sensor data –** None. **Ability to couple with other models –** Not known. **Human activity modeling –** Human in the loop activity supported within the simulation.	
System Requirements	
Hardware	Computer cluster
Software	Not specified.

Figure 1. Geographical Simulation Output

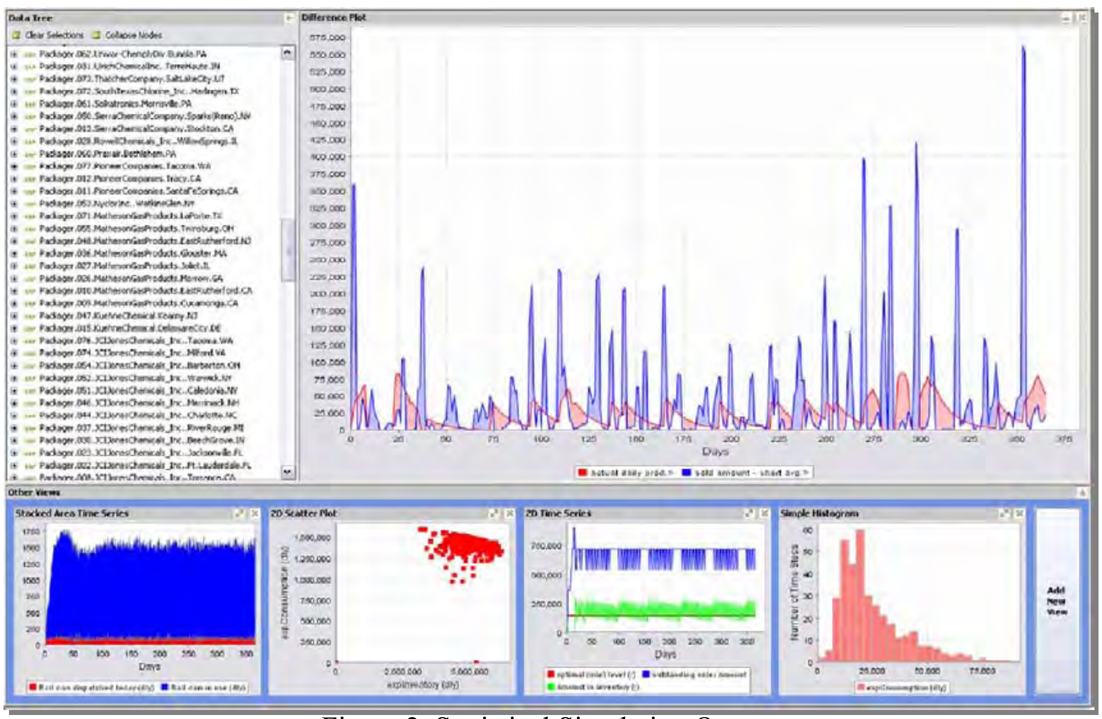


Figure 2. Statistical Simulation Output

References
NISAC Agent-Based Laboratory for Economics (N-ABLE™) Fact Sheet - http://www.sandia.gov/mission/homeland/factsheets/nisac/NISAC_N-ABLE_factsheet.pdf

Model Name	NEXUS Fusion Framework^{TM} – IntePoint, LLC Critical Infrastructure Integration Modeling and Simulation, University of North Carolina at Charlotte (UNCC)	
Organization **POC**	IntePoint, LLC – Commercial Product Mark Armstrong Mark.Armstrong@IntePoint.com University of North Carolina, UNCC Development wjtotone@uncc.edu	**Infrastructures** EP, TC, HW, HA, RL

Description

Overview – NEXUS Fusion Framework^{TM} is a planning and response tool that visualizes intended and unintended effects and consequences of an event across multiple infrastructure, social, and population behavior models. It is a single framework that incorporates geospatial, graph based (social, economic), and population behavior models in the same simulation space for cross-infrastructure relationship analysis. The framework takes a holistic system-of-systems view to support cross system analyses of cascading events within and between complex networks.

Development goals – Not specified.

Intended users – Department of Defense (DoD) Leadership/Analysts.

Output – Output includes 2, 2.5, and 3-D graphical and geospatial temporal views of modeled infrastructure.

Maturity – Version 1.1 was delivered to DoD and accreditation is expected in the summer of 2006.

Multiple infrastructure models have already been built & tested using DoD data. Version 2.0 is under development with delivery in summer 2006.

Areas modeled – Model had been used in many areas including New Orleans, Houston, and Federal Emergency Management Agency (FEMA) Region 5.

Customers/sponsors – The team is working on the sixth project in 3 years with DoD.

Model Framework

Underlying model(s) – Intelligent agent-based system within the context of a Geographic Information System (GIS) environment, open architecture

Simulation – Simulation playback offers a foundation for heuristics and supports a collaborative, sharable simulation result that can be viewed by analysts and consumers. Visual display of cause/effect allows determination of rules and inferred relationships. The model supports network component validation and verification of data points. Facilitates identification of missing intelligence. Modification of rules and branching supports analysis of multiple scenarios based on initial starting boundaries. Additionally, multiple geographical regions can participate in the same simulation.

Data format - Not specified.

Sensor data – Architecture supports sensor data, not actively incorporated into the model.

Human activity – Incorporates infrastructure-aware population behavior models.

Coupling with other models – Flexible, scaleable, and extensible in that it allows "plug and play" of models of the same infrastructure, multiple models of the same infrastructure, and incorporation of other infrastructure models into the simulation.

System Requirements

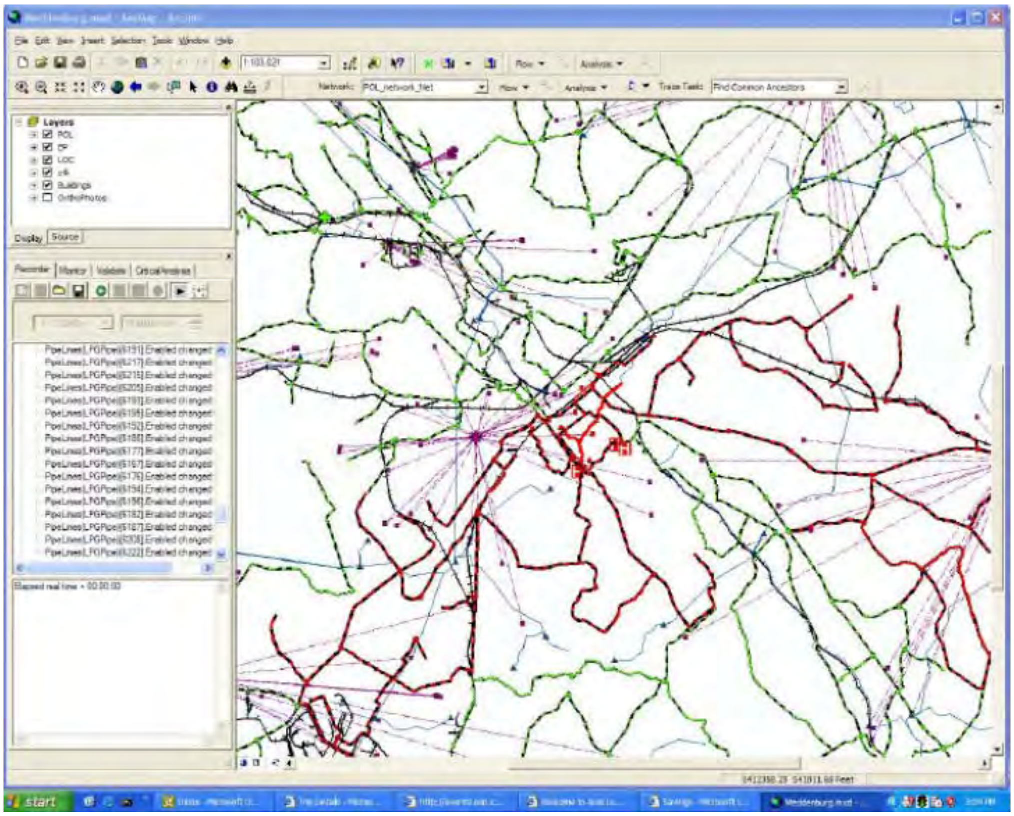
Hardware	Not specified.
Software	Not specified.

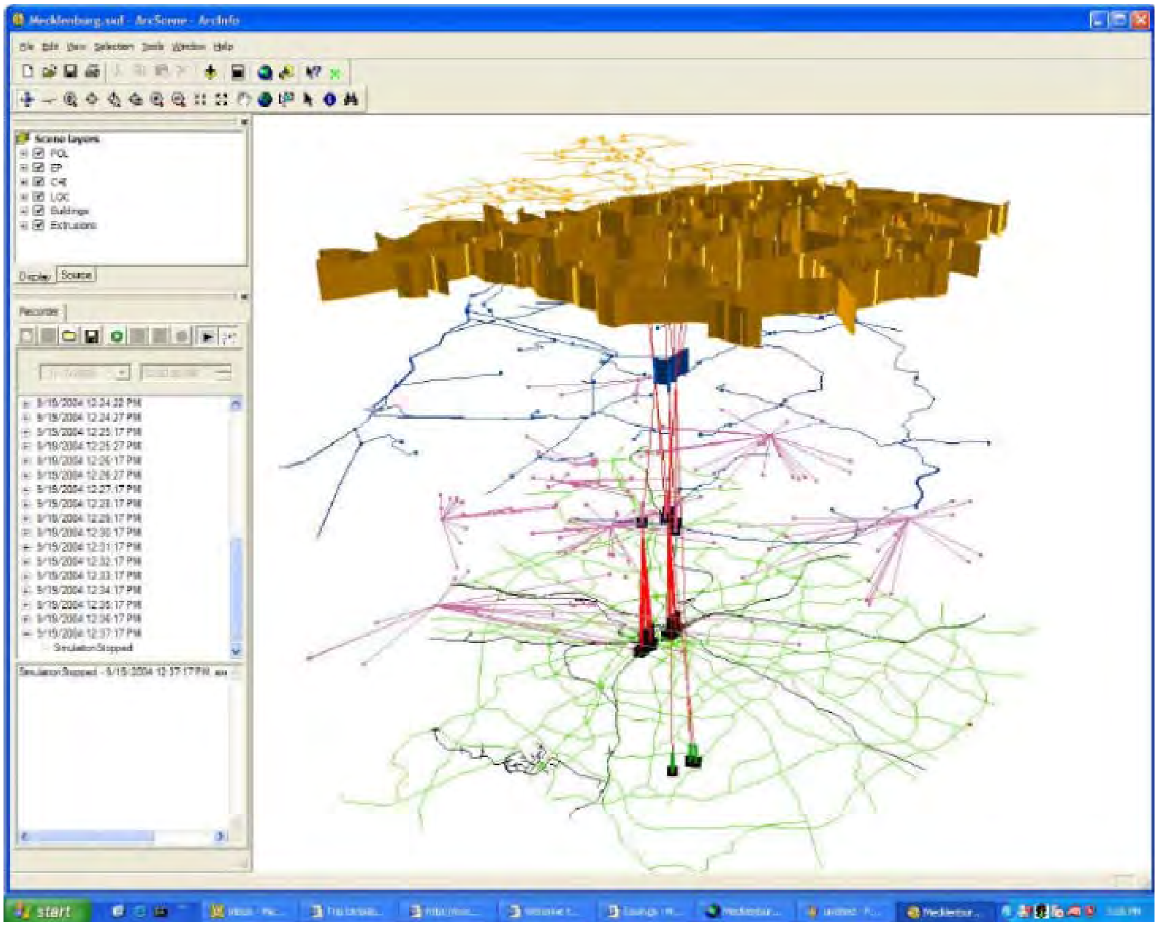
Other Notes

Leverages Environmental Systems Research Institute, Inc. (ESRI) ArcGIS capabilities for geospatial display and analysis.

Uses ESRI ArcGIS Geodatabase to capture:

- Critical attributes
- Critical relationships
- Predictive analytics
- Meta-driven inference engines
- System-of-systems causality analysis
- Temporal view
- Incorporates specialized functionality off-the-shelf as needed.




Mecklenburg.sxd - ArcScene - ArcInfo
Scene layers
POL
EP
CR
LOC
Buildings
Extrusions

References

Model Name	Petroleum Fuels Network Analysis Model (PFNAM)	
Organization	Argonne National Laboratory, Infrastructure Assurance Center	**Infrastructures**
POC	Steve Folga sfolga@anl.gov	NG, OL

Description

Overview – Petroleum Fuels Network Analysis Model (PFNAM) was developed to perform hydraulic calculations of pipeline transport of crude oil and petroleum products. A network consists of links (pipe segments), nodes (pipe junctions), pump stations, valves, and pressure-reducing stations. The model tracks the flow of oil in each pipe and the pressure at each node. “Point-and-click” motions allow the analyst to create a representative model of the liquids pipeline network in order to set up and run a simulation. Graphical and tabular results provided for each simulation enable analysts to quantify the impact of infrastructure disruptions on the pipeline segment or system. This software tool provides a framework for introducing pipeline component dependencies into critical infrastructure analyses.

Development goals – Not specified.

Intended users – Not specified.

System output – Results include graphs and tables for steady-state flow rate, pressure, and line capacity distributions. The hydraulic gradient along the pipeline is also displayed. After a simulation, the analysis results indicate the potential effect on pipeline operations. The diagram below indicates that the long-term loss of a specific pump station can lead to isolation or curtailment of the deliveries of petroleum fuels.

Maturity – The system is in development into the DOT. NET framework.

Areas modeled – Experts at Argonne have applied PFNAM to a number of crude oil and refined petroleum products pipelines. Other potential applications are being explored.

Customers/sponsors – US Department of Defense.

Model Framework

Underlying model – Mathematical model.

Simulation – PFNAM allows the analyst to address a wide range of “what if” questions. Two of the main outputs of a PFNAM simulation are pressure and pipeline capacity estimates along the pipeline. This allows the analyst to determine whether an outage of a pipeline component will result in pipeline shutdown or degradation in pipeline throughput.

Data format – Access database.

Sensor data – Accepts pipeline pressure and flow.

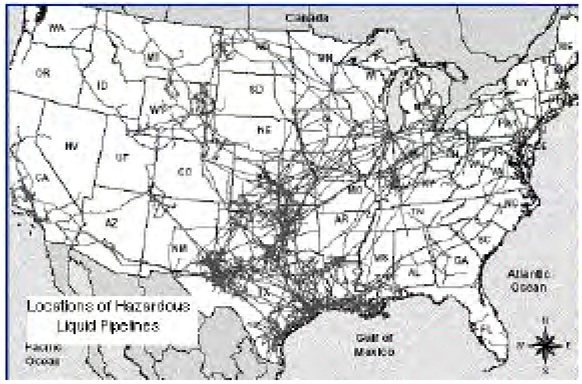
Coupling with other models – This model is compatible with the NG Tool set developed at Argonne.

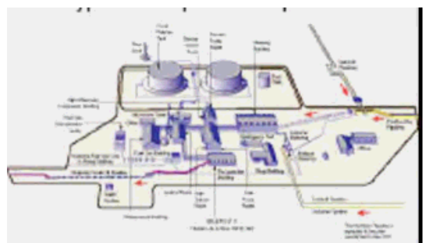
Human activity modeling – Human activities are not modeled.

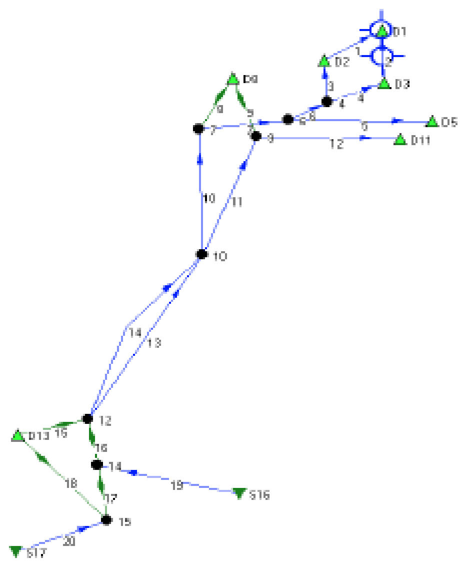
System Requirements

Hardware	Not specified.
Software	Not specified.

Other Notes


Canada
Locations of Hazardous
Liquid Pipelines
Pacific
Ocean
Gulf of
Mexico
Atlantic
Ocean

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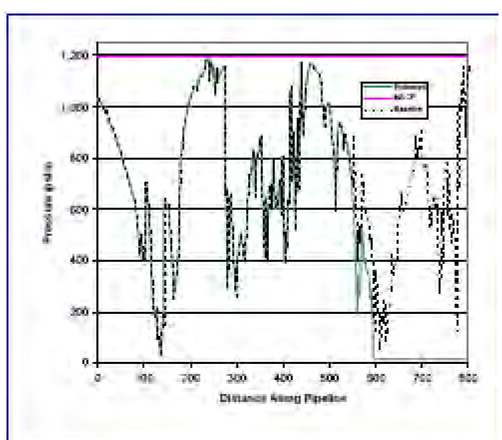

Distance Along Pipeline
0
100
200
300
400
500
600
700
800

References

Model Name	Transportation Routing Analysis Geographic Information System (TRAGIS)	
Organization **POC**	Oak Ridge National Laboratory Paul E. Johnson johnsonpe@ornl.gov	**Infrastructures** RL, HW, WW, POL
Description		

Overview – The Transportation Routing Analysis Geographic Information System (TRAGIS) model is used to calculate highway, rail, or waterway routes within the United States. TRAGIS is a client-server application with the user interface and map data files residing on the user's personal computer and the routing engine and network data files on a network server. By default, the model calculates commercial highway routes; but with the change of the route type, the model can determine routes that meet the U.S. Department of Transportation (DOT) regulations for shipments of highway route-controlled quantities (HRCQ) of radioactive material, routes for shipments to the Waste Isolation Pilot Plant (WIPP), the shortest, or the quickest route.

Development goals – The goal for WebTRAGIS is to have national 1:100,000-scale routing networks. The highway network developed for TRAGIS is a 1:100,000-scale database. The legacy HIGHWAY model used a stick figure network with nodes digitized at 1:250,000-scale. The TRAGIS highway network was developed from the U.S. Geological Survey (USGS) Digital Line Graphs and the U.S. Bureau of Census Topologically Integrated Geographic Encoding and Referencing (TIGER) system. The rail network used in the initial version of TRAGIS was the same database as that used in the INTERLINE model. This network also was a stick figure network with nodes that were digitized from variable scaled maps. A 1:100,000-scale rail network is now incorporated into TRAGIS. The current inland waterway network is based on the USGS 1:2,000,000-U.S. Geodata. Deep-water routes are depicted in WebTRAGIS as straight-line segments. It is planned to incorporate a 1:100,000-scale waterway database into the model at a future time so that all modes will be at a consistent scale.

Intended users – internal and external transportation route planners.

System output – Web-based Graphical 2D map display or textual reports.

Maturity – Mature – commercial.

Areas modeled – United States.

Customers/sponsors – Funding for the development of TRAGIS has been provided by the National Transportation Program (NTP) of the U.S. Department of Energy (DOE).

Model Framework

Underlying model – TRAGIS is a client-server application where the user interface and map data files reside on the user's personal computer (PC) and the routing engine and its large data files reside on the server. The model uses the World Wide Web (WWW) for communications between the client and the server. There are two user interfaces for TRAGIS: WebTRAGIS, which is the primary client user interface, and BatchTRAGIS, which is a specialized user interface that allows multiple routes to be prepared and then calculated at one time.

Simulation – The simulation utilizes a network flow model, which determines the optimal routes based upon an optimization of the impedance measures between endpoints. The impedance is a valued function based upon route type and requirements. Transportation between various sectors is modeled (such as, rail to road transfer, barge to rail, etc.). Population demographics is a component of the model to determine routing criteria for HAZMAT.

Data format – Not specified.

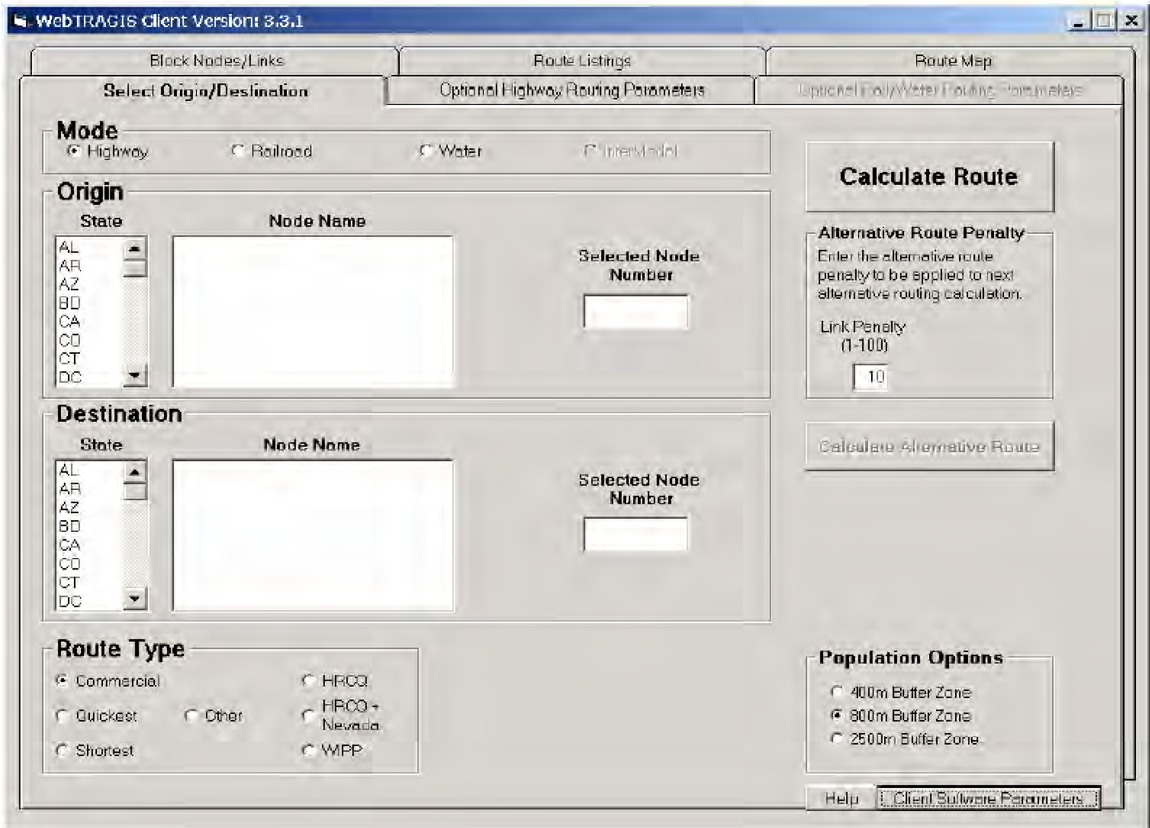
Sensor data – None.

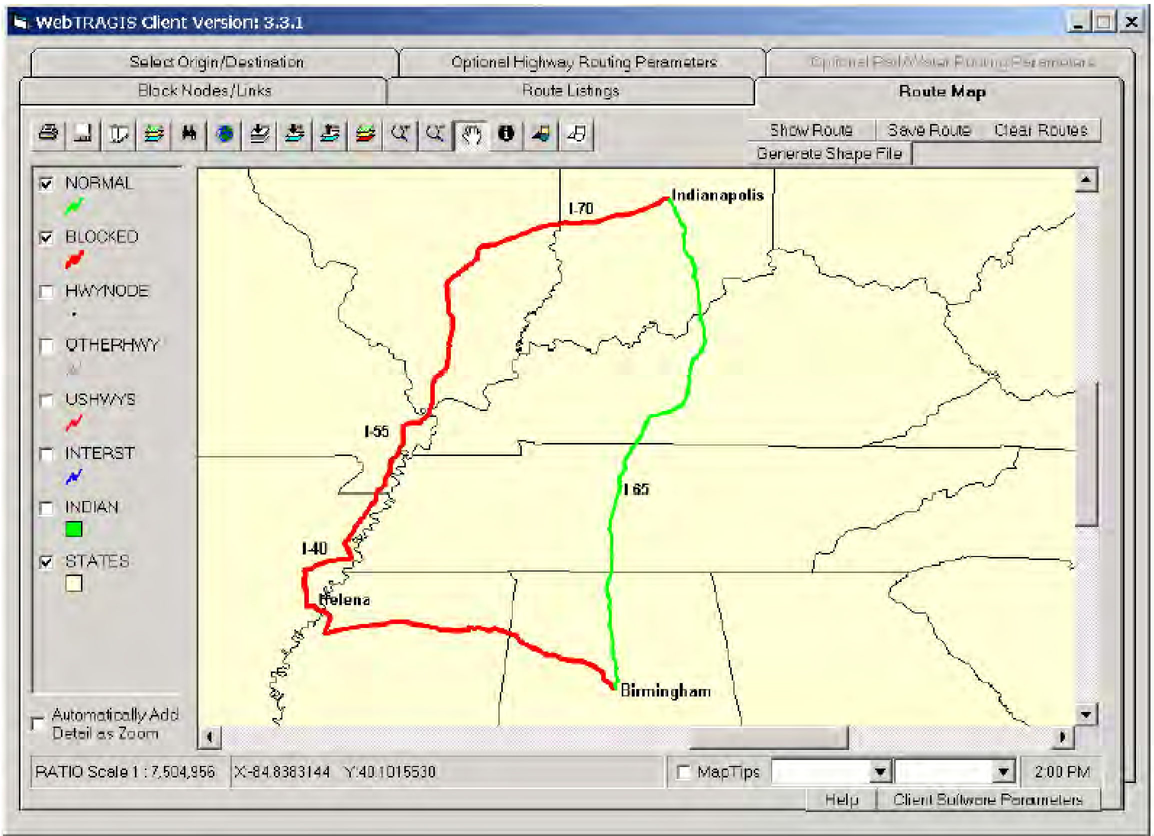
Coupling with other models – Not directly.

Human activity modeling – No.

System Requirements

Hardware	PC with Internet Access.
Software	Windows.
Other Notes	





References

WebTragis https://tragis.ornl.gov/

Transportation RoutingAnalysis Geographic Information System (TRAGIS) User's Manual, Oak Ridge National Laboratory, ORNL/NTRC-006 Rev 0, June 2003. https://tragis.ornl.gov/TRAGISmanual.pdf.

Model Name	TRANSIM		
Organization	Los Alamos National Laboratory	Infrastructures	
POC	Jim Smith	HW, HA	

Description

Overview – TRANSIMS is an agent-based simulation system capable of simulating the second-by-second movements of every person and every vehicle through the transportation network of a large metropolitan area.

It consists of mutually supporting simulations, models, and databases. By employing advanced computational and analytical techniques, it creates an integrated environment for regional transportation system analysis. TRANSIMS is an integrated suite of products containing an easy-to-use graphical user interface for the modeling functions, a GIS-based network editor, 3D data visualization and animation software, and a reporting system. TRANSIMS is designed to give transportation planners more accurate, complete information on:

- Traffic impacts
- Energy consumption
- Traffic congestion
- Land use planning.

The core code version of TRANSIMS (TRANSIMS-LANL), developed at Los Alamos National Laboratory, is distributed for a nominal fee to universities on this Web site. The commercial version of TRANSIMS (TRANSIMS-DOT) was developed from the core software package especially for the Department of Transportation by IBM, and it has a more elaborate interface and specific features to meet requirements by the DOT. It is not available on this Web site.

Development goals – Started as laboratory-directed research and development in the late 1980s for the Department of Transportation. Funding is continuing under Department of Homeland Security (DHS) National Infrastructure Simulation and Analysis Center (NISAC). TRANSIMS technology was developed under U.S. Department of Transportation and EPA funding at the Los Alamos National Laboratory (LANL) over the last eight years. It is a result of an effort to develop new transportation and air quality modeling methodologies required by the Clean Air Act, the Transportation Equity Act for the 21st Century (TEA 21), and other regulations.

Intended users – Internal analyst –used to support the development of an impact report on for specific infrastructure events (such as, hurricanes, terrorist attacks, etc.), external analysts.

System output – Visualization of demographics data with a city or region illustrating the human activity such as traffic patterns and work patterns.

Maturity – Mature internal and commercial.

Areas modeled – Customers/sponsors – NISAC – DHS.

Model Framework

Underlying model – Cellular Autonoma.

Simulation – Discrete event, agent based simulation.

Data – Multiple data sources including Census data, Household Survey Data, Dunn and Bradstreet Data.

Sensor data – No direct sensor feeds.

Coupling with other models – Yes, coupling is done directly (EPISIM).

Human activity modeling – Yes – social network and human mobility model.

System Requirements

Hardware	Memory and disk requirements depend upon the scenario that is used, but large networks require a large Linux cluster. Some scenarios may consist of 10 – 100

	million agents.
Software	The TRANSIMS distribution requires that the user install the following software. Linux · X11R6 libraries (Xmu, Xi, X11, Xext, Xt) · OpenGL and the OpenGL Utilities Toolkit libraries (Mesa/Glut) · Linux libraries (stdc++, ld-linux, ICE, SM) · Perl. All of the third-party software used by TRANSIMS is available on Red Hat Linux distribution CDs. The latest versions of the following packages should be installed: kernel, kernel-headers, gcc, glibc, libstdc++, make, perl, XFree86, Mesa, Mesa-devel, Mesa-Glut, Mesa-Glut-devel, MPI, and PVM. Solaris XllR6 libraries in /usr/openwin, OpenGL, OpenGL Utilities Toolkit libraries (glut), and Perl. Metis, PVM, MPI, and SPRNG are supplied with the TRANSIMS distribution.

Other Notes

Los Alamos National Laboratory's TRANSIMS software is based on a computationally intensive, agent-based simulation technology requiring significant multiprocessor computing hardware. Programs in the TRANSIMS software suite are distributed applications with components running on different hardware/software platforms. To install and run all of the components of the TRANSIMS suite, the customer must procure and set up the following three types of computer systems:

1. Unix/Linux server(s) for hosting the core TRANSIMS software, Oracle database, and server-side components of the TRANSIMS modeling interface. Customers who wish to execute large-size problems must have procured multiserver Linux computing cluster or an equivalent multiprocessor UNIX-based framework.
2. Windows workstation(s) for running the Network Editor, the client-side modeling interface, and Crystal Reports.
3. Optional Linux workstation(s) for running the Visualizer. Alternatively, the customer may wish to equip the Linux server with a high-end graphics card and use the server as the Visualizer platform. A version of the output Visualizer that operates on the Windows workstation is in development.

TRANSIMS was tested in a Linux cluster environment on Red Hat Linux 6.2 and compiled with gcc/g++ 2.95.2. Limited tests in a single-CPU environment were done on Red Hat Linux 7.1 using gcc/g++ 2.96.

To run the traffic microsimulator under PVM or MPI, the Linux kernel must be compiled with networking support and must have an assigned IP address and a host name. An actual network card is not required. The following options must be selected in the Linux kernel configuration:

- Networking support (CONFIG_NET)
- System V IPC (CONFIG_SYSVIPC)
- TCP/IP networking (CONFIG_INET)
- Dummy-net driver support (CONFIG_DUMMY)
- The appropriate network card driver.

The default kernel shipped with Red Hat 6.2 and 7.1 is configured with the appropriate options. The following package categories should be selected during Red Hat Linux installation to run the TRANSIMS components:

- X Window System
- Mesa/GL
- Glut.

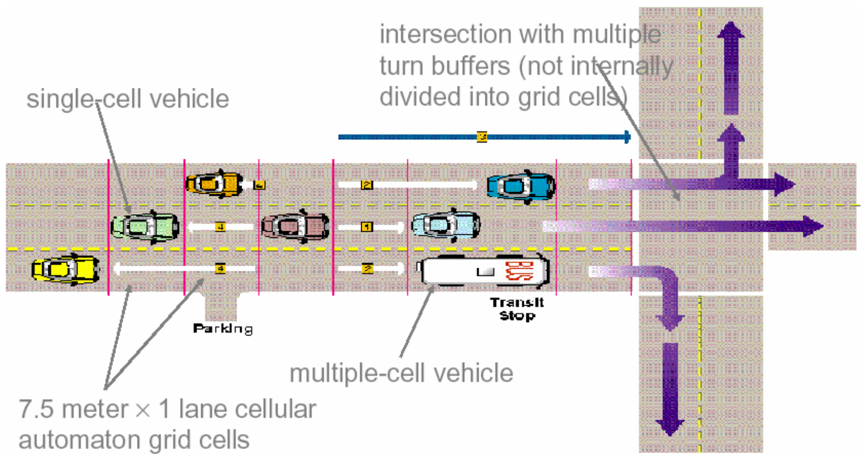
Additional package categories should be selected to compile the TRANSIMS components:

- C Development
- Development Libraries
- C++ Development
- X Development.

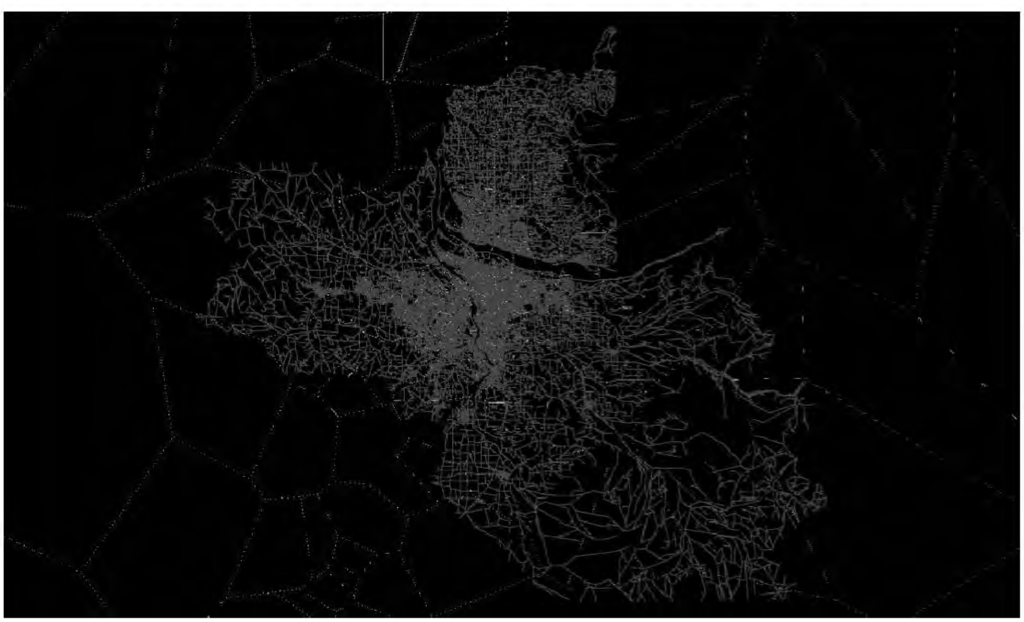
TRANSIM

An agent-based software system for simulating large realistic scale-traffic in urban environments.
It is based on a cellular automata concept.

Resolution: down to 7.5 meters and 1 second. Cars cannot pass through each other.

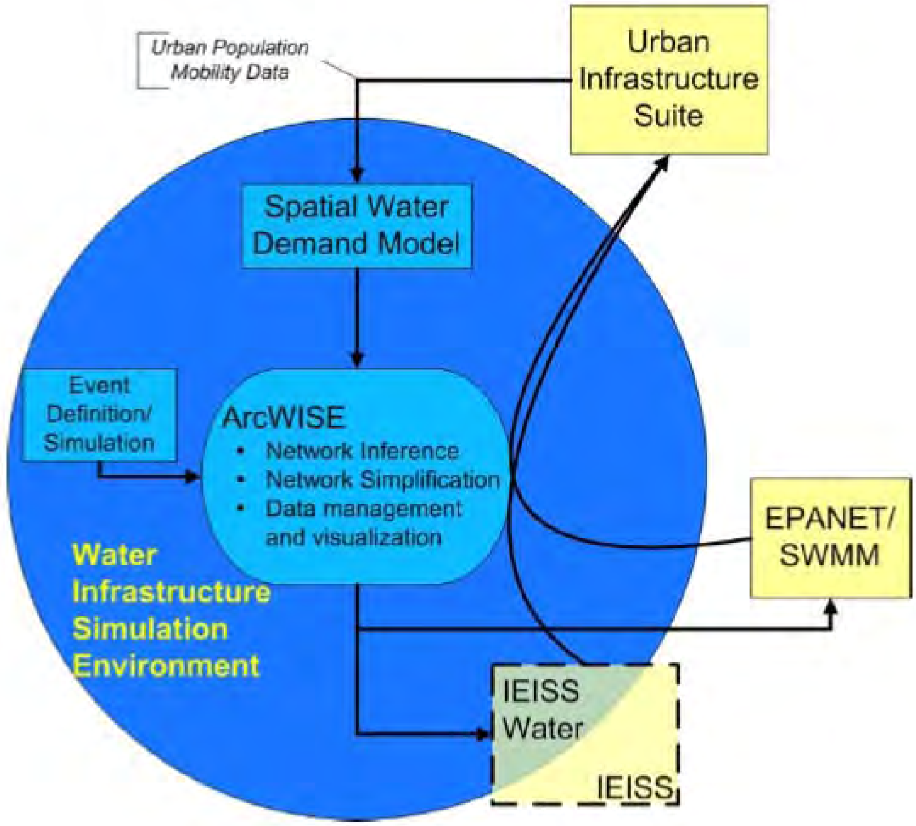


The Portland traffic network:



References
http://www.transims.net/home.html
Zoltán Toroczkai “Agent-Based Modeling as a Decision Making Tool: How to Halt a Smallpox Epidemic How to Halt a Smallpox Epidemic”, Center for Nonlinear Studies, Theoretical Division, Los Alamos National Laboratory.

<table>
<tr><th>Model Name</th><td colspan="3">Water Infrastructure Simulation Environment (WISE)</td></tr>
<tr><th>Organization</th><td>Los Alamos National Laboratory</td><th colspan="2">Infrastructures</th></tr>
<tr><th>POC</th><td>Joe Holland</td><td colspan="2">DW, SW, ST</td></tr>
<tr><th colspan="4">Description</th></tr>
<tr><td colspan="4">Overview – The Water Infrastructure Simulation Environment (WISE) is an analytic framework supporting the evaluation of water infrastructure in terms of both infrastructure specific and interdependency issues.
Development goals – Not specified.
Intended users – Internal analyst – IEISS used to support the development of an impact report on for specific infrastructure events (such as, hurricanes, terrorist attacks, etc.).
System output – Key components in the WISE framework are ArcWISE, a GIS based graphical user interface, and IEISS Water, a water infrastructure interdependency simulation capability within IEISS. ArcWISE leverages the existing data management, analysis, and display capabilities within geographic information systems while also extending them to infer, improve, and amend water infrastructure data in support of running hydraulic simulation engines such as EPANET or IEISS Water. ArcWISE also provides tools for defining and simulating infrastructure damage events, such as a fire, and generating water demand/sewage production estimates. IEISS Water is an extension of the IEISS analysis software to water distribution infrastructure simulation.
Maturity – Development.
Areas modeled – Numerous U.S. metropolitan areas.
Customers/sponsors – NISAC – DHS.</td></tr>
<tr><th colspan="4">Model Framework</th></tr>
<tr><td colspan="4">Underlying model – Flow and Dispersion Model.
Simulation – A continuous time based model with an underling physical engine for system dynamics. WISE involves the integration of geographic information systems with a wide range of infrastructure analysis tools including industry standard hydraulic simulation engines (e.g., EPANET and SWMM) as well as Los Alamos National Laboratory interdependency simulation systems such the Urban Infrastructure Suite (UIS) and the Interdependent Energy Infrastructure Simulation System (IEISS).
Data format – Not specified.
Sensor data – No direct sensor feeds.
Coupling with other models – Yes, coupling is done indirectly. The output of IEISS will serve as the input to other infrastructure models to identify cross infrastructure effects.
Human activity modeling – None at this time.</td></tr>
<tr><th colspan="4">System Requirements</th></tr>
<tr><th>Hardware</th><td colspan="3">Not specified.</td></tr>
<tr><th>Software</th><td colspan="3">ArcWise, EPANET and SWMM.</td></tr>
<tr><th colspan="4">Other Notes</th></tr>
<tr><td colspan="4"></td></tr>
</table>


Urban Population
Mobility Data
Urban
Infrastructure
Suite
Spatial Water
Demand Model
Event
Definition/
Simulation
ArcWISE
• Network Inference
• Network Simplification
• Data management
and visualization
EPANET/
SWMM
Water
Infrastructure
Simulation
Environment
IEISS
Water
IEISS

References

<table>
<tr><td>Model Name</td><td colspan="2">MIT Screening Methodology—A Screening Methodology for the Identification and Ranking of Infrastructure Vulnerabilities Due to Terrorism</td></tr>
<tr><td>Organization

POC</td><td>Massachusetts Institute of Technology (MIT), Engineering Systems Division and Department of Nuclear Science and Engineering
George E. Apostolakis
apostola@mit.edu
Douglas M. Lemon</td><td>Infrastructures
Electric power, natural gas, and drinking water</td></tr>
<tr><td colspan="3">Description</td></tr>
<tr><td colspan="3">Overview – This research proposes a methodology for the identification and prioritization of vulnerabilities in infrastructures. Portions of the Massachusetts Institute of Technology (MIT) campus were assessed using this methodology. Infrastructures are modeled as digraphs and graph theory is employed to identify the candidate vulnerable scenarios. Screening of scenarios is performed to produce a prioritized list of vulnerabilities. Prioritization is based on multiattribute utility theory (MAUT). The value of a lost element is based on a rated impact of losing infrastructure services.
Development goals – Professor Apostolakas and others are continuing to extend this work as described in the “Other Notes” section, which follows.
Intended users – The intended users for this methodology include analysts and decision makers for evaluation and risk management.
System output – The system provides numeric ranking values for infrastructure elements as output.
Maturity – This is a research and development level method.
Areas modeled – Portions of MIT campus including electric power, water, and natural gas infrastructures.
Customers/sponsors – MIT and the U.S. Navy sponsored the work.</td></tr>
<tr><td colspan="3">Model Framework</td></tr>
<tr><td colspan="3">Underlying model – This methodology is based on graph theory, MAUT (for identifying and ranking vulnerabilities), and mathematical network analysis (for infrastructure modeling).
Simulation – The method allows simulations based on perceived terrorist threats.
Data format – Not specified.
Sensor data – None.
Coupling with other models – Not specified.
Human activity modeling – None.</td></tr>
<tr><td colspan="3">System Requirements</td></tr>
<tr><td>Hardware</td><td colspan="2">Not specified.</td></tr>
<tr><td>Software</td><td colspan="2">Not Specified.</td></tr>
<tr><td colspan="3">Other Notes</td></tr>
<tr><td colspan="3">Since the publication of the subject methodology, MIT has continued similar work. A recent paper, “A Methodology for Ranking the Elements of Water-Supply Networks,” co-written by David Michaud—also of MIT—has been accepted for publication in the Journal of Infrastructure Systems in 2006. That work is based on a case study of a mid-sized city and presents a scenario-based methodology for ranking elements of water-supply networks.</td></tr>
</table>

References
Apostolakas, G., and Lemon, D. (2005). "A Screening Methodology for the Identification and Ranking of Infrastructure Vulnerabilities Due to Terrorism," *Risk Analysis*, Vol. 25, No. 2, pp. 361-376.

Model Name	The Urban Infrastructure Suite (UIS)	
Organization **POC**	Los Alamos National Laboratory Randy Michelsen rem@lanl.gov	**Infrastructures** HW, HA, TC, AST, SW, DW

Description

Overview – The Urban Infrastructure Suite (UIS) is a set of interoperable modules that employ advanced modeling and simulation methodologies to represent urban infrastructures and populations. These simulation-based modules are linked through a common interface for the flow of information between UIS sector simulations to model urban transportation, telecommunications, public health, energy, financial (commodity markets), and water-distribution infrastructures and their interdependencies.

- Urban Population Mobility Simulation Technologies (UPMoST) Module
- Epidemiological Simulation Systems (EpiSims) Module
- Telecommunications Sector: AdHopNet Module
- Transportation Analysis Simulation System (TRANSIMS) Module
- Water Infrastructure Simulation Environment (WISE)
- Generic Cities Project

Development goals – The project objective (NISAC) is to understand the infrastructures' performance under unusual conditions, the effects of interdependencies, and the dynamics of their interconnections. To better understand the complexities of the interconnected infrastructures, the team has collaborated with private sector infrastructure experts to develop methodologies and tools for characterizing and simulating their performance.

Intended users – LANL internal analysts.

System Output – Graphical overlays and textual based output.

Maturity – Development.

Areas modeled – Multiple.

Customers/sponsors – DHS – NISAC.

Model Framework

Underlying models:

- Urban Population Mobility Simulation Technologies (UPMoST) Module
- Epidemiological Simulation Systems (EpiSims) Module - a contact-based approach for evaluating the spread of disease among a populace. It looks at infection rates based on the assumed numbers of contacts people in different demographic groups might have with others in their families, workplaces, and communities. Interactions/contacts are based on the TRANSIM's mobility model.
- Telecommunications Sector: MIITS Module (formerly AdHopNet) – end to end communications system simulation, agent based simulating individual packets, devices, connections, etc., input is TRANSIMS mobility model.
- Transportation Analysis Simulation System (TRANSIMS) Module – synthetic population model, cellular automata microsimulation. The output is population mobility with demographics
- Water Infrastructure Simulation Environment (WISE) – is an analytic framework supporting the evaluation of water infrastructure in terms of both infrastructure specific and interdependency issues.
- Generic Cities Project – module to create representative but not necessarily accurate city representations in terms of demographic data.

Simulation – TRANSIM mobility/social network model—agent-based, Epidemic model—differential equation based.

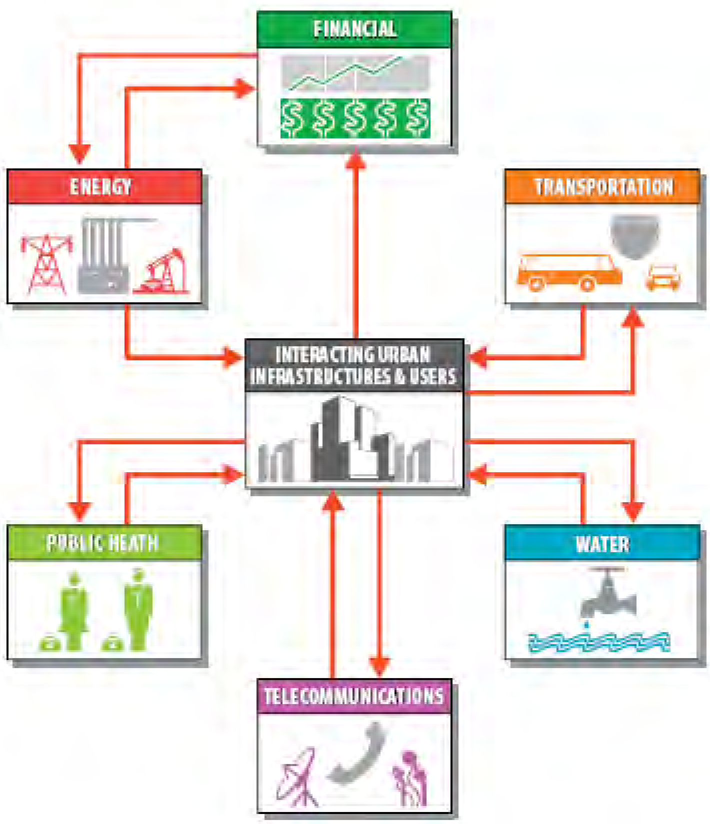
Data – Multiple sources.

Sensor data – None.

Ability to couple with other models – Suite of coupled modules for different infrastructure

sectors. **Human Activity modeling –** Yes. Mobility and Social Interaction Model.	
System Requirements	
Hardware	Large models require a Linux Cluster.
Software	Linux, various.
Other Notes	

Images:



References

Barrett, Christopher L, Stephen Eubank, V.S. Anil Kumar, and Madhav V. Marathe From The Mathematics of Networks, Understanding Large-Scale Social and Infrastructure Networks: A Simulation-Based Approach, SIAM News, Volume 37, Number 4, May 2004

REFERENCES

1. Congressional Research Service Report for Congress. 2002 Critical Infrastructures: Background, Policy and Implementation. Available online at http://www.iwar.org.uk/cip/resources/pdd63/crs-report.pdf.

2. Congressional Research Service Report for Congress. 2002 Critical Infrastructures: Background, Policy and Implementation. Available online at http://www.iwar.org.uk/cip/resources/pdd63/crs-report.pdf.

3. http://www.tswg.gov

4. Executive Order, 13010. Critical Infrastructure Protection. Federal Register. Vol. 61. No. 138. July 17, 1996. pp. 3747-3750.

5. Executive Order, 13130 National Infrastructure Assurance Council, Federal Register, Vol. 64, No. 137, July 19, 1999. pp. 38535-38536.

6. Executive order 13231 Critical Infrastructure Protection in the Information Age. Federal Register. Vol. 66. No. 202. October 18, 2001. pp. 53063–53071. The NIAC is established on page 53069.

7. D. Mussington, "Concepts for Enhancing Critical Infrastructure Protection: Relating Y2K to CIP Research and Development." RAND:Science and Technology Institute, Santa Monica, CA, 2002, p 29.

8. Layton, L. and D. Phillips. 2001. Train Sets Tunnel Afire, Shuts Down Baltimore. Available online via < http://www.washingtonpost.com/ac2/wp-dyn?pagename=article&node=&contentId=A17542-2001Jul18>, accessed March 28, 2002.

9. Ratner, A. 2001. Train derailment severs communications. Available online via <http://www.baltimoresun.com/news/local/bal-email19.story?coll=bal-home-headlines>, accessed March 28, 2002.

10. Little, R. and P. Adams. 2001, Tunnel fire choking East Coast rail freight. Available online via <http://www.baltimoresun.com/news/local/bal-te.bz.freight20jul20.story?coll= bal-home-headlines>, Accessed March 28, 2002.

11. M. Dunn, and I.Wigert. *International CIIP Handbook 2004: An Inventory and Analysis of Protection Policies in Fourteen Countries*. Zurich: Swiss Federal Institute of Technology: 2004, p. 243.

12. D. D. Dudenhoeffer, M. R. Permann, and M Manic, "CIMS: A Framework For Infrastructure Interdependency Modeling And Analysis." *Submitted to Proceedings of the 2006 Winter Simulation Conference*, L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, 2006.

13. S. Rinaldi, J. Peerenboom, and T. Kelly. "Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies*," IEEE Control Systems Magazine*, IEEE, December 2001, pp. 11-25.

14. U.S. Department Of Energy Office of Critical Infrastructure Protection. 2001. *Critical Infrastructure Interdependencies: Impact of the September 11 Terrorist Attacks on the World Trade Center, A Case Study*, 2001, p. 10.

15. UNITED STATES CONGRESS, "U.S.A. Patriot Act", 2001, http://www.epic.org/privacy/terrorism/hr3162.html.

16. UNITED STATES CONGRESS, "U.S.A. Patriot" Act, 2001, http://www.epic.org/privacy/terrorism/hr3162.html

17. United States Joint Forces Command, Operational Net Assessment (ONA) Concept Of Operations For Millennium Challenge 02 (MC-02), October 2001.

18. Hammes, T. *The Sling and the Stone*, Zenith Press, St. Paul MN, 2004, p.2.

19. United States Joint Forces Command, The Joint Warfighting Center, Joint Doctrine Series Pamphlet 4, Doctrinal Implications of Operational Net Assessment (ONA), 2004.

20. LandScan, http://www.ornl.gov/sci/landscan/index.html.

21. Los Alamos National Laboratory, http://lanl.gov/orgs/d/nisac/, http://www.sandia.gov/mission/homeland/programs/critical/nisac.html.

22. National Energy Technology Laboratory, http://www.netl.doe.gov/onsite_research/Facilities/energy.html.

23. Technical Support Working Group, http://www.tswg.gov.

24. Federal Business Opportunities, http://www.fbo.gov/spg/USAF/AFMC/AFRLRRS/Reference%2DNumber%2DBAA%2D06%2D07%2DIFKA/SynopsisP.html.

25. Amin, M. “National Infrastructures as Complex Interactive Networks”, Chapter 14 in *Automation,*Control, and Complexity: New Developments and Directions, Samad & Weyrauch (Eds.), John Wiley and Sons, March 2000, Table 14.1.

26. Schmitz, W. and K. A. Neubecker. 2003. *Architecture of an Integrated Model Hierarchy: Work Package 6, Deliverable D6.2, ACIP Technical Report IST-2001-37257: 32*. Available via http://www.iabg.de/acip/doc/wp6/D62_architecture.pdf, Accessed April 1, 2006.